Progress in Gully Erosion Research

Javier Casalí
Rafael Giménez
(Eds.)

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Prologue

The classic forms of water erosion of the soil comprise sheet, rill, and gully erosion. According to the concept most generalized, in sheet erosion, thin layers of material are uniformly removed from the soil surface due to the action of an overland flow, in a homogeneous manner, over the area affected. This results in a normally very gradual and inappreciable loss of soil. However, in rill and gully erosion, the soil loss is caused by the intense action of a concentrated flow, which thus triggers the formation of small or large channels, i.e. rills or gullies, although the mechanisms implicated in either form of concentrated flow erosion are not identical. One of the main differences probably lies in the (much) greater interrelation between the roughness of the channel bed and the hydraulics of the water flow observed in a eroded rill, with respect to what occurs in a typical gully. So, the latter, as a physical process, deserves a special and specific study.

Gully erosion, of world-wide importance, is catalogued by some of the principal centres devoted to soil resource conservation as being the foremost problem to be solved. As it is one of the most serious forms of water erosion, this phenomenon is capable of generating major soil losses even though it covers limited land surfaces. Additionally, the damage caused by this type of erosion frequently spreads beyond the area directly affected, i.e. through the siltation of lakes and reservoirs due to the large amounts of sediments it originates.

Nevertheless, gully erosion has not received the attention that it warrants from the scientific community. For instance, a rapid search through any important virtual library shows that only less than 10% of soil erosion studies published up to now in international scientific journals deal directly and specifically with gully erosion. More research and surveys are required in order to obtain a better understanding of the physical mechanisms involved in this type of erosion, with the ultimate aim of developing accurate prediction algorithms and efficient control and damage prevention systems.

In fact, there are so many unanswered questions on this important environment topic that scientists all over the world have been holding periodic meetings, in which the latest knowledge and advances in the study of gully erosion have been expounded. The first of these meetings was held in Leuven (Belgium) in 2000, the second in Sicuani (China) in 2002 and the third in Oxford, Mississippi (U.S.A.) in 2004. On that last occasion, the participants proposed that Pamplona (Spain) should be the seat of the following meeting, to be held in September 2007.

This book contains the abstracts both from the key speeches and from the contributions presented in the *IV International Symposium on Gully Erosion* held in Pamplona, in September, 2007.

The *Organizing Committee* of the *IV International Symposium on Gully Erosion* was formed by: Javier Casalí (co-chair), Rafael Giménez (co-chair), Jesús Álvarez, Miguel A. Campo, Jokin del Valle de Lersundi, Rakel Gastesi, Mikel Goñi, José Javier López, César Pérez and Luisa M. De Santisteban.

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Contributions

EPHEMERAL GULLY EROSION RESEARCH: PROCESSES AND MODELING
(Keynote)

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1. Introduction

The USDA Natural Resources Conservation Service (NRCS) defines ephemeral gullies as small channels that can be filled in by normal tillage operations only to reform in the same location by subsequent runoff events. Ephemeral gullies contribute significantly to soil erosion in agricultural fields, and NRCS has consistently identified gully erosion as their number one problem to solve. Moreover, headcut development and migration is closely coupled to the initiation of ephemeral gullies and their extension on hillslopes. Research is needed to further understand the physics of these processes, to derive robust predictive algorithms and methodologies, and to develop reliable control methods.

Previous studies, too numerous to be quoted here, have shown that ephemeral gully development is influenced by dynamic hydrologic and landscape attributes that control surface and subsurface erosion processes. The prevalent consensus is that the location and size of ephemeral gullies can be controlled by the generation of concentrated surface flow of sufficient magnitude and duration to initiate and sustain soil erosion. Concentrated flow in cultivated fields can overtop furrows, thereby creating a cascade of water downslope that leads to ephemeral gully development. Field observations support the concept of ephemeral gully as the transition between a hillslope and a drainage channel. Thus, both surface and subsurface flow may converge and interact at locations that become initiating points of the gullies.

Figure 1. Headcut migration and gully widening in a crop furrowed field.

Ephemeral gully erosion usually, but not always, includes one or more headcuts that migrate upslope over time. These are step changes in bed surface elevation where intense, localized erosion takes place, and that are commonly associated with significant increases in sediment load. Reported experimental data shows that actively migrating ephemeral-gully headcuts display a self-similar organization with migration rates dependent on upstream flow depth and discharge, tailwater depth, and soil properties. The depth of ephemeral gullies is often limited by the presence of a non-erodible or impervious soil layer. When erosion reaches such a layer, the ephemeral gully typically widens, creating a wide shallow cross section. The response of the soil to eroding processes is also affected by wetting and drying from rainstorm events, as well as the annual cycle of tillage, crop growth, and freeze-thaw. Once an ephemeral gully is initiated, transport and deposition of the eroded soil and widening of the gully channel further govern its evolution (Figure 1). However, our knowledge of these processes in shallow concentrated flows within agricultural soils is still quite limited and largely scaled down from river hydraulics.

Compared to the roles of surface flow and soil water tension on rill initiation and growth, the contribution of subsurface flow to ephemeral gully erosion is less well known. The two mechanisms of subsurface flow attributed to erosion are seepage and preferential flow. Seepage is common where restriction of downward percolation results in lateral flow that emerges from the soil surface. There is also evidence that positive and negative seepage also influence surface erosion and sediment transport. Water-restrictive layers that focus flow through soil-pipes can also cause ephemeral gully development through soil-pipe collapse or pop-out failures that initiate ephemeral gully development (Figure 3).

The initiation and growth of ephemeral gullies is also greatly affected by land management practices that control evapotranspiration, infiltration, runoff rate, and soil detachment, which alter runoff patterns. These practices include contouring, no-till, cover crops, crop rotation, vegetative barriers, check dams, soil amendments and subsurface drainage. Current approaches to evaluate ephemeral gully initiation and erosion incorporate two basic steps. The first step uses visual observation based on field reconnaissance or from aerial photographs to pinpoint landscape attributes favorable for gully initiation, or critical slope steepness and contributing area relationships for ephemeral gully initiation. The second step is taken once the gully has been identified and involves the application of process-based water erosion models like the Ephemeral Gully Erosion Model (EGEM, Woodward, 1999).

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2. Selected Results from a Team Research Effort

A multidisciplinary team of scientists from the USDA National Sedimentation Laboratory, NRCS, the University at Buffalo, Oklahoma State University, and the University of Nottingham, UK, is collaborating in experimental and modeling research on several aspects of ephemeral gully erosion. Their recent results are detailed in a series of concurrent (oral and poster) papers at this Symposium, and the remainder of the present abstract is devoted to highlight outcomes of this collaborative effort during the intervening period since the 3rd International Symposium on Gully Erosion held in Oxford, Mississippi, in 2004.

2.1. Experimental Studies

Bennett and Alonso (2007) examined the flow characteristics within fixed-bed models of headcut scour holes typical of upland concentrated flows. Velocity data and streamlines show unequivocally that flow within headcut scour holes is analogous to a reattached plane turbulent wall jet. The overfall nappe entering the scour hole domain evolves into a free jet, with flow reattachment occurring just upstream of the maximum scour depth (Figure 2). Recirculation zones bound the free jet region, and the deflected flow downstream of impingement evolves into a classical wall jet. Within headcut scour holes, three hydrodynamic mechanisms are responsible for soil erosion. These are: (1) high shear stresses due to near-bed velocity gradients; (2) high near-bed Reynolds stresses due to turbulent fluctuations in velocity; and (3) large wall pressure gradients near flow reattachment.

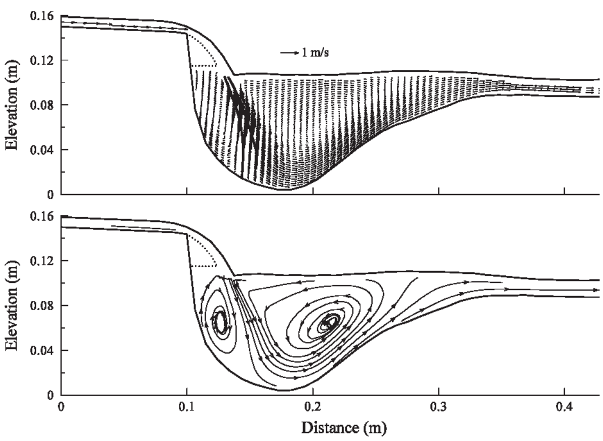

Figure 2. Measured streamline pattern within the scour pool of a fixed-bed headcut model.

Gordon et al. (2007b) investigated the effect of an erosion resistant (ER) soil layer placed at various depths within a fine sandy-loam (Ruston series) on headcut development and migration. When the ER layer was placed at or above the potential scour depth (verified by baseline runs), headcuts were limited in depth to this layer, and while their migration rates remained about the same, total sediment efflux was markedly reduced. These experimental observations were successfully compared to analytic formulations for headcut erosion based on jet impingement theory.

Wells et al. (2007) studied the impact of soil texture, soil pore-water pressure, and tailwater height on scour hole dimensions, migration rate, and sediment yield in headcuts migrating under steady surface runoff conditions. The soils used in this study were the same Ruston soil mentioned above, a silt loam (Atwood series), a silt loam (Dubbs series), and a silty clay loam (Forestdale series). The Ruston and Atwood soils attained steady-state morphology, constant upstream migration, and sediment yield, while the Dubbs and Forestdale soils developed scour geometries characterized by an eroded brinkpoint and tilted back headcut face as the overfall nappe turned into a reattached wall jet. Maximum scour depth increased with decreasing pore-water pressures and an increase in tailwater height dramatically reduced the sediment yield and migration rate.

Figure 3. A soil pipe observed at a gully head immediately above the fragipan layer.

Wilson (2007a) reports results from laboratory lysimeters that examined hydrologic conditions under which soil-pipes initiate or reestablish ephemeral gullies. Tests with continuous soil-pipes did not exhibit sudden development of mature ephemeral gullies by tunnel collapse but experiments on discontinuous soil-pipes did exhibit sudden re-establishment of filled-in gullies. The addition of rainfall resulted in cataclysmic pop-out failures up to 20 times higher than sheet erosion. The result of these pop-out failures is the re-establishment of ephemeral gullies with large initial soil losses. These findings explain the observed reoccurrence of ephemeral gullies at the same locations, and also suggest that conservation practices that focus solely on controlling the surface runoff may be ineffective if subsurface flow controls are not considered (Figure 3).

Parallel field and lysimeter studies reported by Wilson et al. (2007b) use seepage erosion to describe the process of sediment transport out of an edge-of-field gully face by liquefaction of soil particles entrained in the seepage. The undercutting of the gully face by seepage erosion results in mass failure which may be a contributing factor to headcut migration and gully widening. The question remains as to what role this process plays in ephemeral gully erosion in soil profiles containing an erodible surface layer over a water restrictive layer.

2.2. Modeling Studies

The Annualized Agricultural Non-Point Source model (AnnAGNPS; Bingner and Theurer, 2001) is one of the decision tools identified by NRCS for conservation planning on croplands. AnnAGNPS is being developed to provide sediment tracking from all sources within the watershed including ephemeral gullies. Gordon et al. (2007a,c) extended the capabilities of EGEM by adding new algorithms that: (1) create the initial headcut's knickpoint; (2) estimate the headcut migration and erosion rates; and (3) enhance some other existing EGEM components. These enhancements were integrated into the revised Tillage-Induced Ephemeral Gully Erosion Model (TIEGEM). The TIEGEM technology has been incorporated into AnnAGNPS model to provide a watershed-scale assessment of the effect of management practices on the production of sediment from ephemeral gully erosion within croplands (Bingner et al., 2007).

3. Research Needs

The enhancements introduced in the TIEGEM model notwithstanding, some clear limitations remain in this technology. The experimental data reported here and elsewhere by *Bennett* and his coworkers provided the framework for the analytic treatment of headcut migration used in the revision of EGEM. Yet those data were derived in a fixed-width flume where the headcut grew and developed without benefit of adjusting its width. Therefore, the utility of those formulations in field settings and operational models is limited because naturally occurring rills, crop furrows, and ephemeral gullies can, in most cases, freely adjust their widths to the imposed runoff (Figure 1). Similarly, the flume data were collected in flows devoid of upstream sediment load and headcut erosion ensued as the result of a clear-water overfall and scouring jet. This imposed boundary condition is far removed from natural rills, crop furrows, and ephemeral gullies that display the complete spectrum of detachment-limited to transport-limited flows. One can expect that the modulation of jet erosivity due to an upstream sediment load would modify the magnitude of the soil erosion processes within the scour pool. In addition, the complete absence of subsurface flow and erosion treatment imposes further limitations on the application of TIEGEM to natural settings. These limitations, combined with the lack of reliable transport predictors for poorly graded sediments in shallow flows, point to clear directions for future research.

References

Bennett, S.J., and Alonso, C.V. 2007. Turbulent Flow Within Headcut Scour Holes In Rills And Gullies, *Proceedings*, 4th International Symposium on Gully Erosion, Pamplona, Spain.

Bingner, R.L., Theurer, F.D., Gordon, L.M., Bennett, S.J., Parker, C., Thorne, C., and Alonso, C.V. 2007. AnnAGNPS Ephemeral Gully Erosion Simulation Technology, *Proceedings*, 4th International Symposium on Gully Erosion, Pamplona, Spain.

Gordon, L.M., S.J. Bennett, R.L. Bingner, F.D. Theurer, and C.V. Alonso. 2007a. Simulating Ephemeral Gully Erosion in AnnAGNPS. *Transactions of the American Society of Agricultural and Biological Engineers.* in press.

Gordon, L.M., Bennett, S.J., Wells, R.R., and Alonso, C.V. 2007b. Ephemeral Gully Headcut Development And Migration In Stratified Soils, *Proceedings*, 4th International Symposium on Gully Erosion, Pamplona, Spain.

Gordon, L.M., Bennett, S.J., Alonso, C.V., and Bingner, R.L. 2007c. Ephemeral Gullies: To Till Or Not To Till? *Proceedings*, 4th International Symposium on Gully Erosion, Pamplona, Spain.

Wells, R.R., Alonso, C.V., and Bennett, S.J. 2007. Influence of Soil Structure, Pore-Water Pressure, and Tailwater Height on Headcut Migration in Upland Concentrated Flows, *Proceedings*, 4th International Symposium on Gully Erosion, Pamplona, Spain.

Wilson, G.V. 2007a. The Role of Preferential Flow Through Soil-Pipes In Ephemeral Gully Erosion, *Proceedings*, 4th International Symposium on Gully Erosion, Pamplona, Spain.

Wilson, G.V., Fox, G.A., and Chu-Agor, M.L. 2007b. Seepage Erosion Impacts On Edge-Of-Field Gully Erosion, *Proceedings*, 4th International Symposium on Gully Erosion, Pamplona, Spain.

Woodward, D.E. 1999. Method to Predict Cropland Ephemeral Gully Erosion. Catena. 37: 393-399.

TURBULENT FLOW WITHIN HEADCUT SCOUR HOLES IN RILLS AND GULLIES

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1. Introduction

Soil erosion remains the principle cause of soil degradation worldwide, and off-site impacts of sedimentation can severely affect water quality, ecology, and ecological habitat (e.g., Pimentel et al., 1995). On hillslopes and agricultural fields, soil erosion occurs in areas of concentrated flow such as rills, crop furrows, and gullies. Within these relatively small channels, localized erosion often occurs due to the development and upstream migration of headcuts, which are abrupt step-changes in bed elevation (see Bennett et al., 2000). The development and migration of headcuts can significantly increase soil losses and sediment yields (see Bennett et al., 2000).

Recent analytical models for headcut erosion in soils have utilized elements of jet impingement theory (e.g., Stein et al., 1993). In these studies, flow at the headcut brinkpoint and in the scour hole domain, as well as erosion of the soil, all were treated explicitly as an impinging jet and associated wall jets that would act on the erodible boundary. This hypothesis has been further supported by the experiments of Bennett et al. (2000) and the analysis of Alonso et al. (2002), who showed that the plunge pools of actively migrating headcuts have turbulent flow patterns resembling an impinging jet. However, little information exists on the turbulent flow structure within headcut scour holes, and whether such analytic treatments are justified.

The objectives of the present study were to experimentally determine the time-mean turbulent flow characteristics within fixed-bed models of headcut scour holes typical of upland concentrated flows and to assess soil erosion mechanisms within the scour hole domain.

2. Experimental Methods

All experiments were conducted using a recirculating 5.5-m long tilting flume. The main flow channel was 2 m long and 0.165 m wide.

Two wooden models of headcut scour holes were placed into the flume. These forms were replicated from previous live-bed experiments using a sandy loam to sandy clay loam soil. The first headcut form (Model 1) is an exact replica of the time-averaged, steady-state bed profile of Run 9 from Bennett et al. (2000), representing the nonventilated, nearly submerged overfall. For the fixed-bed experiment, bed slope was 1% and unit discharge was 0.0071 m^2 s^{-1}. The second headcut form (Model 2), an exact replica of the instantaneous bed profile from Run 5 of Bennett (1999), represents the partially ventilated, free overfall. For this fixed-bed experiment, bed slope was 5% and unit discharge was 0.0052 m^2 s^{-1}.

Velocity measurements were obtained with a 300 mW Argon-ion laser Doppler anemometer (LDA). The LDA was operated in back-scatter mode using a 400 mm focal-length lens and a velocity resolution of 0.5 mm s^{-1}. Flow velocities were recorded on the flume axial plane of symmetry in the directions parallel and perpendicular to the flume slope, designated as u_i and v_i, their at-a-point time-averaged values designated as u and v, and their turbulent fluctuations designated as $u' = u_i - u$ and $v' = v_i - v$, respectively. Velocities were measured for periods up 120 s, spaced approximately 1 to 2 mm vertically and 5 mm horizontally with data rates exceeding 100 Hz.

