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Stochastic components in the gully erosion modelling

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Abstract

The great complexity of the geo-mechanical, structural, and electro-chemical forces in soil, as well as of initial and boundary conditions in the equations of hydrodynamics, leads to a necessity of spatial/temporal averaging of deterministic equations related to soil behaviour. The stochastic terms, which appear in the equations after averaging procedures, must be incorporated into the modelling of erosion features. In this study, a new method of estimating detachment rate was used in stochastic gully erosion modelling. It is based on estimation of the probability of excess of driving forces above resistance forces in the interaction of water flow and structured soil. Knowledge of the probability density functions for the flow and soil main characteristics (as flow velocity, soil cohesion, aggregate size and others) makes it possible to calculate theoretically the rate of cohesive soil erosion for any combination of these stochastic variables. The proposed theory allows explicit explanation of relationships between detachment rate and flow/soil characteristics. Detachment rate increases with flow velocity more rapidly for soil with higher cohesion and larger aggregates. This theory also shows great difference in type of soil erosion for relatively high and relatively low flow velocities, and explains rather high errors in calculating of soil erosion rate even with detailed models.

Keywords: Gully erosion; Detachment rate; Stochastic modelling

1. Introduction

A gully is one of the most complicated linear erosion features due to multistage gully evolution under the control of the large number of factors. The first stage of gully initiation

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comprises only about 5% of the entire gully lifetime (Kosov et al., 1978), but in that stage more than 90% of gully length, 60% of its area and 35% of the gully's volume may be formed. In the remaining gully's lifetime the morphologic conditions are relatively stable. This is the stage of a slow gully deepening at the upper part and aggradation at the lower part, with increasing of the whole gully width and volume. The main processes of the gully formation are different at these two main stages. For example, in humid conditions the water linear erosion at the gully bed and rapid shallow mass movement at the gully sides are of major importance for gully evolution at the first stage. During the second stage of gully evolution slower processes become more important, such as ground water seepage, soil weathering and topsoil formation, activity of burrowing animals and vegetation growth, earth flow and soil creep.

All of the above-mentioned processes have clear deterministic and stochastic components, which need to be incorporated into prediction models. The interaction between turbulent flow and structured soil at the gully bed, as well as the geo-mechanical stability of the gully sides, are governed by fundamental, deterministic (at the macroscopic level) laws of physics. Great complexity of the geo-mechanical, structural, and electro-chemical forces in soil, as well as of initial and boundary conditions in the equations of hydrodynamics, lead to a necessity of spatial/temporal averaging of these deterministic equations. The stochastic terms, which appear in the equations after averaging procedure, should be either described theoretically or estimated from experiments. Averaging procedure is the first source of stochasticity in the modelling of erosion features. The phenomenon was discussed in Nearing (1991), Wilson (1993a,b), and Sidorchuk (2001a,b). This paper focuses mainly on stochastic mechanics of erosion processes in a gully bed.

The second main cause of stochasticity in gully erosion modelling is the general uncertainty in our knowledge of the spatial/temporal distribution of the main erosion factors. The initial relief, soil texture and vegetation cover characteristics can be measured only with limited spatial/temporal accuracy. These limitations can reduce or even distort the estimated spatial/temporal pattern of the main controlling factors. Semi-empirical models with statistical distribution of the model parameters can be used to avoid scaling effects without unnecessary increasing of the quantity and cost of measurements. Such features as patchiness of seepage erosion, slumping, burrowing animal action, pattern of sidewall dissection by rills, vegetation growth, weathering and topsoil formation are also better described with statistical distributions. The influence of uncertainty in the spatial/temporal pattern of the controlling factors of gully erosion on the modelling procedures will be discussed in the future papers.

2. Stochastic description of erosion

The erosion of cohesive soils is a result of the complicated superposition of driving forces acting on the soil surface and forces resisting erosion. Sediment flux is a variable changing both in space and in time. It is not possible to calculate the trajectory of every soil particle, because an accurate deterministic prediction of the actual (for any time and point) velocities in the turbulent flow and of actual electro-chemical and geo-mechanical