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# Subcatchment Parameterization for Runoff Modeling Using Digital Elevation Models

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## Abstract

Numerical algorithms are presented to estimate the length, width and slope of rectangular planes representing irregularly shaped overland contributing areas defined on raster Digital Elevation Models (DEM). The strength of the procedure lies in that each flow path on the raster overland area is considered in the determination of the representative value for the entire rectangular plane as opposed to relying on a lumped, single flow path approach. The flow path parameters required by the algorithms are derived from raster maps of elevation (DEM), flow direction and upstream area. Qualitative cause-effect relations between flow path and runoff characteristics are used to emphasize those flow paths that are important to runoff formation and propagation. Based upon these considerations, the plane length and slope are computed as a weighted mean flow path length and slope over all flow paths of the overland area. Several alternative weighting factors are proposed. Based on area conservation, the plane width is computed as the overland area divided by the plane length.

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## Introduction

Automated drainage network identification and watershed segmentation from raster Digital Elevation Models (DEMs) is readily performed by a variety of software packages (Band, 1986; Jenson and Domingue, 1988; Martz and Garbrecht, 1993; Wolock and McCabe, 1995; Tarboton et al. 1991). Automated identification of landscape parameters for individual overland areas within a subdivided watershed is the next step in automated DEM processing for hydrologic/hydraulic model applications (Goodrich and Woolhiser, 1991). Overland areas are undissected hillslopes that drain directly into a channel segment between two channel junctions.

Wooding (1965) has proposed a dynamical model for representing the main features of a subcatchment and the stream which it contains. This model consists of two rectangular planes joined to form a V-shaped valley along which the stream flows. This subcatchment representation is illustrated in Fig. 1, in which L, W and S are downstream plane length, width and slope, respectively. For first order channels the upland area contributing to the source of the channel is also approximated by a single rectangular plane with parameters L, W and S. These are parameters required for commonly used watershed rainfall-runoff models such as KINEROS (Smith et al., 1995) and the kinematic option of HEC-1 (Feldman, 1995). Flow path length and slope are essential parameters in the estimation of the magnitude, shape and timing of the overland runoff hydrograph.

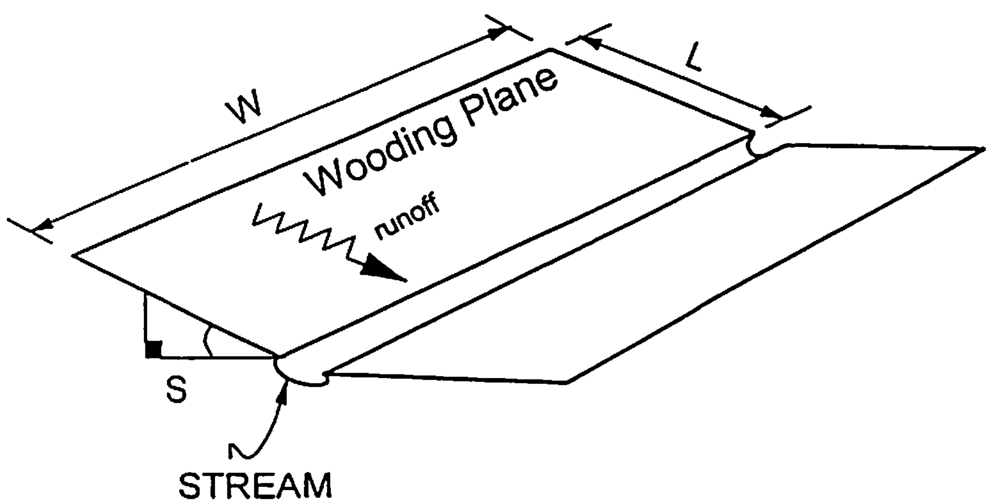


Fig. 1 Wooding catchment representation; first order channels have an additional rectangular overland flow plane draining into the source of the channel.