3. Results

Streamlines based on time-averaged flow vectors within the headcut scour hole models are shown in Figure 1. The overfall nappe enters the scour pool domain and creates a core of high-velocity fluid that extends toward the bed. This high-velocity core is deflected by the scour hole curvature and remains in close proximity to the bed, achieving uniform flow conditions upon exiting the measuring section. Two relatively large recirculation zones occur on both sides of the high-velocity core.

Figure 1 demonstrates that flow within headcut scour holes typical of upland concentrated flows is a turbulent reattached wall jet. For turbulent impinging jets, the free jet axis (or high-velocity core) extends completely to the boundary, creating a point of stagnation and flow deflection (e.g., Beltaos and Rajaratnam, 1973). In contrast, the point of reattachment in the present cases, as determined from the vector data, corresponds to the upper boundary of the recirculation zone delimited by the scour hole and the free jet. Turbulent reattached wall jets, as discussed by Rajaratnam and Subramanya (1968) and shown here, have an elongated impingement zone downstream of flow reattachment, where flow evolves into a plane turbulent wall jet.

Contour plots of select turbulence parameters for headcut Model 1 are shown in Figure 2. Relatively higher turbulence intensities are associated with the free jet upon entry to the scour hole domain. Maximum values of the root-mean-square of the downstream velocity component u_{rms} ($u_{rms} = \sqrt{\overline{u'}}$ where the overbar represents a time-average) occur along the upper part of the free jet, in association with the shear layer separating the submerged

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jet and the downstream recirculation eddy. Conversely, maximum values of v_{rms} ($v_{rms} = \sqrt{\overline{v'^2}}$) occur along the lower part of the free jet, in association with the shear layer separating the submerged jet and the recirculation eddy near the headcut face (Fig. 2). Secondary maxima for both parameters occur within or near the large recirculation zone downstream of the jet. Maximum values of positive Reynolds stress τ ($\tau = -\rho\overline{u'v'}$ where ρ is fluid density) are in close spatial association with the upper shear layer of the submerged jet and near flow reattachment (Fig. 2). Large, positive τ values also dominate the free jet region of the scour hole domain and downstream of flow reattachment. Similar distributions of these turbulence parameters were obtained for headcut Model 2.

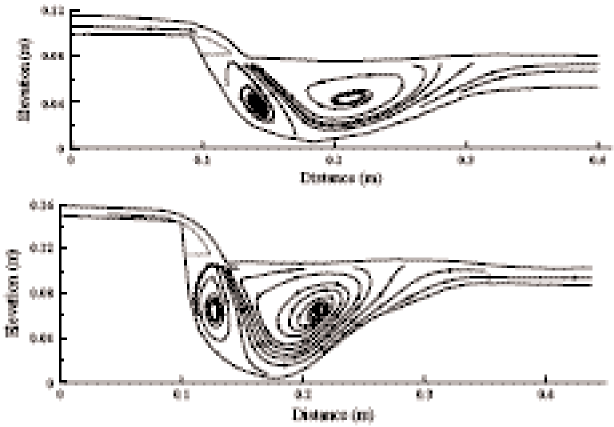

Fig. 1. Flow fields (streamlines) within headcut Model 1 (upper) and Model 2 (lower). Solid lines show water surface and bed profiles.

4. Discussion and Conclusions

In upland concentrated flows, the development and upstream migration of headcuts can significantly increase soil losses, sediment yields, and landscape degradation. Velocity data and streamlines show unequivocally that flow within headcut scour holes is analogous to a reattached plane turbulent wall jet. The overfall nappe entering the scour hole domain evolves into a free jet, with flow reattachment occurring just upstream of the maximum scour depth. Recirculation zones bound the free jet region, and the deflected flow downstream of impingement evolves into a classical wall jet. Maxima for turbulence and Reynolds stress occur along the shear layers of the free jet, near reattachment, and within the recirculation eddies.

Within headcut scour holes, three hydrodynamic mechanisms are responsible for soil erosion. These are: (1) high shear stresses due to large near-bed velocity gradients (e.g., Rajaratnam and Subramanya, 1968); (2) high near-bed Reynolds stresses due to turbulent fluctuations in velocity (Fig. 2); and (3) large wall pressure gradients near flow reattachment (e.g., Bennett and Alonso, 2006).

This study provides experimental confirmation of the turbulent flow structure within headcut scour holes typical of upland areas. Such erosional phenomena can be treated hydrodynamically as plane reattached wall jets. This conclusion enables the further development and application of jet impingement theory for predicting soil erosion processes in rills, crop furrows, and ephemeral gullies.

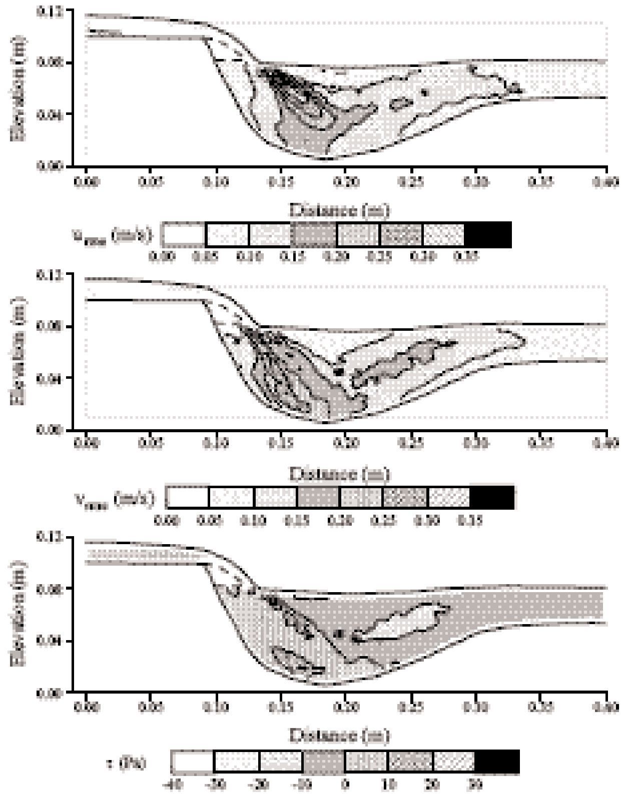

Fig. 2. Contour plots of the root-mean-square of the downstream (upper) and vertical (middle) velocity components and Reynolds stress (lower) for headcut Model 1.

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References

Alonso, C.V., Bennett, S.J. and Stein, O.R. 2002. Predicting head cut erosion and migration in concentrated flows typical of upland areas. *Water Resourc. Res.*, *38*:doi:10.1029/2001WR001173.

Beltaos, S. and Rajaratnam, N. 1973. Plane turbulent impinging jets. *J. Hydraul. Res.*, *11*:29-59.

Bennett, S.J. 1999. Effect of slope on the growth and migration of headcuts in rills. *Geomorphology*, *30*:273-290.

Bennett, S.J. and Alonso, C.V. 2006. Turbulent flow and bed pressure within headcut scour holes due to plane reattached jets. *J. Hydraul. Res.*, 44:510-521.

Bennett, S.J., Alonso, C.V., Prasad, S.N. and Römkens, M.J.M. 2000. A morphological study of headcut growth and migration in upland concentrated flows. *Water Resour. Res.* *36*:1911-1922.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R. and Blair R. 1995. Environmental and economic costs of soil erosion and conservation benefits. *Science*, 267:1117-1123.

Rajaratnam, N. and Subramanya, K. 1968. Plane turbulent reattached wall jets. *J. Hydraul. Div., ASCE.*, *94*:95-112.

Stein, O.R., Julien, P.Y. and Alonso, C.V. 1993. Mechanics of jet scour downstream of a headcut. *J. Hydraul. Res.*, *31*:723-738.

ANNAGNPS EPHEMERAL GULLY EROSION SIMULATION TECHNOLOGY

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1. Introduction

The National Resources Inventory (NRI), conducted by the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS), in cooperation with Iowa State University's Center for Survey Statistics and Methodology, reported that there has been a 42% decrease in sheet and rill erosion in the U.S. between 1982 and 2003. Erosion control practices within agricultural watersheds have a significant impact on reducing the sheet and rill source of sediment to the streams. While these practices have significantly affected sheet and rill erosion, they do not appreciably affect ephemeral gully erosion. Ephemeral gully erosion is becoming a dominate source of cropland erosion simply because sheet and rill erosion is decreasing.

Most ephemeral gullies that develop within croplands are tillage-induced; i.e., certain tillage operations weaken the top layer down to the maximum depth disturbed by this mechanical process during a rotation. What makes a tillage-induced ephemeral gully different from other gullies is the assumption that a non-erosive layer develops at the maximum tillage depth from operations during the management rotation cycle. Ephemeral gullies may form into the soil profile that are greater than tillage depths if the tractive stresses exceed the critical tractive stress of the more resistant bottom layer below the tillage layer. A management operation in the rotation cycle may also remove the gully, by filling in the gully through mechanical soil disturbance, but the gully may reform when conditions are again sufficient to produce ephemeral gully erosion.

Sheet and rill erosion conservation management technologies, such as the Revised Universal Soil Loss Equation (RUSLE, Renard et al, 1997), have provided valuable tools in reducing cropland erosion, but have not considered the impact of ephemeral gully erosion. NRCS has requested improvements in USDA Agricultural Research Service (ARS) technologies to account for watershed sources of sediment from ephemeral gully erosion through the USDA Annualized Agricultural Non-Point Source model (AnnAGNPS, Bingner and Theurer, 2001). AnnAGNPS has been developed to determine the effects of conservation management plans and provide sediment tracking from all sources within the watershed. Technology is also needed to identify where ephemeral gullies may form in the watershed using geographic information system (GIS) technology.

2. AnnAGNPS Model Description

AnnAGNPS is a watershed conservation management planning tool developed by USDA as a partnership between ARS and NRCS. RUSLE technology is used within AnnAGNPS to determine sheet and rill erosion. The model has the capability to track sediment from any source to any point in the watershed for sheet and rill erosion, as well as other sediment sources such as classical gullies and channels. The inclusion of ephemeral gully processes within AnnAGNPS has become a major model developmental need identified by NRCS for conservation planning on croplands.

3. AnnAGNPS Ephemeral Gully Model Enhancements

Although not satisfactorily achieved, the only USDA technology available to assess ephemeral gully erosion on an agricultural field for many years has been the Ephemeral Gully Erosion Model (EGEM, Woodward, 1999). Gordon et al. (2007) has extended the capabilities of EGEM through the Revised EGEM (REGEM) as a stand-alone program, by: (1) adding a new algorithm which estimates the migration rate of the headcut; (2) adding an algorithm which creates the initial headcut's knickpoint; (3) refining some of the existing EGEM components; and (4) developing additional components into a revised and further enhanced algorithm.

The integration of REGEM technology into AnnAGNPS led to other additions to simulate tillage-induced ephemeral gully erosion including: the capability to repair gullies through tillage that defines when an ephemeral gully can again initially form; the influence of prior landuse as defined from RUSLE-technology; utilization of HUSLE (Theurer and Clarke, 1991) components for sediment transport determination; enhanced gully width calculations; and the determination of the amount of scour hole erosion. These enhancements and the inclusion of REGEM-technology have led to the Tillage-Induced Ephemeral Gully Erosion Model (TIEGEM) within AnnAGNPS to provide a watershed-scale assessment of management practice effects on sediment production from ephemeral gully erosion within croplands.

This technology provides an integrated approach in simulating ephemeral gully erosion as the headcut is induced and moves up the length of the pathway with varying widths, depths and migration rates as a result of management practices, watershed characteristics, and climatic effects. Examples of sheet and rill erosion and ephemeral gully erosion control conservation practice assessments include simulations from the conversion of cultivated fields to the Conservation Reserve Program (CRP), from conventional-till to no-till farming practices, or from the use of grassed waterways for ephemeral gully erosion control. Sediment

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from ephemeral gully erosion, as well as from sheet and rill erosion, that eventually reaches the edge of a field (sediment yield), can then be separately tracked as sediment moves further downstream from the utilization of AnnAGNPS.

4. Potential Ephemeral Gully Identification

The identification of where ephemeral gullies occur on a landscape is typically determined through visual observation based on field reconnaissance or from aerial photographs. When there are many fields within a watershed this can be tedious and time consuming to determine. Parker et al. (2007) has developed a topographic analysis technique based on digital elevation models (DEM) that is combined with Geographic Information System (GIS) technology to characterize the location of potential ephemeral gullies and their downstream mouth throughout a watershed system. This approach may provide an automated estimate of the location of potential ephemeral gullies, especially the knickpoint that, when combined with AnnAGNPS, can be used to determine the extent of actual ephemeral gully erosion within a watershed resulting from management practices.

5. Current Model Limitations

The integration and transformation of EGEM to REGEM into TIEGEM within AnnAGNPS has identified several model limitations because little is known about several critical components. Some of the more important limiting components are the identification of and relationships for: (1) ephemeral gully width; (2) soil resistance to gully erosion including a definition for non-erosive layers; (3) the effect of root mass and above ground vegetation on erosion resistance; (4) ephemeral gully networks; and (5) the effect of subsurface flow on ephemeral gullies. Currently, these components are represented through widely divergent to non-existent algorithms, which at best have a heuristic basis.

6. Study Locations

6.1. Ohio–Upper Auglaize Watershed Study

The Upper Auglaize Watershed agricultural non-point source modeling project (Bingner et al, 2006) was an interagency effort to use a GIS-based modeling approach for assessing and reducing pollution from agricultural runoff and other non-point sources that eventually discharges into the Toledo, Ohio Harbor. This watershed is also part of the USDA Conservation Effects Assessment Project (CEAP). A significant source of sediment was identified from ephemeral gully processes and an approach was needed to assess this and determine its contribution to the total sediment load entering the harbor. This project applied AnnAGNPS with EGEM estimates of ephemeral erosion to the Upper Auglaize River Watershed to produce sheet and rill, and ephemeral gully sediment source simulations. Through this approach, sediment load reductions throughout the watershed were evaluated when no-tillage conservation practices were used instead of conventional practices. This produced an overall watershed sediment loading reduction of 60%, with a 70% sediment load reduction from ephemeral gullies.

6.2. Kansas–Cheney Lake Watershed Study

The Cheney Lake Watershed is also part of the USDA CEAP Project, located in south-central Kansas, and is a major source of the fresh-water supply to Wichita, Kansas. Improved drinking water can be created if pollutants entering the lake are reduced. AnnAGNPS was also applied to this watershed where ephemeral gullies were identified as a significant source of sediment. Potential ephemeral gullies were identified in over 1000 unique sites that AnnAGNPS then was used to simulate their impact. Over 35% of the sediment load was determined to originate from ephemeral gully erosion. Only 10% of the drainage area produced 76% of the entire sediment load from the watershed, with this 50% of this from ephemeral gully erosion.

7. Conclusions

Tillage-induced ephemeral gully erosion has been shown to be a significant and sometimes dominant source of sediment within a watershed. An approach has been developed within AnnAGNPS to assess the impact of conservation practices on ephemeral gully erosion as well as sheet and rill erosion. Conservation management treatments should include targeting practices specific for ephemeral gullies differently than for sheet and rill erosion. Within watersheds, gullies are becoming the dominate source of cropland erosion unless preventative conservation practices are installed.

References

Bingner, R. L., Czajkowski, K., Palmer, M., Coss, J., Davis, S., Stafford, J., Widman, N., Theurer, F.D., Koltun, G., Richards, P. and Friona, T. 2006. Upper Auglaize Watershed AGNPS Modeling Project Final Report. Research Report No. 51. US Department of Agriculture, Agricultural Research Service, National Sedimentation Laboratory, Oxford, MS.

Bingner, R. L. and Theurer, F. D. 2001. AnnAGNPS: estimating sediment yield by particle size for sheet & rill erosion. In Proceedings of the Sedimentation: Monitoring, Modeling, and Managing, 7th Federal Interagency Sedimentation Conference, Reno, NV, 25-29 March 2001. p. I-1 - I-7.

Gordon, L.M., S.J. Bennett, R.L. Bingner, F.D. Theurer, C.V. Alonso. 2007. Simulating ephemeral gully erosion in AnnAGNPS. *Transactions of the American Society of Agricultural and Biological Engineers,* vol. 50(3): 857-866.

Parker, C., Thorne, C., Bingner, R.L., Wells, R., and Wilcox, D. 2007. Automated Mapping of Potential for Ephemeral Gully Formation in Agricultural Watersheds. US Department of Agriculture, Agricultural Research Service, National Sedimentation Laboratory Research Report No. 56, Oxford, MS.

Renard, K.G. G.R. Foster, G.A. Weesies, D.K. McCool, & D.C. Yoder (coords.) 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). U.S. Department of Agriculture, Agriculture Handbook No. 703, 404 pp.

Theurer, F.D. and C.D.Clarke. 1991. Wash load component for sediment yield modeling. In Proceedings of the fifth federal interagency sedimentation conference, March 18-21, 1991, pg. 7-1 to 7-8.

Woodward, D.E. 1999. Method to predict cropland ephemeral gully erosion. Catena. 37: 393-399.

ALLUVIAL GULLY EROSION: A LANDSCAPE DENUDATION PROCESS IN NORTHERN AUSTRALIA

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1. Introduction

Recent aerial reconnaissance surveys and subsequent remote sensing mapping of Australia's tropical rivers identified alluvial gully erosion as a key sediment source (Brooks et al. 2007; Knight et al. 2007). Gully erosion is found to varying degrees within alluvial river types in northern Australia, but it is most extensive on alluvial plains of the larger rivers like the Mitchell, Leichhardt and Nicholson Rivers, draining into the Gulf of Carpentaria. However, very little is currently known about gully erosion processes in these landscapes (Figure 1).

