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Geomorphology 76 (2006) 273–279

GEOMORPHOLOGY

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Channel width–flow discharge relationships for rills and gullies

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Received 16 March 2005; received in revised form 24 November 2005; accepted 24 November 2005
Available online 24 January 2006

Abstract

Research conducted during the first half of the last century has shown that a strong power relationship exists between channel width and total flow discharge in streams. Recent studies have shown that this power relationship can be theoretically derived for bankfull discharge in channels. The relationship has been extended empirically to rills and gullies, revealing that the discharge exponent for rills and gullies is significantly smaller than that for rivers. However, water flow in rills and gullies is only rarely bankfull, indicating that the theoretical explanation for the power relationship found for rivers does not apply to rills and gullies. In order to investigate the width–discharge relationships for rills and gullies, a new method is proposed based on field measurements of widths of concentrated-flow erosion channels both upstream and downstream of channel junctions. Although the method only allows the determination of the exponent of the power relationship, it is easy and inexpensive to apply. A total of 322 rill and gully channel junctions with various soils and land use types were investigated in Belgium, Italy and Spain. The obtained data confirmed the existence of the power relationship for rills and gullies, with the exponent varying from 0.43 for small rills (about 3 cm in width) to 0.5 for gullies (about 50 to 100 cm in width). The data did not allow deciding whether the exponent varies consistently with channel width or in a step-wise fashion. The exponent values obtained in this study are larger than those reported in previous studies, but this may result from differences in the definition of the discharge that eroded the channel to its current width.

Keywords: Rills; Gullies; Channel junctions; Soil erosion; Width–discharge relationship

1. Introduction

Water erosion on slopes, in thalwegs and in low-order channels has been studied in detail, and relationships between erosive power and the dimension of resultant landforms have been established. Lacey (1929), Leopold and Maddock (1953) and others (see Savenije, 2003 for a detailed review) found a strong power relationship between channel width and total flow discharge. Although researcher-oriented articles (e.g., Rodriguez-Iturbe, 1993) and even some textbooks deal with the flow width–discharge relationship as a basic geomorphological concept (e.g., Knighton, 1996), the relationship has not been investigated in detail at the hillslope scale where concentrated runoff can erode rills and gullies.

Some recent literature on slope hydrology dealt with relevant topics. Govers (1992) observed that flow velocity in rills developed in loose, non-layered materials depends mostly on flow discharge, while bed slope and

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doi:10.1016/j.geomorph.2005.11.010

hydraulic roughness are irrelevant. These results were confirmed and generalized by Giménez and Govers (2001) who explained the slope-independence of rill flow velocity by a feedback mechanisms between rill bed morphology and flow conditions. Nachtergaele et al. (2002), reviewing the literature on rills and gullies, extended the width–discharge relationships to these channel sizes.

Recently, Savenije (2003) showed that the power relationship between discharge and channel width is theoretically derivable for the case of bankfull discharge. This may apply to most streams but not to rills and gullies where bankfull discharge is only episodic when incision is at its initial stages. Once a channel of a rill or a gully is eroded into the topsoil, it is easily enlarged and deepened by flow within the channel, which usually removes sediment produced by sidewall collapses, especially during peak flow.

The channel width (w) – runoff discharge (Q) relationship can be expressed as:

$$w = kQ^{\alpha} \quad (1)$$

where k and α are constants.

The exponent α takes values of ca. 0.3, 0.4 and 0.5 for rills, gullies and rivers, respectively (Nachtergaele et al., 2002), suggesting that the exponent is a function of discharge. However, the relationship for rills and gullies needs further investigations because the number of such studies is limited.

The above short summary of the state of the art suggests that the hydro-geomorphological relationships observed in the field do not correspond to those expected from models of overland flow and soil erosion. Because these models usually apply equations based on Manning's velocity–depth relation, they generally ignore feedbacks from erosion and deposition processes, and they scarcely take into account the characteristics of eroded material.

Most studies on the width–discharge relationship for rills and gullies have been conducted in the laboratory or in the field under simulated rainfall and/or runoff conditions (e.g., Lane and Foster, 1980; Sidorchuk, 1998; Bennett et al., 2000). It is difficult to obtain data on discharge and rill or gully width during natural rainfall events because many factors are beyond control. However, simulated conditions may differ from actual conditions in the field. Consequently, we need to develop a method to explore the width–discharge relations in the field, under natural conditions. This study aims to acquire better knowledge of the dynamics of Eq. (1) by analysing data for natural rills and gullies using a new method.

2. Study areas

Field data on rill and gully channel geometry were collected in Belgium, Italy and Spain. Measurements were conducted by two independent teams over a series of land use and soil types (Table 1).

The study areas in Italy are mainly located in Tuscany and include one vineyard in full production on sandy loam soil, two new vineyards recently levelled using bulldozers (with partial or total removal of soil material and mixing of soil material with underlying Pliocenic marine deposits—both soils being silty clay, one skeletal, with 40–60% rock fragments), two service roads on cropland used by tractors (silty clay, one with rock fragment content of 40%), and one escarpment between a service road and a field. A few more gullies formed in morainic deposits and slope debris in the Italian Alps (Rabbi Valley, Trento) were surveyed. In Belgium, rills and ephemeral gullies were selected on loess-derived soils under sealed winter wheat seedbed conditions near Leuven. In Spain, the selected rills and gullies were located on stony, shallow soils on slates with intensively chiselled almond groves (Guadalentin Basin; Poesen et al., 1997). Following the Köppen–Geiger climate classification, the explored sites are located in warm temperate climates either with sufficient precipitation every month (Cfb for Belgium and Cfa for part of Italy), or with a dry season in summer (Csa for Spain and the majority of Italy).

3. Materials and methods

In each study area, rill and gully channel junctions (Fig. 1) were selected for measuring representative

Table 1
Number of channel junctions with main land use types and soil textural classes

Country	Land use	Soil textural class (USDA)	Number of junctions
Italy	Vineyard	Sandy loam; silty clay, some stones	30
	Service road in cropland; vineyard	Silt	14
	Service road in cropland	Silty clay	19
	Cropland (seedbed)	Clay; silty clay; silty clay loam	40
Belgium	Cropland (winter wheat)	Silt loam; loamy sand	79
	Cropland (fallow)	Silt loam; sandy loam; loamy sand;	45
Spain	Almond grove	Stony to very stony sandy loam	69