This paper presents numerical algorithms that identify a hydraulically representative length, width and slope of a rectangular plane contributing laterally or to the head of a channel on the DEM. The proposed numerical algorithms are designed for converging flow conditions and are not applicable to divergent flow conditions. Data needed by the algorithms consist of a raster DEM, a raster identification of channels and overland areas, and raster maps of flow direction and upstream drainage area. The flow direction raster must indicate the direction of the steepest downward slope from each DEM cell to one of its eight immediately adjacent cells. Consistency between the data rasters is usually obtained by deriving the upstream drainage area and the overland area from the flow direction raster which itself was derived from the DEM. The raster data required by the algorithm can be obtained by suitable DEM processing software such as the digital landscape analysis tool TOPAZ (Garbrecht and Martz, 1995).

Plane length approximation

A flow path is the route indicated by the flow direction raster from an upstream source to the channel at the downstream edge of the overland area. Upstream sources are defined as raster cells with zero upstream area and channels are already defined in the overland definition raster. Flow path length is the distance between the upstream source and the channel at the downstream edge of the overland area.

Flow paths that drain a larger upstream area contribute proportionally more to the runoff hydrograph characteristics than flow paths that drain a smaller upstream area. Also, discharge and upstream drainage area are generally interchangeable because most distributed models assume uniform conditions over an overland modelling element, and upstream area is proportional to runoff. Therefore, the proposed model for hydraulically representative plane length (L) is a discharge (area) weighted mean length of all flow paths within the irregular overland area:

$$L = \frac{\sum_{i=1}^{n} l_i * a_i}{\sum_{i=1}^{n} a_i} \tag{1}$$

where l is flow path length, a is upstream drainage area, and subscript i is flow path counter. Upstream drainage area is measured at the end of the flow path. Appropriate adjustments are made to the drainage area for the case where several flow paths converge and share a common stretch of flow path before reaching the channel. This adjustment is necessary to preclude double weighting for shared flow paths.

Plane width approximation

Plane width is derived from area and water conservation considerations. To insure water continuity and area conservation, plane width is computed as the overland area (A) divided by the plane length (L) which was computed in the previous section:

$$W = \frac{A}{L} \tag{2}$$

Plane slope approximation

Flow path slope is defined as the change in elevation from the top to the bottom of the flow path divided by flow path length. Elevation at the source and end point of the flow path are obtained from the DEM. Flow path length is obtained by accumulating cell lengths during a flow path trace from its source to its downstream end point using the flow direction raster. The proposed model for the plane slope is then a weighted mean slope of all flow paths within the irregular overland area:

$$S = \frac{\sum_{i=1}^{n} s_i * k_i}{\sum_{i=1}^{n} k_i} \tag{3}$$

where s is flow path slope and k is a weighting factor. The weighting is defined in one of four ways: 1) simple average with $k_i=1$; 2) upstream drainage area weighted with $k_i=a_i$; 3) flow path length weighted with $k_i=l_i$; or, 4) upstream drainage area times flow path length weighted with $k_i=a_i*l_i$.

In the first case, simple averaging has the shortcoming of attributing the same weight to all flow paths independently of flow path length or discharge. In the second case, length weighting is used to compensate for the effect of raster resolution noise. Slope estimates of long flow paths are generally more accurate because the elevation and length values have been obtained over a larger number of discrete raster units, which reduces the effect of raster resolution noise. Length weighting also favors flow paths with larger drainage areas (i.e. larger discharge) because drainage area and flow path length are generally correlated. In the third case, drainage area weighting is used to emphasize flow paths with larger drainage areas which contribute proportionally more to the runoff hydrograph characteristics than those with smaller drainage areas. Area weighting also reduces the effect of raster resolution noise by emphasizing the longer channels. The fourth case is a combination of the second and third with the product of length and drainage area as weighting factor. Until further research establishes the most appropriate method for the estimation of plane slope, the results of each of the four methods should be considered in the determination of the final plane slope.

## Conclusions

Numerical algorithms are presented to estimate overland area plane length, width, and slope that represent irregularly shaped overland areas derived from DEMs. Input data for the algorithm consists of raster maps of flow direction, elevation and upstream drainage area. The plane length is computed as the upstream drainage area weighted mean length of all flow paths in the overland area; the plane width is computed as the overland area divided by the plane length; and the plane slope is computed as a weighted mean slope of all flow paths on the overland area. The strength of the procedure lies in its consideration of the geometric properties of each contributing flow path rather than relying on a lumped approach, and in the consideration of qualitative cause-effect relations between flow path and runoff characteristics to emphasize flow paths that are more important to the runoff process.

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