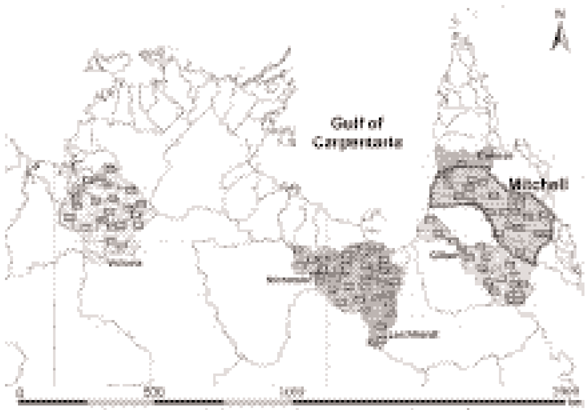

Fig. 1. Map of Catchments in Northern Australia showing the focus areas for a current mapping program. Boxes are remote sensing training sites.

2. Alluvial Gully Erosion Definitions

The definition of a gully is often ambiguous, but can be defined as an unstable eroding channel that expands upslope or laterally into previously un-channel surfaces (e.g., hillslopes, colluvium or alluvium) via surface or subsurface erosion (Schumm et al. 1984). The driving erosional forces of discharge and energy slope need to be greater than the resisting forces of boundary material (i.e., grain friction and cohesion, bed roughness, vegetation) for gully erosion to occur (Lane 1955). Gully complexes are here defined as actively eroding and expanding water catchments that contain a dense drainage network of micro- and meso-scale gullies nested hierarchically within larger macro-gully complexes. Alluvial gully complexes in northern Australian rivers develop in vast alluvial fan, terrace, and floodplains silt deposits of lower- and mid-catchment areas. They are broadly similar to bank gullies defined by Vandekerckhove et al. (2000), but very different in scale. The process of alluvial gully complex erosion appears to differ greatly in scale and process from the well documented, largely colluvial, gullies that abound in southern Australia (e.g., Prosser and Winchester 1996).

3. Alluvial Gully Erosion Processes

The high connectivity between alluvial gullies complexes and trunk rivers makes these features a significant sediment sources to the Gulf. New conceptual models of the processes driving these gullies, their morphology and the controls on their spatial distribution, are required if this process is to be adequately managed and parameterised into existing sediment budget models for northern Australia. A range of gully morphologies have been identified by remote sensing and ground reconnaissance (linear, continuous scarp, dendritic, amphitheatre) (Figure 2). In most of these gully forms, the active gully front is often parallel to the river channel, whereas erosion of the head scarp often migrates away from and perpendicular to the channel. The key feature of alluvial gully complexes is that multiple water sources contribute to erosion across the floodplain perirheic zone (sensu Mertes 1997), such as direct scour from river water, floodplain backwater from the main river, direct precipitation and runoff within the gully catchment, groundwater seepage at the gully head, and advected floodplain water (surface or subsurface) from distal sources.

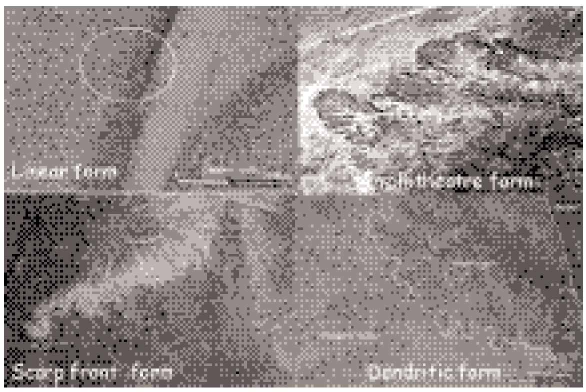

Fig. 2. Gully classification or typology from Brooks et al. (2007).

Our conceptual model outlines two dominant processes underpinning the array of gully forms: basal sapping and overland flow. The dominant process appears to be basal

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sapping, where saturated dispersible soils can erode in the absence of overland flow. Gully initiation, subsequent rate of activity, and morphological variability can be accounted for by the complex interplay between soil type, floodplain relief, vegetation, climate, fire regime, grazing pressure, river flow regime, inundation hydrology, and local rainfall within the context of these two primary driving processes. It is hypothesised that altered land use primarily associated with cattle grazing, altered fire regimes and increased road density, have accelerated gully erosion processes. In addition at the catchment scale, base level lowering of the channel relative to the alluvial surface appears to be the ultimate driver of gully activation.

4. Case Example: The Mitchell River Fan

The Mitchell River has a large catchment area (72,000 km^2) and drains from the western Great Dividing Range into the Gulf (Figure 1). The climate is seasonally wet with 95% of annual rainfall (800 to 2000mm) occurring from November to April. The lower Mitchell savannah plains consist of alluvial silts, sands and clays across a broad coalescing and ancient alluvial fan (Figure 3).

The major loci of deep, well developed gullying occurs within the upper, incised, and high-relief part of the Mitchell fan (M12 & M9 in Figure 3), and there is evidence to suggest a 2nd loci exists near the tidal interface (M2, M3), possibly driven by the hydro-isostatic adjustment identified by Rhodes (1980, p290) and sodic soils. In places, gullies of up to 5m or more in height (Figure 4) form continuous scarps along both high-floodplain margins for 10s of kms (Figure 5), locally occupying > 8% of the total alluvial land surface area. Preliminary field measurements recorded specific sediment yields of 1250 t/ha/yr from a single gully of around 1ha in size. Estimates of sediment production from the contemporary active floodplain within the Mitchell Fan (4200 km^2), suggests an annual sediment production rate of 11.5Mt/yr from gullying alone, equal to an average of 27 t/ha/yr across the fan.

Future research in the Mitchell will focus on additional on-the-ground quantification of alluvial gully erosion rates, processes, and driving factors (described above) at a subset of gully morphologies.

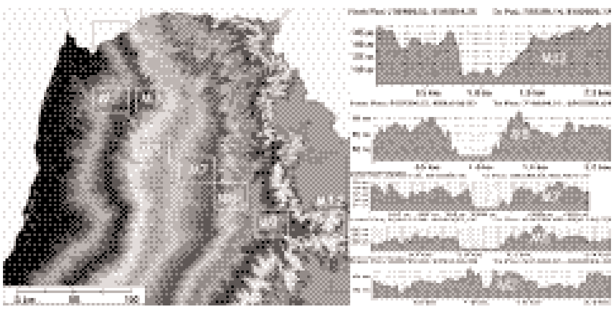

Fig. 3. 30m DEM of the Mitchell River alluvial fan showing zones of high, medium and low relative relief to the trunk river. Greyscale bands represent 10m contours.

Fig. 4. Ground photo of a gully head scarp in the Mitchell.

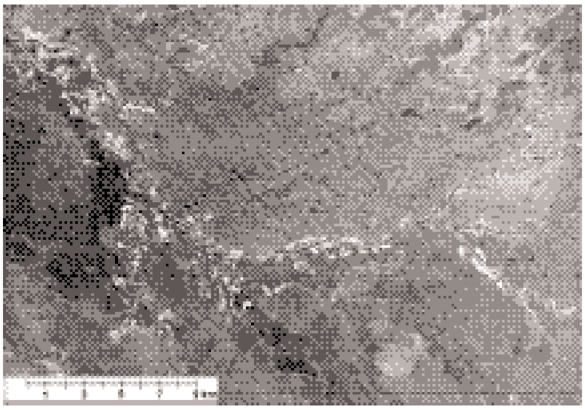

Fig. 5. ASTER image of M3 in Figure 3. Note white areas along river channels are gullies.

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References

Brooks, A., Spencer, J., and Knight, J. 2007. Alluvial gully erosion in Australia's tropical rivers: a conceptual model as a basis for a remote sensing mapping procedure. In Wilson, A.L. et al. (eds) *Proceedings of the 5th Australian Stream Management Conference:* 43-48.

Knight, J., Spencer, J., Brooks, A., and Phinn, S. 2007. Large area, high-resolution remote sensing based mapping of alluvial gully erosion in Australia's tropical rivers. In Wilson, A.L. et al. (eds) *Proceedings of the 5th Australian Stream Management Conference:* 199-204.

Lane, E.W. 1955. Design of stable channels. *ASCE Transactions 120*: 1234-1279.

Mertes, L.A.K. 1997. Documentation and significance of the perirheic zone on inundated floodplains. *Water Resources Research 33*: 1749-1762.

Prosser, I.P. and Winchester, S.J. 1996. History and processes of gully initiation and development in eastern Australia. *Zeitschrift fur Geomorpholigie Suppl Bnd 105*: 91-109.

Rhodes, E.G. 1980. *Modes of Holocene coastal progradation, Gulf of Carpentaria*. Unpublished PhD Thesis, Australian National University, Canberra, Australia.

Schumm, S.A., Harvey, M.D., and Watson, C.C. 1984. *Incised channels: morphology, dynamics, and control*. Water Resources Publications, Littleton, CO.

Vandekerckhove, L., Poesen, J., Oostwound Wijdenes, D., Gyssels, G., Beuselinck, L., and de Luna, E. 2000. Characteristics and controlling factors of bank gullies in two semi-arid Mediterranean environments. *Geomorphology 33*: 37-58.

EFFECT OF TOPOGRAPHY ON RETREAT RATE OF DIFFERENT GULLY HEADCUTS IN BARDENAS REALES (NAVARRE, SPAIN)

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1. Introduction

One of the most important aims of (gully) erosion models is to relate potential soil loss with definable topographic parameters. Precisely, contributing area upslope of the gully headcut (C_{area}) and slope gradient (S) are recognized as the most important topographic factors related to gully erosion (e.g., De Santisteban et al. 2005). As regards different measuring techniques, photogrammetry has proved to be a very useful tool to compute topographic factors such as those mentioned above (e.g., Oostwoud Wijdenes et al., 2000).

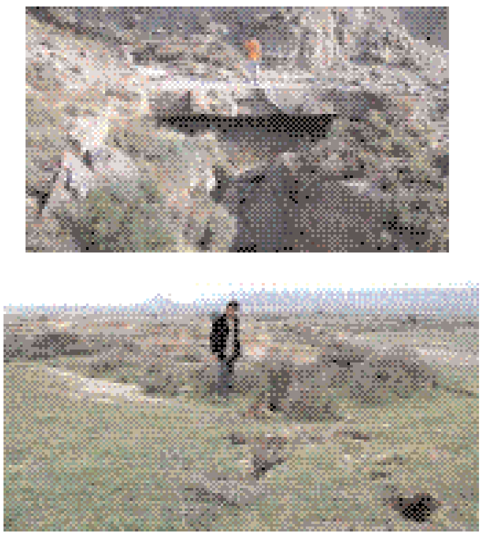

Fig. 1. Above: sandstone gully headcut. Below: piping associated gully headcut.

In Northeast Spain, gullying is a widespread phenomenon. This type of erosion is especially intense in Bardenas Reales (Navarre) where at least two major typical kinds of gully headcut are present. A first group developed in soil material (named, conventional gully headcut), and second group of gully headcut with a sandstone layer as a top horizon (named, sandstone gully headcut) (Fig. 1). In addition, within the former group, we can distinguish a subgroup of gully headcuts developed in soils particularly prone to piping and tunnelling due to the dispersive condition of the materials (named piping associated gully headcut) (Fig 1). In this situation, a question arises: to what extent simple topographic parameters account for the retreat rate of the different kind of gully headcuts observed in the region of Bardenas Reales? The aim of this study was to investigate and gain insight in this issue.

2. Material and methods

A 300-ha watershed, namely Cantalar, within Bardenas Reales, was selected for this study (Fig. 2). This was formed in Tertiary Continental and Quaternary materials (Del Valle and Del Val, 1990). The average slope grade is *ca*. 9% and maximum slope is *ca*. 74%. Height 385 m on average (from 325 to 450 m) and. Annual precipitation is 402 mm.

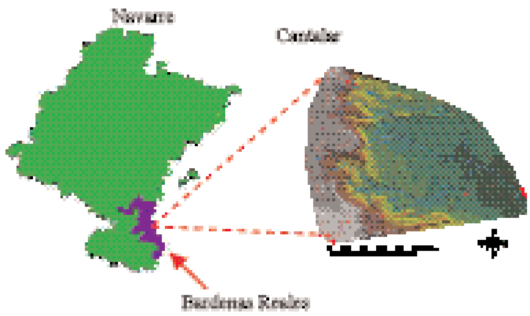

Fig. 2. Location of the Cantalar watershed.

Aerial photographic stereo-pairs covering the study area were used. These were taken on 1976 (1:17,500), 1982 (1:13,500) and 2003 (1:20,000). Manual restitution of photographs was carried out by a public enterprise. 1m-resolution DEMs were obtained by triangular interpolation (Triangular Irregular Network). From the aerial photos and the DEMs, ortho-photographs with a final resolution of 0.40 m were made. The geocoding of these scenes had a Root Mean Square error of 0.13 m in both X and Y directions and of 0.18 m in Z (altitude). Different kind of gully headcuts (as described above) previously recognized by field survey were identified in the photos.

Several topographic parameters related to every gully present in the field were calculated from the DEM of 2003.

Furthermore, from the ortho-photographs, volumetric headcut retreat rates were determined as the product of the lineal retreat and a representative section of each headcut.

Finally, simple models to estimate volumetric gully headcut retreat rate through topographic parameters were carried out by regression analysis.

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3. Results and Discussion

Average gully headcut retreat rate (GHRR) for *conventional* and *sandstone* gully headcuts, for the period 1967-2003, was around 4 and 2 $m^3\ ha^{-1}\ y^{-1}$, respectively. However, this figure arises to about one order of magnitude for *piping associated* gully headcut (Table 1). This is in agreement with GHRR of 12 permanent gullies reported by Vandekerckhove et al. (2003) in southeast Spain for a time period of 20-40 years: between 1-5 $m^3\ ha^{-1}\ y^{-1}$. Nevertheless, they also reported a GHRR of *ca*. 90 $m^3\ ha^{-1}\ y^{-1}$ in two others gully headcuts.

Contributing area is the only topographic parameter high (and positive) correlated (R= 0.97) with volumetric retreat rate, but only for *conventional* gully headcuts (Fig. 3). This is in agreement with previous findings of Vandekerckhove et al. (2003) (Fig. 3). The reason why average slope gradient of the contributing area is not related with gully retreat is uncertain.

C_{area}, surrogate of discharge at the inlet of headcut, does not significantly account for *sandstone* GHRR as soil is somewhat protected against erosive runoff by a low erodible top layer. GHRR is then lower in *sandstone* gully headcuts than in *conventional* gullies (Table 1). In the other hand, *piping associated* gully headcuts are not well related to C_{area} (Fig. 3) since piping and tunnelling are mainly dependent not only on intrinsic characteristics of the material but also on subsurface flow energy (Bull and Kirkby, 2002).

Table1. Average gully headcut retreat rates (GHRR).

Headcut	G $m^3\ y^{-1}$	H $m^3\ y^{-1}$	R $m^3\ y^{-1}$	R $kg\ m^{-2\dagger}\ y^{-1}$	n††
Date	1967 1982	1982 2003	1967 2003	1967 2003	
Sandstone	0.52	0.37	0.43±0.29	0.29	16
Piping assoc.	1.17	1.18	1.18±0.15	9.36	3
Conventional	1.26	0.92	1.04±0.55	0.57	21

† area ($m^{2\dagger}$) refers to C_{area}. Bulk density = 1500 kg/m^3. ††n: total number

Unlike *conventional* gully headcuts, *piping associated* gully headcuts may present an important erosion rate despite a relative small C_{area}. This leads to very high GHRR values when the headcut erosion is expressed in terms of unit of contributing area (see the last column in Table 1). Therefore, caution should be taken to avoid underestimate the erosion rate of this kind of gully headcut when the estimation is based on the contributing area.

4. Conclusions

In Bardenas Reales and for a time period of few decades, gully erosion by headcut retreat is an important source of sediment: around 2-4 $m^3\ ha^{-1}\ y^{-1}\ m^3$. However, in dispersive soil where piping erosion is a notorious process, the last figure can easily be one order of magnitude higher. Statistical analysis showed that volumetric gully headcut retreat rate of gullies developed in soil material (i.e., *conventional* gully headcuts) are well correlated with the contributing area upstream of the headcut. This confirms the importance of runoff discharge entering the headcut. This finding was put forward and documented by Vandekerckhove et al. (2003). Nevertheless, our study shows that when gully headcut development is either mainly controlled by piping or tunnelling erosion or gullying is somewhat hampered by a top layer of a consolidated material, simple topographical parameters do no account for the medium-term (few decades) headcut retreat rate.

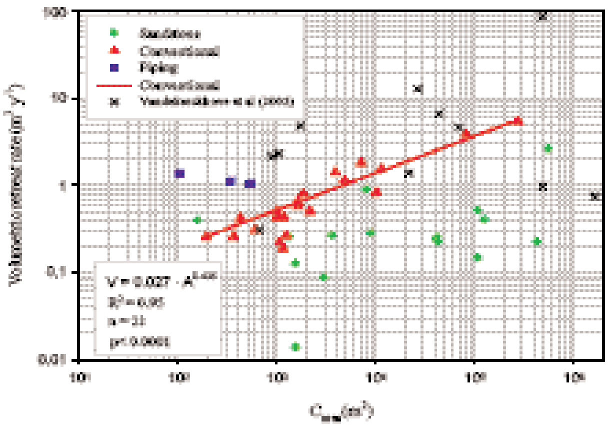

Fig. 3. Power relationship between contributing area (C_{area}) and volumetric gully retreat rate for different kind of headcuts.

