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Journal of Hydrology 324 (2006) 301–322

Journal of Hydrology

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SCS-CN-based modeling of sediment yield

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Received 24 October 2003; revised 6 October 2005; accepted 12 October 2005

Abstract

Coupling the soil conservation service curve number (SCN-CN) method with the universal soil loss equation (USLE), a new model is proposed for the estimation of the rainstorm-generated sediment yield from a watershed. The coupling is based on three hypotheses: (1) the runoff coefficient is equal to the degree of saturation, (2) the potential maximum retention can be expressed in terms of the USLE parameters, and (3) the sediment delivery ratio is equal to the runoff coefficient. The proposed sediment yield model is applied to a large set of rainfall-runoff-sediment yield data (98 storm events) obtained from 12 watersheds of different land uses (urban, agricultural, and forest). For all watersheds the computed sediment yield is found to be in good agreement with the observed values. The results and analysis of model application show that the model has considerable potential in field.

Keywords: Curve number; Degree of saturation; Potential maximum retention; Runoff coefficient; Sediment yield; Sediment delivery ratio

1. Introduction

The soil conservation service curve number (SCN-CN) method (SCS, 1956) and the universal soil loss equation (USLE) (Wischmeier and Smith, 1965) are widely used in hydrology and environmental engineering for computing the amount of direct runoff from a given amount of rainfall and the potential soil erosion from small watersheds, respectively. A great deal of published material on these methods along with their applications is available in hydrologic literature. The texts of Novotny and Olem (1994); Ponce (1989) and Singh (1988, 1992) are but a few examples. Since USLE was developed for estimation of the annual soil loss from small plots of an average length of 22 m, its application to individual storm events and large areas leads to large errors, but its accuracy increases if it is coupled with a hydrologic rainfall-excess model (Novotny and Olem, 1994). The current practice is to derive hydrologic information from a rainfall-runoff model and utilize it in the computation of potential erosion using USLE for determining the sediment yield (Knisel, 1980; Leonard et al., 1987; Rode and Frede, 1997; Young et al., 1987), which is of paramount importance in

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doi:10.1016/j.jhydrol.2005.10.006

watershed management. The work of Clark et al. (1985) is noteworthy on the impact of erosion and sedimentation on the environment in general, and water quality in particular.

This discussion suggests that the SCS-CN method can be used as a rainfall-runoff model. Furthermore, both the SCS-CN method and the USLE method share a common characteristic in that they account for watershed characteristics, albeit differently. It is therefore conjectured that by coupling these two methods one can compute the sediment yield from the knowledge of rainfall, soil type, land use and antecedent soil moisture condition. Thus, this study aims at the development of an analytical model by coupling the SCS-CN method with USLE for computing sediment yield. This coupling has not yet been reported in the literature. The coupling is based on three hypotheses: (1) the runoff coefficient is equal to the degree of saturation, (2) the potential maximum retention can be expressed in terms of the USLE parameters, and (3) the sediment delivery ratio is equal to the runoff coefficient. The proposed sediment yield model is applied to a large set of rainfall-runoff-sediment yield data (98 storm events) obtained from 12 watersheds of different land uses (urban, agricultural, and forest) from 300 m^2 to a few km^2 in size.

2. Review of SCS-CN and USLE methods

Pertinent aspects of the SCS-CN method and the USLE method are briefly revisited before the development of the proposed sediment yield model.

2.1. SCS-CN method

The SCS-CN method couples the water balance equation (Eq. (1)) with two hypotheses, which are given by Eqs. (2) and (3), respectively, as:

$$P = I_a + F + Q \qquad (1)$$

$$\frac{Q}{P - I_a} = \frac{F}{S} \qquad (2)$$

$$I_a = \lambda S \qquad (3)$$

where P is the total rainfall (mm), I_a is the initial abstraction (mm), F is the cumulative infiltration (mm), Q is the direct runoff (mm), S is the potential maximum retention (mm), and λ (=0.2, taken as a standard value) is the initial abstraction coefficient. Eq. (2) is a proportionality concept (Fig. 1). Combination of Eqs. (2) and (1) leads to the SCS-CN method:

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \qquad (4)$$

which is valid for $P \geq I_a$, $Q=0$, otherwise. Coupling of Eq. (4) with Eq. (3) for $\lambda=0.2$ enables determination of S from the $P-Q$ data. In practice, S is derived from a mapping equation expressed in terms of the curve number (CN):

$$S = \frac{25400}{\text{CN}} - 254 \qquad (5)$$

The non-dimensional CN is derived from the tables given in the National Engineering Handbook, Section-4 (NEH-4) (SCS, 1956) for catchment characteristics, such as soil type, land use, hydrologic condition, and antecedent soil moisture condition. Since CN indicates the runoff producing potential of a watershed, it should rely on several other characteristics, such as drainage density, slope length, gradient, etc. which significantly affect runoff (Gardiner and Gregory, 1981). The higher the CN value, the greater the runoff factor, C, or runoff potential of the watershed, and vice versa. Michel et al. (2005) suggested S to be an intrinsic model parameter independent of initial moisture conditions. Though the simplification of SCS-CN method with $I_a=0.2S$ has found numerous successful applications the world over, Michel et al. (2005) found I_a and S to be independent of each other, for I_a is not an intrinsic

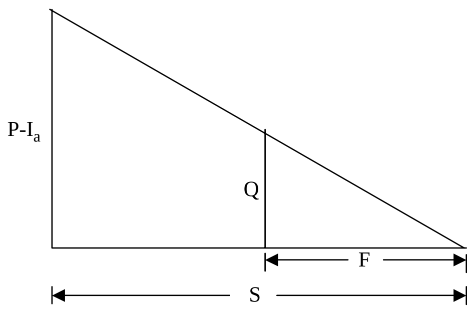

Fig. 1. Proportionality concept.