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References

Bull, L.J., Kirkby, M.J. 2002. Channel heads and channel extension. In Bull, L.J., Kirkby, M.J (Eds.) Dryland Rivers: Hydrology and geomorphology of semi-arid channels. Wiley, Chichester, England, pp. 263-298.

De Santisteban, L. M., Casalí, J., López, J. J., Giráldez, J. V., Poesen, J., Nachtergaele, J. 2005. Exploring the role of topography in small channel erosion. Earth Surf. Process. Landforms 30, 591–599.

Del Valle de Lersundi, J. and Del Val J., 1990. Procesos de erosión y análisis de sus condicionantes en una región semiárida: la Cuenca de Cornialto (Bardenas, Navarra). Cuaternario y Geomorfología, 4: 55-67.

Oostwoud Wijdenes, D.J., Poesen, J., Vandekerckhove, L., Ghesquiere, M. 2000. Spatial distribution of gully head activity and sediment supply along an ephemeral channel in a Mediterranean environment. Catena (39) 3:147-167.

Vandaele, K. , Poesen, J., Marques De Silva, J.R. , Govers, G. , Desmet, P. 1997.Assessment of factors controlling ephemeral gully erosion in Southern Portugal and Central Belgium using aerial photographs. Zeitschrift fur Geomorphologie (41) 3: 273-287.

Vandekerckhove, L.Poesen, J.Govers, G. 2003. Medium-term gully headcut retreat rates in Southeast Spain determined from aerial photographs and ground measurements. Catena (50): 329-352.

RUNOFF AND SEDIMENT SUPPLY FROM SMALL GULLIED AND UNGULLIED BASINS IN A SEMI-ARID GRAZED ENVIRONMENT

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1. Introduction

The development of a channel network is both unsteady and nonuniform. The fluvial-morphology of rangelands is commonly characterized by headwater ephemeral stream channels and unchanneled valleys. These may incise, thereby forming gullies. The study of gully systems is important because they are a very significant source of sediment and are conduits for sediments and water in semi-arid environments (Poesen et al., 2002), transporting not only suspended sediment but also coarse bedload sedimentary fragments (Rustomji, 2006). Because high-intensity rainfall often generates Hortonian runoff in drylands, temporal correlation between hydrograph and hyetograph peaks is common.

The aim of the presented study is to determine links between rainfall, runoff, gully erosion and sediments. The extent of sediment yield (suspended sediment and bedload) and runoff response from gullied and ungullied basins have been explored. The outcomes of this study are discussed in the context of spatial and temporal scales.

2. Study area

The research is undertaken on a tributary of Nahal (Wadi) Bikhra, located on the southern edge of the Hebron Mountains and the northern fringe of the Negev desert. The climate is semi-arid with a mean annual precipitation of 230 mm. The landscape is characterized by rounded hills dissected by an intense channel network. Loess covers most of the area. Bedrock is Senonian chalk, limestone and some chert. The vegetation, mainly dwarf scrub and annual herbs is sparse, partly because of the intense grazing. Channel incision in the Bikhra is part of a natural regional process that started at the end of the Pleistocene, although accelerated incision has also been anthropic.

3. Methodology

We have monitored rainfall, runoff and sediment at the outlets of a 4th-order basin (0.6 km^2) termed FOB and four of its 1st-order tributaries (0.007-0.015 km^2). Two of these tributaries are gullied (NG & SG) and one pair is ungullied (NU & SU). The southern paired tributary basins (SG, SU) share a common divide and the northern are separated by one small 1st order basin. The two ungullied sub-basins have a denser vegetation cover (mainly shrubs) within their channels.

Miniature and recording rainfall gauges monitor rainfall in the sub-basins and at the basin outlet. Both hydrological and meteorological rainfall are recorded.

Water stage is monitored by pressure transducers at the basin and sub-basin outlets, placed inside a stilling well at stabilized (cemented) cross sections. Suspended sediment is automatically monitored by (1) an automatic water sampler at the basin outlet and (2) at each sub-basin in two cumulative 1.5 L bottles sampling at two flow depths (2 and 5 cm). Pit bedload samplers are located at the outlet of each of the sub-basins. The pits have a 110-mm slot width. Sediments from the pits were analyzed by wet and dry sieving for grain-size distribution. Bedload in this study is defined as sediment coarser than 0.125 mm.

Source of sediment and extent of erosional activity were determined by spray-painting bed material patches (20x20 cm) and 100*100 cm patches on hillslopes. Erosion pins were deployed into the loess above gully heads to determine gully head advancement.

4. Preliminary results

4.1. Rainfall and Runoff

This study has been conducted for the past two hydrologic years (2005-06 and 2006-07). One so-called Cyprus cyclone rainstorm (20-21 Jan., 2007) has been chosen during which all the monitored basins generated runoff. Average rainfall depth was 25 mm with maximum 1 and 5 min intensities of 33 and 13 mm/h, respectively The variation of rainfall between sub-basins was insignificant (±1.6 mm), but inter-basin variation of runoff was considerable (Fig. 1).

At FOB and SG altogether 5 runoff peaks were recorded while at NG and SU merely 3, whereas only one peak at NU. Runoff duration was largest at the basin outlet (FOB) and SG (nearly four hours). A rainfall intensity of 13 mm/h lasting 5 min was required for runoff response throughout the monitored basins. However, partial basin response was detected during rainfall of lesser intensity.

Maximum discharge in this event was 0.8, 1.3, 1.4 and 7.1 l/sec at the SU, NU, NG and SG, respectively. Runoff peak resulted due to maximum rainfall intensity; lag between maximum rainfall intensity and runoff was 11 min for FOB, 8 min for ungullied sub-basins and only 5-6 min for the gullied sub-basins.

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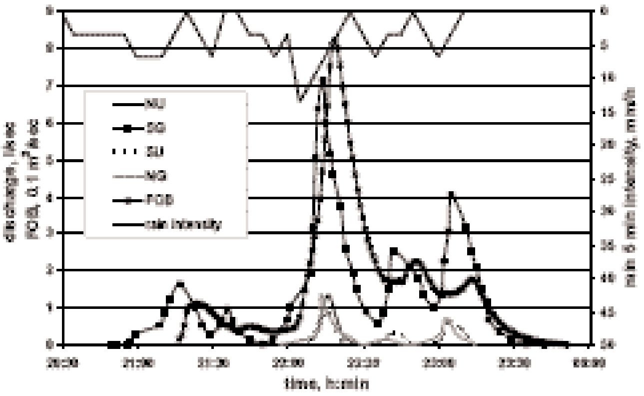

Fig. 1. Rainfall intensity and hydrographs of four 1st-order sub-basins (l/sec) and Fourth-Order Basin - FOB (0.1 m^3/sec) outlets on 20 January 2007.

4.2. Sediments

Suspended sediment concentration (SSC) generally increased with water depth (Table 1). Interestingly, the SSC in the larger FOB was higher than in its tributaries except the sample from NG at a relative high flow depth (5 cm at the sampling point and 2 cm at depth measurement point).

Table 1. Suspended sediment concentration (SSC), mass of bedload in pits, average bedload flux, size and mass of largest grains (average of three largest grains) sampled in pits on 20-21 Jan. 2007. The upper cells in the SSC row are samples from a larger flow depth (5 cm at the sampling point).

	FOB	NG	NU	SG	SU
total bedload, g	n.d.[2]	18,950[1]	276	1,035	52
average bedload flux g/(sec*m)		36.2	0.6	0.4	0.3
max grain size mm		47	34	34	19
max grain mass, g		88	42	36	4
SSC (mg/liter)	16,389	60,236	5,194	865	4,548
		2,182		1,465	1,446

[1]The pit was full.
[2]Bedload is not measured at FOB.

The bedload yield from the gullied basins (NG & SG) is significantly higher than in the ungullied counterparts (Table 1). The bedload in the NG pit was 70 times larger than at NU, while the bedload in the SG pit was 20 times that of SU. More than 50 percent of the sediment (by mass) in the pits is granules and pebbles. Differences in yield are considerably larger than in bedload size. Bedload in the NG pit included painted gravels from as far as the gully head (ca 60 m upstream), thereby demonstrating the high efficiency of the gully system to transport coarse sediment.

5. Discussion

Runoff inhomogeneity in space and in time is ascribed to differences in surface properties (e.g., crusting and vegetation cover). Part of the channel network development of a gullied valley is the decline in vegetal cover. The role of vegetation in our study is to allow high infiltration rates and to lower runoff velocity, including within gullied channel. This study demonstrates that ungullied basins have a higher rainfall threshold for runoff generation in comparison with the ungullied counterparts and, therefore, are more productive in sediment transport and yield.

Gullying process may be an important source for coarse sediment (bedload). In this study, bedload transport rate is lower in ungullied valleys than in gullied valleys. The small difference in bedload rate between the southern pair can be explained by different event duration. Observations at NG and other gullies show that the behavior of bedload movement in gullies is essentially a cut & fill process as in higher order channels. Because flow duration is short, this process occurs in few (1-2) events, during which the gully base may be incised and in the succeeding event it may fill.

The differences in SSC and bedload yield between the 1st order basins may represent their stages of development. The NG gullied basin is far more productive with fine sediment and bedload because the basin is unstable, whereas the SG gully is presently at a repairing condition and therefore is more stable and less sediment-productive. Both ungullied (NU & SU) basins are stabilized by vegetation with almost no remnants of incision.

The SSC in the 4th order channel is one magnitude higher than most of measured SSC in the 1st order channels, likely because at the higher scale the channel flow is characterized by higher shear stresses that erode channel bed and banks and thereby transport larger concentrations of suspended sediments.

Acknowledgements: This study was funded by the International Arid Lands Consortium (IALC), Jewish National Fund and the Israel Ministry of Agriculture.

References

Poesen, J., Vandekerckhove, L., Nachtergaele, J., Oostwoud Wijdenes, D., Verstraeten, G. and Van Wesemal, B. 2002. Gully erosion in dryland environments. In Bull, L.J. and Kirkby M.J. (Ed.), *Dryland rivers: hydrology and geomorphology of semi-arid channels.* By, John Wiley & Sons: 229-262.

Rustomji, P. 2006. Analysis of gully dimensions and sediment texture from southeast Australia for catchment sediment budgeting. *Catena*, 67: 119-127.

Tucker, G.E., Arnold, L., Bras, R.L., Flores, H., Istanbulluoglu, E. and Sólyom, P. 2006. Headwater channel dynamics in semiarid rangelands, Colorado high plains, USA. *Geological Society of America,* 118: 959-974.

SCOURING-SEDIMENTATION BALANCE FOR GULLY REACHES AFFECTED BY CHECK DAMS IN MEDITERRANEAN ENVIRONMENTS

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1. Introduction

Many of the geomorphological impacts caused by check dams are usually fairly common in torrential channels (bed agradation upstream into the sedimentary wedges, deepening and narrowing of the *bankfull* channel downstream, etc). Nevertheless, the extent of these impacts and consequently the degree of effectiveness of the cross-structures is very different depending on the environmental characteristics of the catchments and on the hydrological rectification systems (spatial distribution of check dams, location, number and type of work). A clear indicator of such an influence is the channel response to the deficit and overfeeding of sediments (Brandt, 2000; Lenzi *et al*., 2003; Marion *et al*., 2006; Comiti *et al*., 2005). In such a way, this study has as its objective to show the influence of staggered check dams of gabions on the scouring-sedi-mentation balance in Mediterranean ephemeral gullies submitted to Projects of Hydrological Forest Restoration (PHFR).

For areas of study, two semiarid gullied catchments with a strong tendency to dry up have been chosen: Torrecilla and Cárcavo catchments (South-east Spain). The Torrecilla catchment (15.5 km^2) shows a gullied area develo-ped on metamorphic materials (slates, phyllites, schists and quartzites), while the Cárcavo catchment (34.8 km^2) is drained by ephemeral channels and gullies that dissect deeply the Miocene marls and Quaternary pediments. The hydrological rectification projects undertaken are similar in both catchments: 33 and 40 check dam series were cons-tructed respectively during the 1970s, the majority of them with gabions (Fig. 1).

2. Methodology

The alluvial-fill thickness in each point of the sedimentary wedge, behind the check dam, has been calculated using the values of elevation of a three-dimensional image generated from the surfaces of the original and current beds. The surface area of the wedge was measured with GPS (Geoexplorer3C Trimble©) and the bottom area (bed previous to filling) deduced from trigonometrical calculations and from the topographical plans included in the memory of the PHFR (Ministry of Agriculture, 1972). For the cubing of the erosion wedges, consecutive channel cross-sections have been topographied, with intervals of separation of 10 to 20 m depending on each case. Taken from these have been obtained by interpolation other intervening cros-sections setting intervals of 5 m. As much as the spatial interpolation of the cross-sections as the estimation of their geometrical data, in particular of the area, is carried out via the HEC-RAS software.

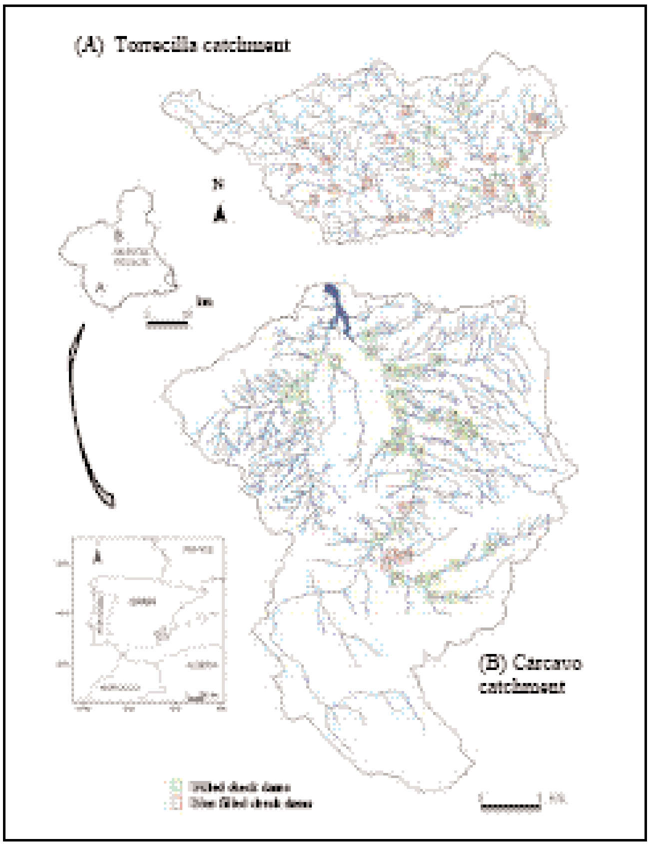

Fig. 1. Location of check dams in the Torrecilla and Cárcavo catchments. Murcia Region, Spain.

The field information has been simplified and the relations between variables explained through factorial analysis of principal components (APC), applying a orthogonal varimax rotation.

3. Results y discussion

The comparison between the sediments retained upstream (Up) of check dams and the eroded downstream (Dw) shows marked differences between the two catchments under study (Fig. 2), associated with its environ-

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mental characteristics, especially lithology and slopes. In the case of the Cárcavo, most retention, scouring, and total removal of sediments is concentrated in the lower reach of the main channel, as it was hoped; but it did not happen in the Torrecilla catchment, distinguished by a drainage network palmated with three main arteries (streams of Navazo, Cocón and Torrecilla s.s.), whose lower and middle reaches hoard the main proportion of sediments at the same time as having recently built check dams which are practically empty.

- In the Cárcavo catchment the average mass of excavated material downstream from check dams (4,794 t/check dam) represents 70.9 % of that stored upstream (6,765.7 t/check dam). On the contrary, in the Torrecilla catchment such a proportion is reduced to 31.2 % of the 3,146 t/check dam which makes up the average mass of the sedimentary wedges.
- The absolute balance of retention versus bed scour deduced from the construction of check dams is considerably greater in the Cárcavo catchment.
- The total valuation of removal caused by check dams in the Cárcavo (6.61 $t \cdot ha^{-1} \cdot year^{-1}$) is more than double that which is reached in the Torrecilla catchment.

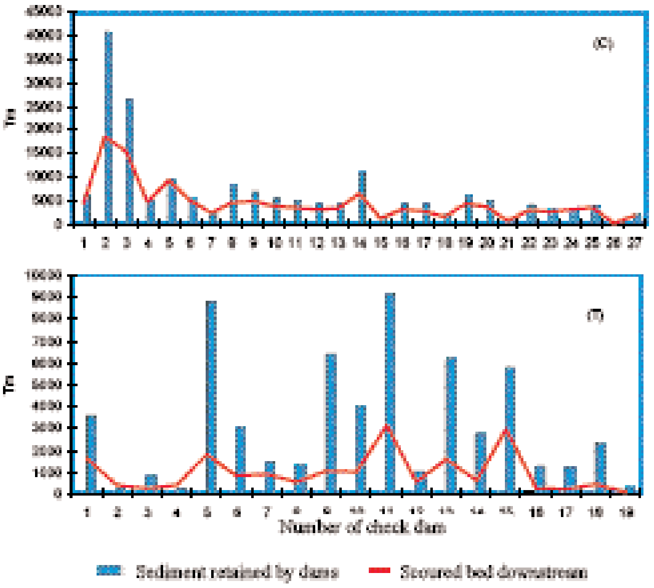

Fig. 2. Comparison of the sediments retained by check dams and the eroded downstream in the Cárcavo (C) and Torrecilla (T) catchments. Period 1970-2005.

- Positions of the variables involved in graphs for CP1 and CP2 dimensions (Fig. 3) can be seen with regard to the factorial rotated axis.
- They are all well represented on the plan, and the majority of the factorial coefficients accumulated in the higher right quadrant.

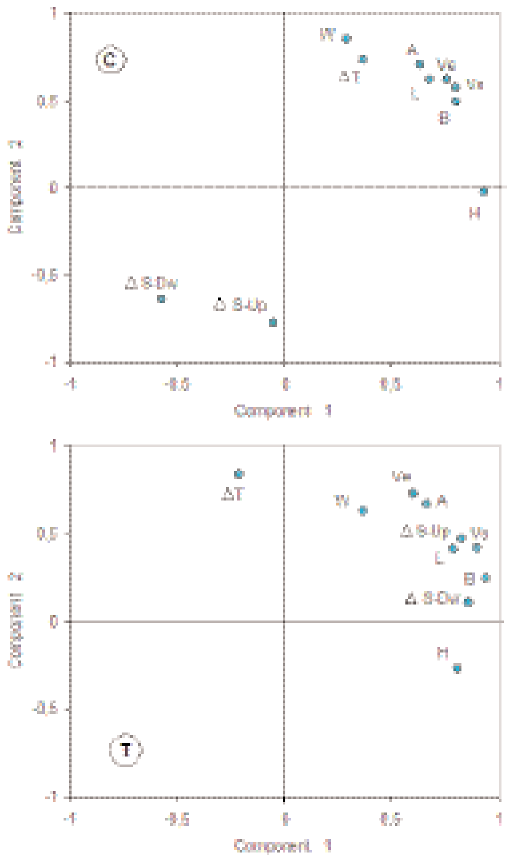

Fig. 3. Graph of components in rotated space. Geometrical variables of the sedimentary wedge: area (A), length (L), average width (W), maximum thickness (H), volume of retained sediments (Vs). Other variables: Ve = volume of the scour wedge; B = scouring-sedimentation balance; ΔS-Up = decrease of slope upstream of check dams; ΔS-Dw = decrease of slope downstream of check dams; ΔT = change in bed texture between upstream and downstream reaches ($D_{84}Dw - D_{84}Up$).

4. Conclusions

Scouring-sedimentation balance caused by check dams is greater in the Cárcavo catchment, where an important volume of bed material is removed. This is due to a high soil erodibility, scanty influence on the hillslope stability, low reduction in bedload transport rate and strong local bed scour. The gravel bed in the Torrecilla rambla is more stable.

References

Brandt, S.A. 2000. Classification of geomorphological effects downstream of dams. *Catena*, 40, pp. 375-401.

Comiti F., Andreoli, A. and Lenzi, M.A. 2005. Morphological effects of local scouring in step-pool streams, *Earth Surf. Process. Landforms,* 30(12), 1567-1581.

Lenzi, M.A.; Marion, A. and Comiti, F. 2003. Local scouring at grade-control structures in alluvial mountain rivers, *Water Resources Research* 39(7), 1176-1188.

Marion, A.; Tregnaghi, M. and Tait, S. 2006. Sediment supply and local scouring at bed sills in high-gradient streams, *Water Resour. Res.*, 42.

Ministerio de Agricultura, 1972. *Proyecto de Corrección Hidrológico-Forestal de la cuenca del Cárcavo*. Dirección General de Montes, Caza y Pesca Fluvial. Memoria técnica.

RELATION BETWEEN THE LOCATION OF CHECK DAMS AND ADJACENT VEGETATION COVER IN EPHEMERAL GULLIES (SOUTHEAST SPAIN)

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1. Introduction

In general, the work carried out on vegetation in the Mediterranean catchments is focused more on the hillside vegetation cover than the riparian. Apart from occasional contributions by Alcaraz *et al*. (1997), Salinas *et al*. (2000), Mant (2002), Corbacho *et al*., (2003), Hooke *et al*. (2005), little more has been published about the vegetation of ephemeral channels in the Southeast of Spain. Specifically, the gullies create a very dynamic fluvial environment of which its connection with the morphological and hydraulic effects of riparian vegetation has been little studied up until now. The channel stability within these torrential streams depends a great deal on how much it is subject to erosion, as well as the production of sediments from the areas directly related to them (upper channel reaches and adjacent hillslopes). This is of unquestionable interest in channels being corrected by check dams, especially to assess the adequacy of their location (Conesa-García *et al*., 2007). The current paper adds a straightforward methodology in such a way, which relates the location of check dams to the level of vegetation cover developing in the plots of land surrounding the thalweg.

For the purpose of study, two semiarid gullied catchments have been chosen, which have a strong tendency to dry up: the Torrecilla and Cárcavo catchments (Southeast Spain). The catchment of Torrecilla (15.5 km^2) shows a “gullied” landscape developed on metamorphic materials (slates, phyllites, schists and quartzites), while the Cárvaco catchment (34.8 km^2) is drained by ephemeral channels and gullies that deeply dissect the Miocene marls and Quaternary pediments. The projects of hydrological rectification undertaken are similar in both catchments: 33 and 40 check dam series were respectively built during the 1970´s, most of them with gabions.

2. Methodology

Firstly, a cartography of vegetation response has been drawn up, using the information of the high resolution sensor of the *Quickbird* satellite (images from 2003). The resulting information is taken from the data obtained by this same sensor that works within the visible range (450-690 Ìm) up to the infrared range (760-900 Ìm). The vegetation response has been assessed by means of the *Transformed Normalised Difference Vegetation Index* (TNDVI), which allows to obtain values of chlorophyllous production from the spectral emission of the different vegetation classes.

$$TNDVI = \left(\frac{IR - R}{IR + R} + 0,5 \right)^2 \qquad (1)$$

where *IR* is the information taken from the close infrared and *R* represents the values of the visible or red spectrum. In turn this information is analyzed statistically by means a not supervised sorter of maximum probability, obtaining four classes of different degrees of vegetation cover: nonexistent, low, average or high cover (Fig. 1).

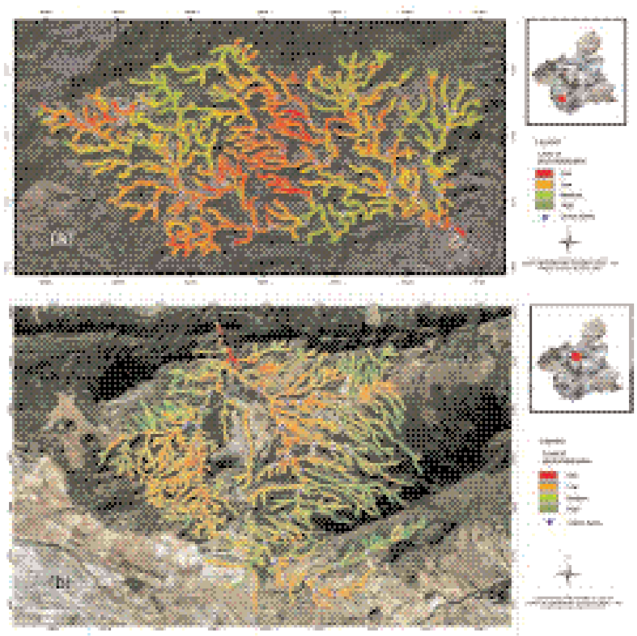

Fig. 1. Degree of vegetation cover and phytostabilization in plots of land adjoining the channel (buffer of 30 m) from TNDVI values using *Quickbird* images (2003). Torrecilla (a) and Cárcavo (b) catchments. Murcia Region, Spain.

To obtain the adjoining areas to the channel in both streams a “*buffer*” has been created, or an adjacent area to the thalweg. This surface of land is generated with a radius of 15 and 30 m from the central channel axis (Fig. 1).

The processing and analysis of the images have been carried out by ERDAS Imagine 8.7, whilst the “buffers” have been taken from ArcGis 9.0. Both GIS are technologies of information, processing and spatial analysis of great capacity. Finally, different effects of check dams in

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their very immediate neighbourhood have been analysed from fieldwork.

3. Results and discussion

The four identified classes show a clearly uneven distribution in the study catchments. In fact, the Torrecilla catchment has a medium area of practically bare soils, with nonexistent or very poor vegetation. This area (34 % of the watershed area) has links with other sectors of less spatial continuity located in the headwaters of *ramblas* and gullies, extending the sparse character of the vegetation to more than 62 % of the total length of channel reaches. The lithological characteristics are an influential factor in such distribution, as the majority of the buffers as those of areas extracted from quartzites, schistes and metaconglomerates show a very limited development of vegetation. The emphasis is on a fairly significant proportion at the base of hillslopes and the remainder of geoforms surrounding such channels, represent a nonexistent phytostabilization in 22 % of the total surface of buffers (Table 1).

Table 1. Superficial distribution of the classes of vegetation cover defined by TNDVI values for a buffer of 30 m around the Torrecilla and Cárcavo drainage networks. Data from Quickbird images (2003). DPH: degree of phytostabilization.

		Torrecilla catchment		Cárcavo catchment	
Clase	DPH	Area (ha)	(%)	Area (ha)	(%)
1	nonexistent	128,37	22,8	60,87	6,9
2	low	223,58	39,7	383,95	43,3
3	medium	146,00	25,9	272,44	30,7
4	high	65,11	11,6	169,50	19,1
Total		563,06	100,0	886.76	100,0

The comparison of the TNDVI values included in the buffer of the Torrecilla drainage network with the slope data and silting level of check dams show that the location of almost 26% of these structures is not suitable enough for the retention of sediments. In the case of the Cárcavo the check dams are located more practically in relation to the source areas of sediments, and to the TNDVI values of the buffer which contains the fluvial stretches. The classes of non existent and low phytostabilization represented in the *buffers* of these streams makes up 29 % of the total surface of *buffers* in the Cárcavo catchment, but in this area there only exists an 8 % of the check dams installed in the whole catchment. Three main situations can be observed:

- Geomorphological uselessness or limited effectiveness of check dams in densely vegetated headwater areas of gullies.
- Lack of check dams in areas of gullies with channel reaches and adjoining talus lacking in vegetation and morphologically active.
- Unequal control of the erosion and the bed slope in middle and low reaches, depending on the degree of dam filling, its geometric characteristics and spacing amongst them.

Check dams have strong local effects on vegetation along the channel. In fact, the initial growth and survival of riperian vegetation are favoured by the presence of silt, waterlogging and temporary water retention, and above all by the greater degree of bed stability arrived at upstream from these grade control structures. The greatest density of undergrowth can be found upstream from the headwater dams (*Nerium oleander, Rhamnus lycioides* y *Pistacia lentiscus*). *Tamarix canariensis* bushes are more frequent in silt beds on the lower reaches. Downstream from the check dams short-term pools are formed where groups of long-stemmed juncus predominate along with cane breaks of *Phragmites australis* in the channel bottom and *Limonium delicatulum* on the banks. At the dam foot a more entrenched and deeper new channel is formed. While the process of morphological readaptation is going on in this new channel, the main bed shows a high roughness, with bedrock outcrops and armoured reaches, and riperian vegetation is displaced onto narrow side sectors subject to periodical flooding. When channel depth downstream from the check dams is considerable, the old bed hangs above the level of ordinary floods, and this is where esparto grass usually takes over.

Together with morphological adjustments produced by the check dams, changes in sediment transport capacity, marked variations in bed texture and roughness, location of sediment supply sources and groundwater influences may also be important.

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References

Alcaraz, F., Ríos, S., Inocencio, C. and Robledo, A. 1997. Variation in the riparian landscape of the Segura River Basin, SE Spain. *J. Veg. Sci.*, 8(4): 597-600.

Conesa García, C., López Bermúdez, F. and García Lorenzo, R. 2007. Bed stability variations after check dam construction in torrential channels (South-East Spain). *Earth Surface Processes and Landforms*, Accepted: Mar 1 2007. 20 p.

Corbacho, C., Sánchez, J.M. and Costillo, E. 2003. Patterns of structural complexity and human disturbance of riparian vegetation in agricultural landscapes of a Mediterranean area. *Agric. Ecosyst. Environ.*, 95(2-3): 495-507.

Mant, J. 2002. *Vegetation in the ephemeral channels of southeast Spain: its impact on and response to morphological change*, University of Portsmouth, 404 p.

Hooke, J., Van Wesemael, B., Torri, D., Castillo, V., Cammeraat, E. and Poesen, J. 2005. *RECONDES, Conditions for Restoration and Mitigation of Desertified Areas Using Vegetation. Specific Targeted Research or Innovation Project Sustainable development, global change and ecosystems.* Report, March 2005. Project coordinator organisation: University of Portsmouth. Coord.: J. Hooke. 92 p.

Salina, M.J., Blanca, G. and Romero, A.T. 2000. Evaluating riparian vegetation in semi-arid Mediterranean watercourses in the south-eastern Iberian Peninsula. *Environ. Conserv.*, 27(1): 24-35.

IMPACT OF ROOT ARCHITECTURE, SOIL AND FLOW CHARACTERISTICS ON THE EROSION-REDUCING POTENTIAL OF ROOTS DURING CONCENTRATED FLOW

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1. Introduction

Many studies focus on the effects of vegetation cover on water erosion rates, whereas little attention has been given to the effects of the below ground biomass. However, few studies (e.g. De Baets et al., 2006, Gyssels et al., 2003, Gyssels et al., 2005, Li et al., 1991, Mamo and Bubenzer, 2001a, 2001b, Zhou and Shangguan, 2005) indicate that roots can reduce concentrated flow erosion rates significantly. Nevertheless, the impact of roots on water erosion rates might become very important when the above ground biomass disappears because of grazing or surface fire and when concentrated flow occurs. Especially in semi-arid environments, where vegetation cover can be restricted and shoots can temporally disappear, roots can play a crucial role. In order to predict this root effect more accurately, this research aims to gain more insight into the influence of root morphology, soil and flow characteristics on the erosion-reducing effect of plant roots during concentrated flow. Although not experimentally investigated, Wischmeier already assumed in 1975 that plant species with contrasting root morphologies have a different reducing effect on soil losses by interrill and rill erosion (Fig. 1).

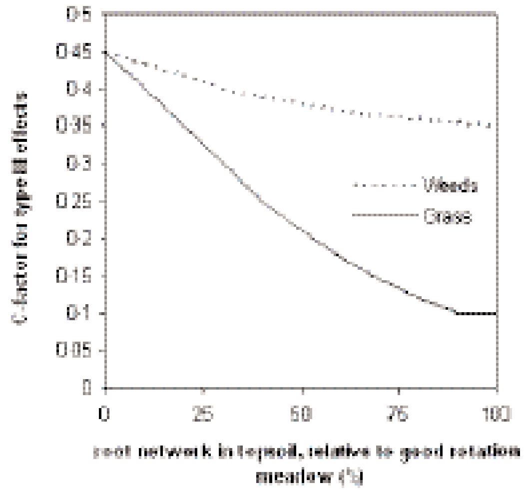

Fig. 1. Type-III effects (i.e. below soil surface effects of vegetation) of undisturbed land on the RUSLE C-factor (i.e. cover and management factor) depending on the development of a root network in the topsoil (after Wisschmeier, 1975).

2. Objectives

In this study, the effects of roots of different root morphologies (tap roots vs. fine-branched roots) on concentrated flow erosion rates are studied experimentally. The impact of soil type, soil moisture conditions (saturated vs. dry topsoil samples) and flow shear stress on the erosion reducing effect of roots is also considered.

3. Materials and methods

Treatments were (1) bare, (2) grass (simulating fine-branched roots) and (3) carrots (simulating taproots). The soils used were a sandy loam and a silt loam, under saturated and dry conditions. Next, laboratory experiments during which concentrated flow was simulated in a flume were conducted (Fig. 2). Slope, flow discharge, mean velocity, water temperature and sediment concentration were measured. Root density (RD) and root length density (RLD) values were assessed. Relative soil detachment rates (SDR) and mean flow shear stresses were calculated.

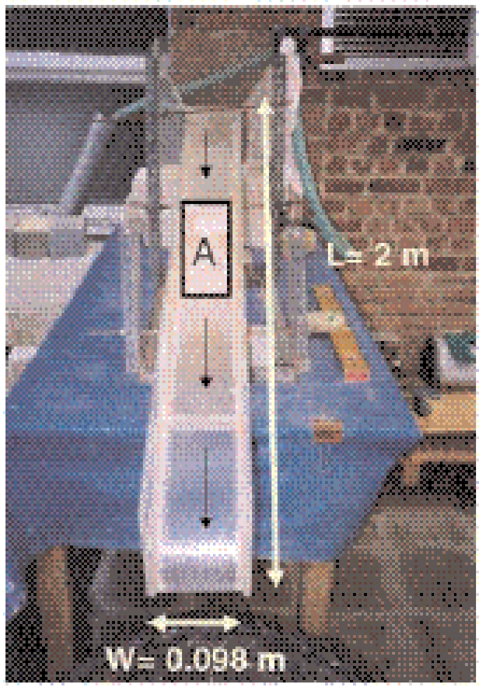

Fig. 2. Hydraulic flume used to measure detachment rated on bare and root permeated topsoil samples. A indicates test section, arrows indicate flow direction.

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4. Results

Roots play an important role in increasing the topsoil resistance against erosion by concentrated flow. Relative soil detachment rate (*SDR*) decreases to very low values (from 1 to 0.001 for grass roots and to 0.03 for carrot roots) for a silt loam topsoil with increasing root density (*RD*) from 0 to 2 kg m^{-3} only. *SDR* for a sandy loam soil decreases from 1 to 0.18 for carrots and to 0.10 for grasses with increasing *RD* from 0 to 2 kg m^{-3}. The results indicate that tap roots reduce the erosion rates to a lesser extent compared to fine-branched roots. Different relationships linking relative soil detachment rate with root density could be established for different root diameter classes (Fig.3). Carrots with very fine roots (D<5 mm) show a similar negative exponential relationship between root density and relative soil detachment rate as grass roots. With increasing root diameter (5<D<15 mm) the erosion-reducing effect of carrot type roots becomes less pronounced. Additionally, an equation estimating the erosion-reducing potential of root systems containing both tap roots and fine-branched roots could be established (1).

$$SDR = e^{-1,45 RD_{1<D<5mm}} \, e^{-0,47 RD_{5<D<15mm}} \qquad (1)$$

Equation 1 can be used to predict the erosion-reducing effect of plant species having roots of different diameters. Moreover, the erosion-reducing potential of grass roots is less pronounced for a sandy loam soil compared to a silt loam soil and a larger erosion-reducing potential for both grass and carrot roots was found for initially wet soils. For carrots grown on a sandy loam soil, the erosion-reducing effect of roots decreases with increasing flow shear stress. This can be explained by the occurrence of local turbulence and vortex erosion scars around individual carrot roots, which form an obstacle to the flow and increase the detachment rate. For grasses, grown on both soil types, no significant differences could be found according to flow shear stress. The erosion-reducing effect of roots during concentrated flow is much more pronounced than suggested in previous studies dealing with interrill and rill erosion. Root density and root diameter explain the observed erosion rates during concentrated flow well for the different soil types tested.

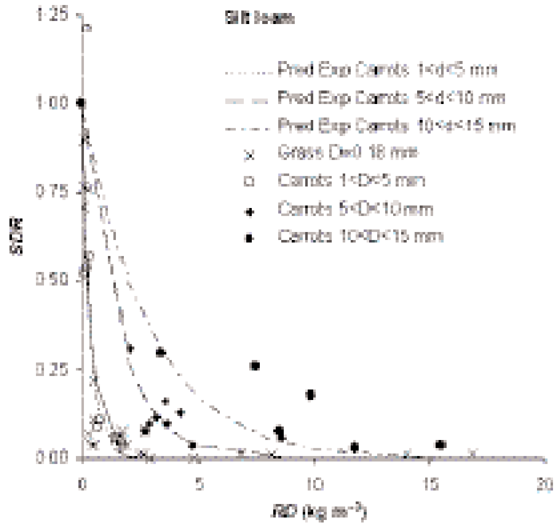

Fig. 3. Relationship between root density (*RD*) and relative soil detachment rate (*SDR*) for topsoils with grass and carrot roots for different root diameter classes. D is mean root diameter. Pred Exp is predicted values obtained with the exponential model (De Baets et al, in press).

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References

De Baets, S., Poesen, J., Gyssels, G., Knapen, A. 2006. Effects of grass roots on the erodibility of topsoils during concentrated flow. *Geomorphology*, 76:54-67.

De Baets, S., Poesen J., Galindo-Morales, P., Knapen, A. 2007. Impact of root architecture on the erosion-reducing potential of roots during concentrated flow. *Earth Surface Processes and Landforms*. In press

Gyssels, G., Poesen, J. 2003. The importance of plant root characteristics in controlling concentrated flow erosion rates. *Earth Surface Processes and Landforms,* 28: 371-384.

Gyssels, G., Poesen, J., Bochet, E., Li, Y. 2005. Impact of plant roots on the resistance of soils to erosion by water: a review. *Progress in Physical Geography,* 29: 189-217.

Li, Y., Zhu, X., Tian, J. 1991. Effectiveness of plant roots to increase the anti-scourability of soil on the Loess Plateau. *Chinese Science Bulletin,* 36: 2077-2082.

Mamo, M., Bubenzer, G.D. 2001a. Detachment rate, soil erodibility and soil strength as influenced by living plant roots, Part II: Field study. *American Society of Agricultural Engineers,* 44: 1175-1181.

Mamo, M., Bubenzer, G.D. 2001b. Detachment rate, soil erodibility and soil strength as influenced by living plant roots, Part I: Laboratory study. *American Society of Agricultural Engineers,* 44: 1167-1174.

Wischmeier, W.H. 1975. Estimating the soil loss equation's cover and management factor for undisturbed areas. In *Proceedings of the sediment-yield workshop*, U.S. Department of Agriculture, Agriculture Research Service, ARS-S-40, Nov. 1972, 118-124: Oxford, Mississippi.

Zhou, Z., Shangguan, Z. 2005. Soil anti-scourability enhanced by plant roots. *Journal of Integrated Plant Biology,* 47: 676-682.

IMPROVING THE STRUCTURAL STABILITY OF CROPPED SOILS IN OLITE (NAVARRE) USING CONSERVATION TILLAGE TO REDUCE WATER EROSION

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1. Introduction

Soils in semi-arid climates are highly susceptible to erosion due to their low organic matter (SOM) contents, and, in some cases, their weakly developed structure. Erosion might affect soil quality through the degradation of the soil physical, chemical and biological properties, leading to reduced agricultural productivity.

Aggregate stability has been shown to be a major indicator of the soil susceptibility to water erosion (Karlen and Stott, 1994). This type of erosion is caused by the impact of raindrops on the bare soil, and by the effect of runoff water on the soil surface. The stability of soil aggregates in face to this process is controlled by two opposing factors: the development of stresses inside the aggregate pore space during wetting due to the compression of the entrapped air and the different water affinity of its components, and the strength of the inter-particle bonds (Concaret, 1967). The importance of such factors in gully erosion modelling has recently been summarized by Sidorchuk (2005). SOM influences aggregate stability by reducing the rate of wetting and increasing the resistance to stresses generated during wetting (Monnier, 1965; Quirk and Murray, 1991; Rasiah and Kay, 1995; Caron et al., 1996).

Erosion reduces soil surface stability and redistributes topsoil. As a result, the soil physical conditions for plant growth deteriorate and nutrient and organic materials are depleted. The interaction between tillage, SOM and aggregation has been long time studied (Six et al., 2004). In general, tillage reduces the SOM content and aggregate stability, accelerating erosion. Conservation Agriculture practices, where tillage is reduced and crop residues are left on the soil surface can decrease soil losses by erosion, by two means. On the one hand, reducing tillage intensity can help to maintain the SOM levels; on the other hand crop residues provide a surface mulch that protects the soil from raindrops and slows down runoff flow velocity (Karlen and Cambardella, 1996).

The objective of this work was to compare the soil wet aggregate stability and its relationship to the soil organic matter stock in an agricultural soil under different types of tillage in a semi-arid area of Northern Spain.

2. Materials and Methods

2.1. General Experiment Setup

The experimental site was established in 1994 in a semi-arid area in Olite (Navarre), Northern Spain. Mean annual rainfall is 525mm, and mean annual potential evapotranspiration (PET) is 740mm. The soil was classified as a clay-loam *Calcic Haploxerept* and the area was described as of moderate water erosion risk by Donézar et al. (1990).

The experimental design was a randomized complete block with four replicates. Plots were 9 x 24 m in size (216 m^2). Treatments were: no-tillage (NT), reduced tillage (RT) and conventional tillage with mouldboard plough (MT). For NT, seeding was done without any previous seedbed preparation. RT consisted of an initial 0.15 m-deep chisel tillage followed by a cultivator pass before seeding. MT consisted of a 0.25 m-deep primary tillage with mouldboard plough, followed by a float. In the RT and MT treatments, crop residues were incorporated into the arable layer during tillage. In NT, crop residues were left on the soil surface after harvest. Barley (*Hordeum vulgare* L. var. Tipper) was planted in all plots at the same seeding rate.

2.2. Soil Sampling and Handling

Soil was sampled for laboratory analyses in March 2003. Samples were collected from the surface layer (0-0.05 m), using a spade. Once in the laboratory, they were air-dried and gently sieved in an 8 mm-openings sieve.

2.3. Measurements

Wet aggregate stability was determined by wet sieving. Air dried soil samples were washed through a column of six sieves of decreasing openings-size (6.3, 4, 2, 1, 0.5 and 0.25mm), using a Restsch VS 1000 sieving apparatus connected to a source of water that simulated rainfall on the top sieve. After one minute of washing and sieving, the fraction remaining on each sieve was collected, oven-dried at 105°C, and weighed. Wet aggregate stability was quantified by the Mean Weight Diameter (MWD) of the recovered fractions after sieving, defined as:

$$MWD = \sum_{i=1}^{n} \frac{r_{i+1} + r_i}{2} . m_i \tag{1}$$

where r_i = aperture of the ith mesh (mm); m_i= proportion of the mass remaining on ith sieve with respect to the total sample; n=number of the sieves.

Total soil organic matter (SOM) of the soil samples was analyzed by wet oxidation (Walkley-Black), and the results were expressed in g C kg soil^{-1}.

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2.4. Statistical Analyses

Statistical analyses were performed using SPSS 10.0 software (SPSS Inc., 1999. Chicago, IL.). Data were analysed as repeated measures over space using ANOVA (univariate linear model). Post-hoc analyses were performed by Duncan test. Correlation among variables was tested, and the significance was declared at $P \leq 0.05$.

3. Results and Discussion

Aggregate size distribution after wet sieving is shown in Figure 1 for the studied treatments. Macroaggregates < 2 mm and 0.25 – 2 mm in size, and microaggregates (< 0.25 mm) were chosen because these fractions represent the different hierarchical stages at which the different binding agents act in soil (Six et al., 2004), according to the hierarchical theory of aggregate formation and stabilization (Tisdall & Oades, 1982; Franzluebbers and Arshad, 1996; Pinheiro et al., 2004; Wright and Hons, 2005; cited by Six et al., 2004). Although microaggregates were the dominant fraction in the soil under all the studied treatments, their mass was significantly bigger under MT. NT resulted in the lowest amount of aggregates of this size. Concurrently, the inverse was shown for the >2 mm aggregate fraction, so that RT displayed an intermediate aggregate size-distribution between NT and MT.

The intermediate macroaggregate fraction (2-0.25 mm) represented the smallest proportion of soil mass under all treatments, and showed no differences in relation to tillage.

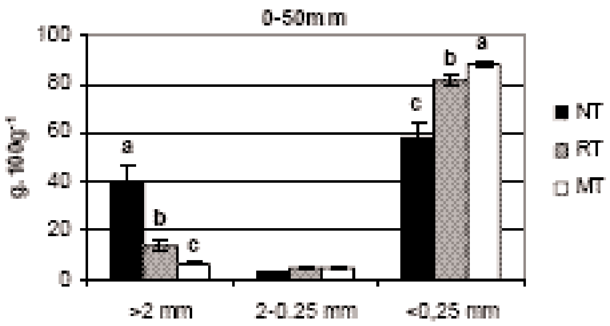

Fig. 1. Aggregate size-distribution after wet sieving.

Table 1 shows data on SOM content and the MWD index corresponding to each of the studied treatments. MWD was significantly higher under NT than under RT and MT, while RT and MT did not show statistical differences between them.

As it is has been widely documented, SOM values were significantly higher under NT than under RT and MT, where no statistical differences were found. Increased SOM mineralization associated to aggregate destruction, oxygenation of the soil profile and enhanced access to SOM for microbial decomposers are the causes generally accepted for SOM loss in tilled soils.

Table 1. Aggregate stability measured by the wet sieving method.

	MWD (mm)	SOM (g/kg)
NT	2,833 a	29,46 a
RT	0,784 b	23,18 b
MT	0,441 b	20,64 b

A positive correlation was thus observed between the soil organic matter content and aggregate stability in this soil (Imaz, 2005). This means that even in this calcareous soil, where organic matter is not likely to be the major factor in control of aggregation, the increment in SOM in the topsoil due to NT contributes to enhancing the aggregate stability to the stresses of drying and wetting processes, improving the soil structure and physical characteristics.

4. Conclusions

The higher stability of soil aggregates to the action of water, along with the existence of an organic layer on the soil surface that decreases runoff velocity and reduces the energy of raindrop impacts in the soil under NT, increased the soil resistance to be swept out by the runoff water in the studied area. Considering that surface aggregate detachment plays a major role in gully erosion (Sidorchuk, 2005), and that NT has been seen to increase water infiltration in the studied soil , we conclude that NT is more effective than RT and MT in reducing water erosion in the croplands of semiarid areas in Navarre.

References

Caron, J., Espindola, C.R., Angers, D.A. 1996. Soil structural stability during rapid wetting: Influence of land use on some aggregate properties. *Soil Science Society of America Journal 60*: 901-908.

Concaret, J. 1967. Etude des mécanismes de la destruction des aggregats de terre au contact de solutions acqueuses. *Annales Agronomiques 18*: 99-144.

Donézar, M., Ilarregui, M., del Valle de Lersundi J. 1990. Erosión Actual en Navarra. *Publicación Gobierno de Navarra e Instituto Tecnológico Geominero de España.*

Imaz, M.J. 2005. Determinación y selección de indicadores de calidad del suelo para la evaluación de sistemas de Agricultura de Conservación en cultivo de cereal de zonas semiáridas en Navarra. *Doctoral Thesis*. *Universidad Pública de Navarra.*

Karlen, D.L., Cambardella, C.A. 1996. Conservation strategies for improving soil quality and organic matter storage. *Structure and organic matter storage in agricultural soils*. *Advances in Soil Sciences Series*: 395-420.

Karlen, D.L., Stott, D.E. 1994. A framework for evaluating physical and Chemical Indicators Of soil Quality. In: Defining Soil Quality for a Sustainable Environment. *SSSA Special Publication N.35; Soil Science Society of America: Madison WI, 1994*:53-72.

Monnier, G. 1965. Action des matières organiques sur l'estabilité structurale des sols. *Annales Agronomiques 16*: 327-400.

Quirck, J.P., Murray, R.S. 1991. Towards a model for soil structural behaviour. *Aust. J. Soil Res 29*: 828-867.

Rasiah, V., Kay, B.D. 1995. Characterizing rate of wetting: Impact on structural destabilization. *Soil Science 160*: 176-182.

Sidorchuk, A. 2005. Stochastic components in the gully erosion modelling. *Catena 63*: 299-317.

Six, J., Bossuyt, H., Degryze, S. and Denef, K. 2004. A history of research on the link between (micro)aggregates, soil biota, and soil organic matter dynamics. *Soil and Tillage Research*, *79*: 7-31.

GULLY EROSION IN CENTRAL ITALY: DENUDATION RATE ESTIMATION AND MORPHOEVOLUTION OF *CALANCHI* AND *BIANCANE* BADLANDS

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1. Introduction

Long lasting geomorphological researches (Ciccacci et al., 1981, 1986, 2003; Del Monte et al., 2002; Del Monte, 2003; Della Seta et al., 2006) allowed the evaluation of denudation rates in some of the major catchments of Central Italy. It was observed a noticeable spatial variability of the *denudation index* (*Tu*) values (Ciccacci et al., 1981, 1986) and field monitoring suggested that gully erosion at badlands is likely to afford the major contribution to overall denudation at catchments scale.

This paper summarizes the original results of the last three years of researches, performed on Tevere, Paglia and Ombrone river basins. By thickening field monitoring, it was evidenced as well a variability of denudation rates among sharp- and rounded-edged badlands (*calanchi* and *biancane*), according to their different morphoevolution.

2. Denudation rate estimation

Denudation rates were indirectly estimated at the catchment scale in terms of suspended sediment yield (*Tu*). *Tu* was calculated using the equations (1) and (2) computed by means of morphometric parameters (Horton, 1945; Strahler, 1952; 1957; Avena et alii, 1967; Lupia Palmieri, 1983):

$$\log Tu = 1.05954 + 2.79687 \log D + 0.13985\Delta a \quad \text{with } D \geq 6 \qquad (1)$$

$$\log Tu = 1.44780 + 0.32619 D + 0.10247\Delta a \quad \text{with } D < 6 \qquad (2)$$

Ciccacci et al. (1981, 1986) experimentally derived these equations: they found that values of measured suspended sediment yield at the outlet of several Italian catchments showed the best simple statistical correlation with *drainage density* (D) and even better multiple correlations with D and *hierarchical anomaly index* (Δa). On the contrary, measured *Tu* values didn't correlate with climatic parameters p^2/P (Fournier, 1960) and $P \times \sigma$ (Ciccacci et al., 1977).

The *denudation index map* of Fig. 1a shows the strong spatial variability of the indirectly estimated *Tu* values, which range between 100 e 6000 t/km?/year. The highest values pertain to small catchments widely affected by *calanchi* and *biancane* badlands. As shown in Fig.1b, field monitoring at the hillslope scale was performed using iron pins (Del Monte, 2003; Della Seta et al., 2006) suitably placed to record sheet, rill and gully erosion on clayey deposits. Earth micro-pyramids (naturally formed or induced by placing coins on the soil surface) provided further data. Uphill and downdale differences in the topographic surface measured at each station provided denudation plots showing a step-like trend (example given in Fig. 1c), with critical denudation periods triggered by rainfall events several days long. We identified a rough minimum rainfall threshold of *70 mm per 6 consecutive days* as possible trigger of critical soil losses (higher than 2 cm). On the contrary, even strong, single-day events were not followed by drops in the denudation graph.

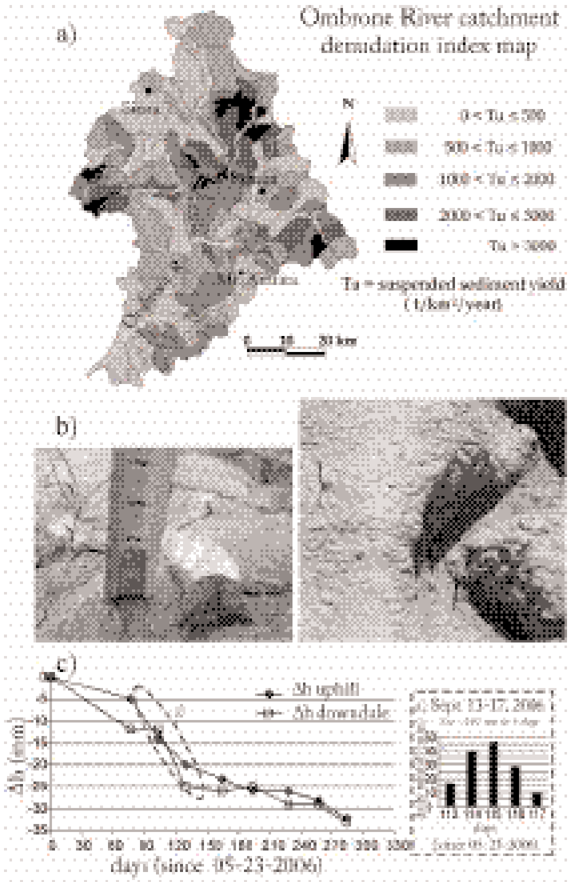

Fig. 1. Denudation rate estimation. Indirectly estimated *denudation index* (*Tu*) (a) and direct field monitoring (b). The sample plot shows the monitored denudation trend within the above gully, compared to a critical rainfall event (c).

Point measures on rapidly evolving slopes provided considerable mean denudation rates ranging from 1-2.5

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cm/year at *calanchi* badlands to 4-5 cm/year at *biancane* badlands.

Differences in the morphoevolution of these two badland types might partly explain this denudation rate variability.

3. Morphoevolution

Data from long lasting slope monitoring suggest that the development of either *calanchi* or *biancane* badlands is strictly connected to slope steepness (S). In particular, sharp-edged *calanchi* badlands develop on scarp slopes (S=30% to 50%) and their growth is supported by caprocks at the summit (Fig. 2a). Rounded-edged *biancane* are small clay domes up to about ten meters high, mostly uncovered on the southern (generally steeper) slope where denudation is particularly strong (Fig. 2b). They are typically located near the hills foot as well as at the summit of steep *calanchi* slopes and their distribution is always associated to gentle gradients (S=15% to 30%). Occurrence of *biancane* at the summit of *calanchi* slopes made us exclude that they could represent residual landforms, as proposed by some Authors (Del Prete et al., 1997).

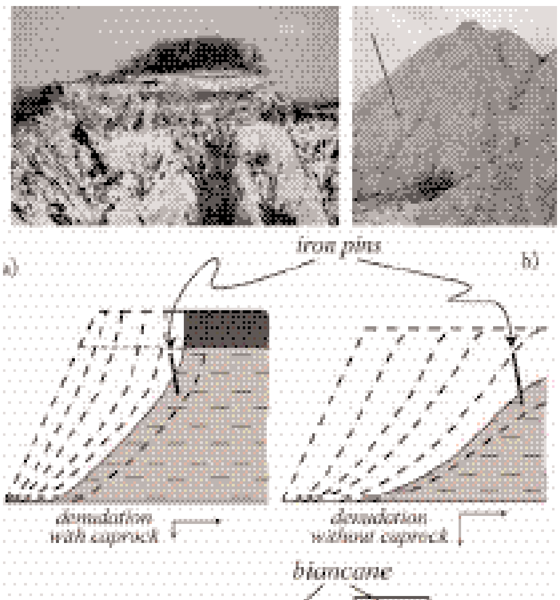

Fig. 2. Distribution of sharp-edged (*calanchi*) and rounded-edged (*biancane*) badlands. Morphoevolutive sketches are shown in (a) and (b) (modified after Scheidegger, 1964).

These two landform types are more probably the results of quite different morphoevolutive trends (Fig. 2a-b): *calanchi* slopes evolve by substantial parallel retreat, helped by caprocks, whereas *biancane* slopes undergo a progressive steepness decrease, according to the Scheidegger's model (Scheidegger, 1961, 1964). The greater vertical component of denudation on *biancane* slopes, with respect to the *calanchi* ones, can partly justify their higher mean denudation rates recorded at pins (up to 5 cm/year; see plot in Fig. 1). Moreover, on steeper *calanchi* slopes, landsliding may contribute to in site effects of denudation (Fig. 2a) by frequent mud flows and earth slides damaging iron pins. On the contrary, on gentler *biancane* slopes sheet, rill and gully erosion processes afford the major input to denudation.

References

Avena, G.C., Giuliano, G., Lupia Palmieri, E. 1967. Sulla valutazione quantitativa della gerarchizzazione ed evoluzione dei reticoli fluviali. *Bollettino della Società Geologica Italiana, 86*: 781–796.

Ciccacci, S., Fredi, P., Lupia Palmieri, E. 1977. Rapporti fra trasporto solido e parametri climatici e geomorfici in alcuni bacini idrografici italiani. *Atti del Convegno "Misura del trasporto solido al fondo nei corsi d'acqua"*, CNR, Firenze: C-4.1 – C-4.16.

Ciccacci, S., Fredi, P., Lupia Palmieri, E., Pugliese, F. 1981. Contributo dell'analisi geomorfica quantitativa alla valutazione dell'entità dell'erosione nei bacini fluviali. *Bollettino della Società Geologica Italiana, 99*: 455–516.

Ciccacci, S., Fredi, P., Lupia Palmieri, E., Pugliese, F. 1986. Indirect evaluation of erosion entity in drainage basins through geomorphic, climatic and hydrological parameters. *International Geomorphology, 2*: 33–48.

Ciccacci, S., Del Monte, M., Marini, R. 2003. Erosion and recent morphological change in a sample area of the Orcia River upper basin (Southern Tuscany). *Geografia Fisica e Dinamica Quaternaria, 26*: 97–109.

Della Seta, M., Del Monte, M., Fredi, P., Lupia Palmieri, E. 2006. Direct and indirect evaluation of denudation rates in Central Italy. *Catena (2006), doi:10.1016/j.catena.2006.06.008*.

Del Monte, M. 2003. Caratteristiche morfometriche e morfodinamiche dell'alto bacino del Fiume Orcia (Toscana meridionale). *Atti del XXVIII Congresso Geografico Italiano*, Roma: 1938–1975.

Del Monte, M., Fredi, P., Lupia Palmieri, E., Marini, R. 2002. Contribution of quantitative geomorphic analysis to the evaluation of geomorphological hazards. In *Applied Geomorphology: Theory and Practice* (Allison R. J. Ed.). J. Wiley & Sons: 335-358.

Del Prete, M., Bentivenga, M., Amato, M., Basso, F., Tacconi, P. 1997. Badland erosion processes and their interactions with vegetation: a case study from Pisticci, Basilicata, Southern Italy. *Geografia Fisica e Dinamica Quaternaria, 20*: 147-155.

Fournier, F. 1960. Climat et erosion: la relation entre l'erosion du sol par l'eau et les précipitations atmosphériques. *Presses Univ. de France, Paris*. 201 pp.

Horton, R.E. 1945. Erosional development of streams and their drainage basins: hydrophysical approach to quantitative morphology. *Geological Society of America Bulletin, 56*: 275–370.

Lupia Palmieri, E. 1983. Il problema della valutazione dell'entità dell'erosione nei bacini fluviali. *Atti del XXIII Congresso Geografico Italiano*, Catania: 143–176.

Scheidegger, A.E. 1961. Mathematical models of slope development. *Geological Society of America Bulletin, 72*: 37–50.

Scheidegger, A.E. 1964. Lithologic variations in slope development theory. *U.S. Geological Survey Circular*: 485.

Strahler, A.N. 1952. Hypsometric (area–altitude) analysis of erosional topography. *Geological Society of America Bulletin, 63*: 1117–1142.

Strahler, A.N. 1957. Quantitative analysis of watershed geomorphology. *American Geophysical Union Transactions, 38*: 913–920.

EFFECTS OF SLOPE PROCESSES AND MANAGEMENT IN GULLYING

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1. Introduction

Most erosion studies have been typically done in rill and interrill areas because the complexity of gullies and their large size have made their study very difficult.

Morgan (1979) and Hudson (1985) define gullies as water courses with very steep walls that are submitted to spasmodic flows during storms. More recently, permanent gullies are defined as channels too deep to be ameliorated with ordinary farming tools (Soil Science Society of America, 2001; Poesen et al., 2003). Gullies range from 0.5 m to up 25-30 m depth.

FAO (1978) indicates that gully evolution takes place by means of several processes, which can act together or separately. Schnabel (1997) points out that the main processes on gully erosion are headcut retreat, channel deepening, undermining and scouring. Bull and Kirkby (2002) and Poesen et al., (2002) show that most gullies expand by headcut retreat and sidewall retreat. In our study area there is piping as another important process on gully erosion (Desir et al., 2005; Desir and Marín, 2006). Piping has been described as one of te most important process acting on dispersive clays (Martínez-Casanovas et al., 2004). In our study 7area where dispersive clays are common gullies reach a great extension. To know and understand the way in which each processes interact can help us to explain the landform and which factors influence on the origin and evolution of gullies. Having two different behaviours related to slope exposure as it is the case, it is possible to highlight the differences in morphology, development and processes involved. To reach this objective piping, slope and thickness have been measured on both slopes between more than 90 gully heads although only the most representative piping areas have been represented.

2. Regional setting

The Bardenas Reales is an erosive depression located in the south-eastern margin of Navarra Province, in the middle-western sector of the Tertiary Ebro Basin. The erosional depression takes up 415 km^2 with steep slopes at the margins and deeply dissected valleys at the centre. The geology is built in Tertiary and Quaternary sediments.

The Tertiary materials, of Miocene age, correspond to different lithologies: Lerín Gypsums, Tudela Formation and Limestones of Sancho Abarca (Castiella et al., 1978; Gracia, 1985).

Quaternary deposits are Holocene clays and silts, originate from erosion of the surrounding clays of the Tudela Formation. Since this material is poorly lithified it can be easily incised. In these sediments deep gullies have developed that mobilize large quantities of material during important rainfall events. Within the Holocene materials, 3 levels can be differentiated: an upper laminated unit, an intermediate massive unit and a lower laminated unit (Marín and Desir, 2004). The upper laminated unit is composed of an alternation of laminar and massive layers of clays, covered by a biocrust and crowning by a charcoal level. The massive intermediate unit is loamy with a high density of pipes and rills. It also shows well-developed popcorn morphologies. The lower laminated unit is made of clays with laminar structure alternating with massive layers.

Climatically, it is a semi arid zone with mean annual precipitation of 350 mm of stormy, the annual distribution showing two maximum. The mean annual temperature is 13°C.

3. Description

The studied site is a tabular relief (Cabecico Losado), 300 m a.s.l. and 6.60 Ha in surface (Fig. 1) that is composed of Holocene materials and crowned by a 30 cm thick soil profile. At present half of the area is managed as a crop field with cereal in fallow and the rest is covered by shrubs. On cropland the soil profile has been nearly removed and the upper Holocene level is exposed. The area is drained by two permanent gullies surrounding the platform. These gullies act as a local base level. The northern gully is placed over the Tertiary formations which control and limit it. On the other hand, the southern one develops over sediments that filled previously existing gullies. This last gully is permanent with steep slopes evolving by topples, undermining and headcut retreat.

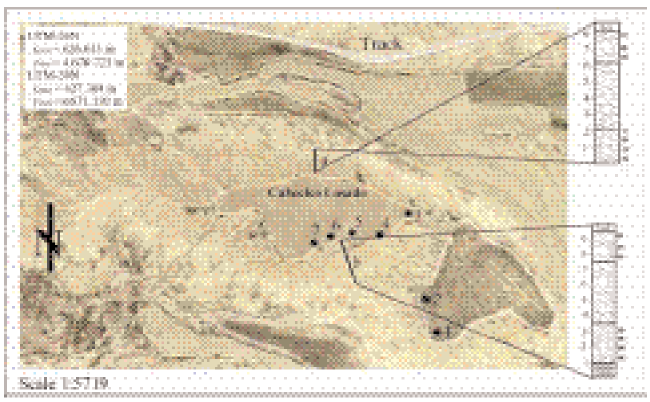

Fig. 1. Sketch of the studied zone included the schematic stratigraphic columns on the northern and southern margin and the points where pipes have been measured.

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The slopes of the tabular relief show two different erosional behaviours related with slope exposure and the vecinity of first order gullies. Because gullies act as drainage collectors of the area, the more or less proximity to those gullies will affect slope processes and form. On both sides, mesa slopes are developed over the three Holocene levels despite the southern one that ends over gully sediments actually incised by a permanent gully (Fig.1). Gentle slopes of the northern face, 10º, show a high sinuosity degree and low hierarchy order (Table 1). Although the south facing slope is steeper, 40º, rills and gullies do not reach a high sinuosity showing straight and deep low order channels.

Table 1. Differences between north (N) and south (S) slopes.

	Thickness	Slope	Rill order
Upper (N)	2.00 m	10-11°	2
Massive (N)	4.10 m	13°	3
Lower (N)	2.00 m	8°	2
Upper (S)	2.00 m	45°	2
Massive (S)	4.00 m	42°	2-3
Lower (S)	2.5 m	35°	2
Filling Sed	1 m	0°	1-0

In both cases piping processes are restricted to the gully headwall where it takes place in the upper laminated unit. Physico-chemical properties show high SAR and ESP values across the slope profile (Desir et al. 2005). In this location piping is reported on the upper laminated unit and on the intermediate one. Piping related to gully heads is found on the upper laminated level whereas piping on the intermediate one are not. Although piping is present on both sides the highest degree is reached on the southern part.

4. Discussion

Rills and gullies show a different trend and evolution in relation to slope exposure, gully vicinity and land management. Gully evolution can be separated in two parts; headcut retreat due to piping and fast channel deepening in the first slope segment and channel widening and slope processes in the middle lower segment.

It is significant that piping only develops over the south facing slopes of both parts of the mesa, on both cropland and scrubland. The highest piping density is located on the platform surface close to the scarp where the hydraulic gradient is higher. Minor pipes are also present in the middle slope segment where the intermediate massive unit crops out. These minor pipes play an important rule on rilling processes and may control the higher stream order and slope retreat of this unit.

One significant factor is the role played by the first order gullies acting as a local base level. The gully on the south-facing slope from the southern part is much deeper and has a greater drainage basin area than the northern one. The gully depth controls slope steepness and therefore final runoff velocity. In the northern one, slopes are smoother and rills show a high sinuosity. On the contrary, on south slopes rills draw straight and steep profiles that greatly increase channel incision and runoff velocity in a short space lapse. An inverse relationship between sinuosity and piping density exists. With increasing sinuosity slope gradient and runoff velocity decrease and therefore piping may be neglected.

Pipes are located along the southern rim. The biggest ones are situated on points 1, 2, 3 that correspond to shrub areas. Nevertheless, it would be better developed on the crop field because the soil profile, acting as surface protection, has been erased by farming. During farming activities, pipes could be periodically filled so they aren't as well developed as those on the natural shrub area. This could be the reason for not developing on the crop field.

References

Bull, L.J. and Kirkby, M.J. 2002. Channel heads and channel extension. In: Bull, L.J. and Kirkby, M.J. (eds.), *Dryland Rivers: Hydrology and Geomorphology of Semi-Arid Channels*. Wiley. Chichester.

Castiella, J., Solé, J. and del Valle, J. 1978. *Mapa Geológico de Navarra E. 1:200.000. Cartografía Geológica a partir de la investigación geológica de Navarra a escala 1:25.000.* Diputación Foral de Navarra. Ser. Geol. Dir. O.P. Pamplona.

Desir, G. and Marín, C. 2006. Evolución y procesos de erosion en gullies. Bardenas Reales (Navarra). España. In: Pérez-Alberti, A. and López-Bedoya, J. (eds.), *Geomorfología y Territorio*. Sociedad Española de Geomorfología. Universidad de Santiago de Compostela.

Desir, G., Marín, C. and Guerrero, J. 2005. Badlands and Talus Flatirons in the Bardenas Reales Region. *Field Trip Guide B3. VI International Conference on Geomorphology*. Zaragoza.

FAO. 1978. *Soil Erosion by water: some measures for its control on cultivated land*. FAO Land and Water Development Series, 7, 284 p.

Gracia, F.J. 1985. *Geomorfología de las Bardenas Orientales*. Tesis de Licenciatura. Universidad de Zaragoza.

Hudson, N.W. 1985. *Soil Conservation*. Brastford. London, 324 p.

Marín, C. and Desir, G. 2004. Influencia de las propiedades físico-químicas del regolito en los procesos de erosión. Bardenas Reales (Navarra). In: Benito, G. and Díez Herrero, A. (eds.), *Riesgos Naturales y Antrópicos en Geomorfología*. Sociedad Española de Geomorfología. Madrid.

Martínez-Casasnovas, J.A., Ramos, M.C. and Poesen, J. 2004. Assessement of sidewall erosion in large gullies using multi-temporal DEMs and logistic regression analysisl. *Geomorphology*, 58, 305-321.

Morgan, R.P.C. 1979. *Soil Erosion*. Longman, New York, 312 p.

Poesen, J., Vandekerckhove, L., Nachtergaele, J., Oostwoud Wijdenes, D., Verstraeten, G. and Van Wesemael, B. 2002. Gully erosion in dryland environment. In: Bull, L.J. and Kirkby, M.J. (eds.), *Dryland Rivers: Hydrology and Geomorphology of Semi-Arid Channels*. Wiley. Chichester.

Poesen, J., Nachtergaele, J., Verstraeten, G. and Valentin, C. 2003. Gully erosion and environmental change: importante and research needs. *Catena*, 50, 91-133.

Schnabel, S. 1997. S*oil erosion and runoff production in a small watershed under silvo-pastoral landuse (Dehesas) in Extremadura, Spain*. Serie Monografías Científicas. Geoforma. Logroño, 167 p.

Soil Science Society of America. 2001. Glossary of Soil Science Terms. Soil Science Society of America, Madison, W1, http://www.soils.org/sssagloss

GULLY EROSION ON CINDER CONES OF TENERIFE (CANARY ISLANDS, SPAIN)

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1. Introduction

Scoria cones are created by rapid construction stages ranging from days to years and erosion stages that progress at different rates over long temporal intervals. The erosion of cinder cones is a natural process that begins once the eruptive activity ends.

The factors that regulate the erosion of monogenetic volcanoes are: the morphology of the cinder cones, the type and distribution of the material, its age, the topography and the characteristics of the emplacement, the morphoclimatic environment, local runoff depth, etc. The authors recognize two stages, regardless of the factors that intervene in the erosion of the scoria cones (Romero, 1991; Inbar et al., 1994). The first stage occurs once the eruption ends and is associated with the cooling and settling of the different material. In the second stage the erosion of the cinder cones is related to the morphoclimatic environment where the volcanoes are emplaced.

Although there are various processes that erode the volcanoes, creating many different landforms, Hopper and Sheridan (1998) identified gully erosion and alluvial and colluvial processes as the most significant.

The aim of this study is to observe the evolution of gully erosion on cinder cones over time and verify whether or not age is a critical factor in the level of degradation of scoria cones, independent of other factors.

2. Study area

Tenerife, the largest island of the Canarian Archipelago, is characterized by its volcanic complexity. It is formed by the accumulation of different volcanic materials over several million years (Fig. 1). Different types of volcanic edifices can be recognized, among which stand out 297 monogenetic volcanoes. Most of them correspond to cinder cones that have been grouped in five volcanic fields characterized by similar volcanological features (Dóniz, 2004). The basaltic monogenetic volcanoes, characterized by effusive and explosive strombolian activity.

Currently Tenerife has no permanent waterways. Drainage on the island takes place via gullies with broad heads and deep, narrow drainage channels that are only active intermittently. This situation is caused by atmospheric instability in the form of storms from the NW and the SW. Tenerife receives around 300 mm of precipitation per year (Marzol, 1988), distributed throughout the fall and spring months. Torrential erosion is caused by violent downpours that are highly concentrated in time and extremely intense. This kind of precipitation can produce more than 100 mm of water in 24 hours; 50 mm/day or more can lead to geomorphological consequences (Marzol, 1988).

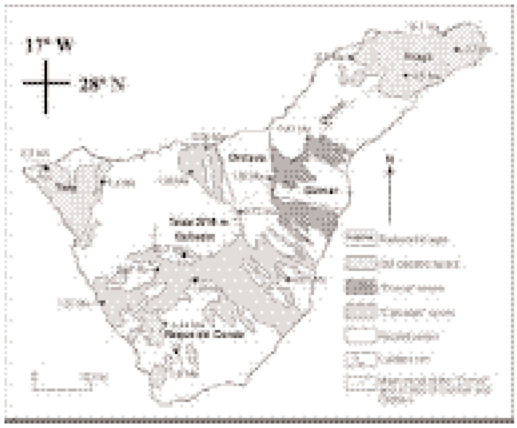

Fig. 1. Geological map of Tenerife (Ancochea et al., 1990).

3. Methodology

The methodology employed is based on a geomorphological study of monogenetic volcanoes (1:10,000 topographic and 1:25,000 geological cartography, 1:18,000 aerial photography and field work), as well as the morphometric analysis of hydrographic networks developed by Strahler (1988) and the morphometric relationships of cinder cones proposed by Wood (1980) and Dohrenwend et al., (1986). Only volcanoes with absolute dates (Fig. 2) and gullies originating within the craters and on the flanks of the volcanoes that are not associated with run-off produced upstream from the emplacement of the volcanic edifice were studied.

4. Results

The 43 cinder or scoria cones dated in Tenerife correspond to 14.48% of the whole island (Fig. 2). Thirty cinder cones (69.77%) were created in the last 10Ka (Holocene) and the other 13 (30.23%) are Pleistocene.

Because the processes leading to morphological transformation that have had the greatest impact on the volcanoes are associated with torrential rains (Dóniz, 2001 and 2004) the relationships between the 43 dated volcanoes and their gullies.

Only 39.54% of these volcanoes have gullies. More than 84.6% of the Pleistocene cones have gullies, compared to only 20% of the Holocene cones. This means that Holocene cones without gullies constitute 80%, while the Pleistocene

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cones barely reach 15.38%. Therefore, it appears that the older a volcano is the more it will have been incised by torrential rain.

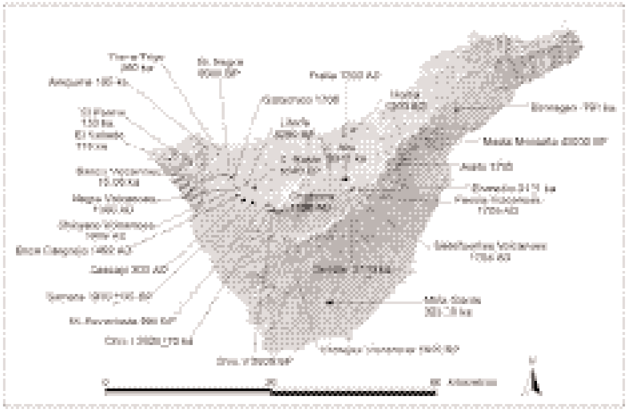

Fig. 2. Ages of the cinder cones of Tenerife (based in Carracedo - coord.- 2006).

The drainage network of these 17 volcanoes is made up of 70 channels with an average of 4.1 gullies per cone. There is no difference between the total number of thalwegs carved on the flanks and craters of the cones. The hydromorphological importance of both groups of gullies is not equal since 94.1% of the erosion volcanoes have channels in their craters forming centripetal catchment basins that are at the most 2nd order. The dorsal channels are not always distributed radially and they never form a hierarchical network since they never surpass 1st order. The majority of the gullies on the flanks are located on the most pronounced gradients, producing parallel asymmetric networks. The asymmetry of the morphology of the cones caused by the gullies is accentuated in steep areas and water divides and attenuated in areas with little or no gradient, or in areas characterized by a lack of running water due to recent volcanic activity (Romero et al., 2006).

5. Discussion and conclusions

Some authors (Wood, 1980; Dohrenwend et al., 1986) claim that as the age of the volcano increases so to does its dismantling and therefore it tends to diminish in height (H_{co}), volume, slope and crater depth (D_{cr}), while the diameter of the crater (W_{cr}) and cone (W_{co}) increase. The H_{co}/W_{co} and D_{cr}/W_{cr} indexes are greater when the cinder cones are more recent; The W_{cr}/W_{co} index evolves inversely (Wood, 1980).

The morphometric study of these volcanoes by age intervals reveals that in Tenerife the H_{co}/W_{co} and D_{cr}/W_{cr} correlations do not evolve according to Wood's postulates, but instead they evolve inversely (Table 1).

Table 1. Indexes for morphometric parameters.

Group Age	Cinder cones	%	H_{co}/W_{co}	W_{cr}/W_{co}	D_{cr}/W_{cr}
Holocene	30	69.78	0.18	0.62	0.24
Pleistocene	13	30.22	0.20	0.51	0.31
Total	43	100	0.19	0.57	0.27

Although the Pleistocene volcanoes have been most incised (between 5 and 12 channels) the degradation of the cinder cones analyzed in Tenerife does not appear to depend on the amount of time that has passed since their creation. In this sense, all of the Pleistocene volcanoes that have a large number of gullies (Tierra Trigo, Birmagen. M. Gorda, Alto, Enmedio and Media Montaña volcanoes) are always emplaced on water divides between large cathment basins, ranging from 4th and 5th orders. However, it must be kept in mind that there are Pleistocene volcanoes that are older and that have been incised less by erosional gullies (between 1 and 4 gullies) emplaced within lower-hierarchy basins (Vallado, Aregume and Palmar cinder cones). In addition, there are Holocene scoria cones (Chío, Horca, Cascajo) that have the same number of gullies as Pleistocene volcanoes (Liferfe, Banco or Cueva Ratón). All of this illustrates the fundamental role that the emplacement of a volcano plays in its torrential remodelling.

Therefore, although the age of a volcano is an essential factor in the degree of torrential erosion it has gone through, there are other types of factors that intervene as well. The rate and evolution of these volcanoes depends on a combination of these factors.

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References

Ancochea, E., Fúster, J., Ibarrola, E., Cendreros, A., Coello, J., Hernan, F., Cantagrel, M., Jamond, C. 1990. Volcanic evolution of the island of Tenerife (Canary Islands) in the light of new K-Ar data. *J. Volcanol. Geother. Res*., 44: 231-249.

Carracedo, J. (2006). *Los volcanes del Parque Nacional del Teide.* Organismo Parques Nacionales. Madrid. 69-97.

Dohrenwed, J., Wells, S., Turrin, B. (1986). Degradation of Quaternary cinder cones in the Cima volcanic field, Mojave Desert, California. *Geol. Soc. Am. Bull*., 97:421-427.

Dóniz, J. (2001). La remodelación torrencial de los edificios volcánicos simples de la isla de Tenerife. *Actas del XVII Congreso Nacional de Geografía*. Oviedo. 154-158.

Dóniz, J. (2004). *Caracterización geomorfológica del volcanismo basáltico monogénico de la isla de Tenerife*. Unpublished D.Ph Thesis, Department of Geography, U. of La Laguna, Spain.

Hooper, D., Sheridan, M. (1998). Computer-simulation models of scoria cone degradation. *J. Volcanol. Geother. Res*., 83:241-267.

Inbar, M., Lugo-Hubt, J., Villers, L. (1994). The geomorphological evolution of the Paricutin cone and lava flows, México, 1943-1990. *Geomorphology*, 9:57-76.

Kear, D. (1957). Erosional stages of volcanic cones as indicators of age. *J. Science, Technol*., 38:671-682.

Marzol, V. (1988). *La lluvia: un recurso natural para Canarias*. Caja General de Ahorros de Canarias. Santa Cruz de Tenerife.

Romero, C. (1991). *Las Manifestaciones volcánicas históricas de Canarias*. Gobierno de Canarias. S/C Tenerife.

Romero, C., Yanes, A., Marzol, V. (2006). Las áreas arreicas en la organización hídrica de las islas volcánicas atlánticas (Azores, Madeira, Canarias y Cabo Verde). In: Pérez Alberti, A., López Bedoya, J. (eds): *Geomorfología y territorio*. Universidad de Santiago de Compostela. 697-709.

Strahler, A. (1988). *Geografía Física*. Ediciones Omega. Barcelona.

Wood, C. (1980). *Morphometric analysis of cinder cone degradation*. *J. Volcanol. Geother. Res*., 8:137-160.

PREHISTORIC AND MODERN IMPACTS ON GULLY FORMATION ON THE LOESS HILLS OF NORTHERN MISSISSIPPI, USA

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1. Introduction

The Loess Hills of Northern Mississippi are underlain by Marine and Fluvial sediments deposited during the upper Cretaceous through the Paleocene. These deposits were subsequently covered by Loess or by Forest and Grassland Soils throughout the Pleistocene and consist largely of materials with a particle size of fine-sand or smaller, and are above all, highly erodible. During the Holocene, these soils and sediments were repeatedly exposed, eroded, and trans-located by fluvial systems.
Approximately 7,000 years ago, during the *Middle Archaic* period, Native Americans began to modify the land through Agriculture and the building of Earthen Works, the most remarkable of which are their ceremonial or burial Mounds. Archeologists are now trying to rebuild the rise and collapse of their societies as settlements expanded, only to later abandon the site when resources became limiting. Europeans, beginning in the 1530's, brought with them new ideas, technologies, and landuse practices. Many of these landuse practices where ill-adapted to the geomorphic reality of the 'Loess-Plains Upland Forest & Grassland Complex'.
The widespread implementation of mechanized Forestry and Agriculture during the early 1900's resulted in the reduction of up to 80% of the *Uplands*. Vast *Badland* area development provided us with the best documented (photographs and written accounts, though not scientific in origin) example of anthropomorphically induced erosion in the region (Fig. 1-3). More in depth records are preserved within the sediments, and are recorded as *catastrophic erosion events*, which often forced the abandonment of the land. In order to reconstruct the *Holocene landscape evolution*, we are utilizing a interdisciplinary approach combining the fields of *pedology*, *environmental geography*, *geoarchaeology*, and *archaeology*.

Here we will present 2 sites that will help us to understand the *processes that drive gully formation* in the uplands of northern Mississippi and how these processes are affected by *anthropomorphic influences*. Briefly, the sites are:

Owl Creek Indian Mound Site, occupied by humans at least 3,000 years B.P. with the extant remains of *Indian Mounds*, *Wagon Road*, *Homesteads*, *and Landuse Management*.
Charley Cooper Site, exhibiting a European settlement *Wagon Road* from the early 1830's (perhaps from the 1700's) which was quickly abandoned due to erosion.

Fig. 1. Logging of the trees in the 19th century. In a few decades nearly the whole state was deforested. Intensive agriculture enabled soil erosion leading to extensive badlands (Picture: USDA Forest Service)

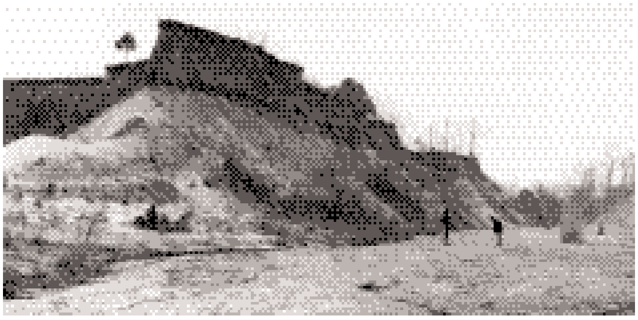

Fig. 2. In 1929 during a heavy rainstorm a huge gully was cut. Barns and houses were destroyed. In a few decades 80 % of the loess hills of North Mississippi were transformed into badlands (Picture: USDA Soil Conservation Service).

Fig. 3. To avoid further soil erosion in 1948 a reforestation program was started. During the first 15 years, up to 50 million trees/year were planted over an entire area of 1.8 million ha (Picture: USDA Soil Conservation Service).

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2. Results and Discussion

2.1. Owl Creek Indian Mound Site

During the early Holocene sandy sediments where deposited on top of a Cretaceous Mudstone, resulting in forested swamp as indicated by pollen analysis and dated wood remains. A series of truncated alluvial floodplains developed upon sand which where then covered by a silty deposit in which a Mollic horizon developed until the end of the agricultural period of the Mississippian Mound building Indian (~1000 to ~1200 AD). Subsequent catastrophic deposition of sands transformed these fields into a broad braided river fluvial system as revealed by a survey conducted before European settlement in the 1830's. The new surface was not reclaimed for agriculture until the advent of mechanised farm equipment. In the first half of the 20th Century a drainage ditch across the floodplain was built. Intensive run-off led to gullying cutting of the sediments of the floodplain (Fig. 4).

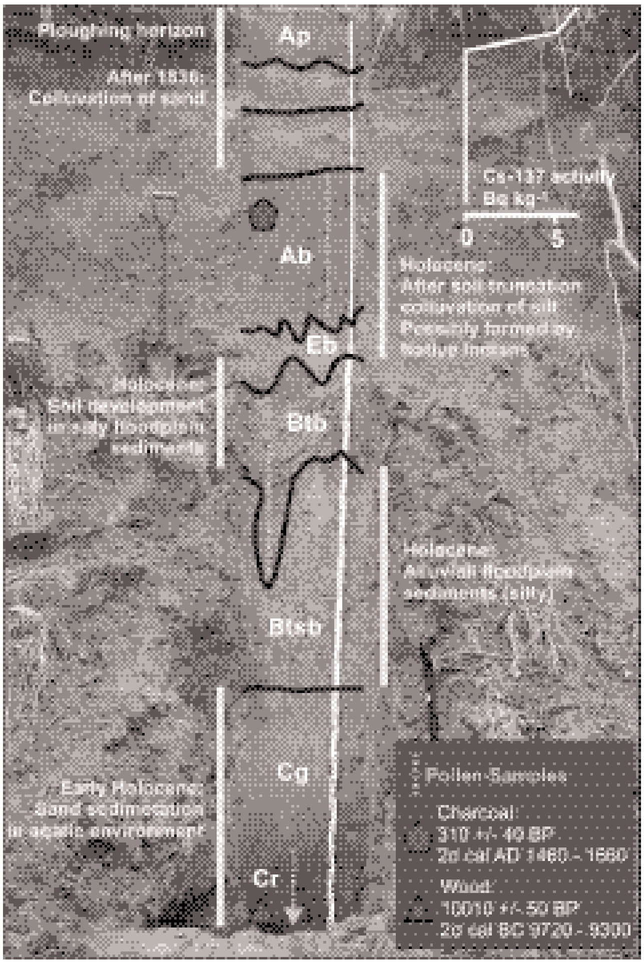

Fig. 4. Sediment and soil sequence truncated by a gully near an Indian Mound site at Owl Creek.

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2.2. Charley Cooper Site

At the end of the Pleistocene a thin Loess cover laid over the marine sand forming an undulating surface (Fig. 5, Phase 1). During the Holocene period until 1835 soil formation was the dominant process. But natural and / or anthropogenic caused woodland fires combined with Indian agriculture enabled intensive sheet erosion of the highly erodible loess material up to 2 m (Phase 2). In the 19th a wagon road and intensive agriculture caused gullying along the thalweg (Phase 3). In the early 20th century land use switched into forest. Only along forest roads and along the gully soil erosion is active (Phase 4).

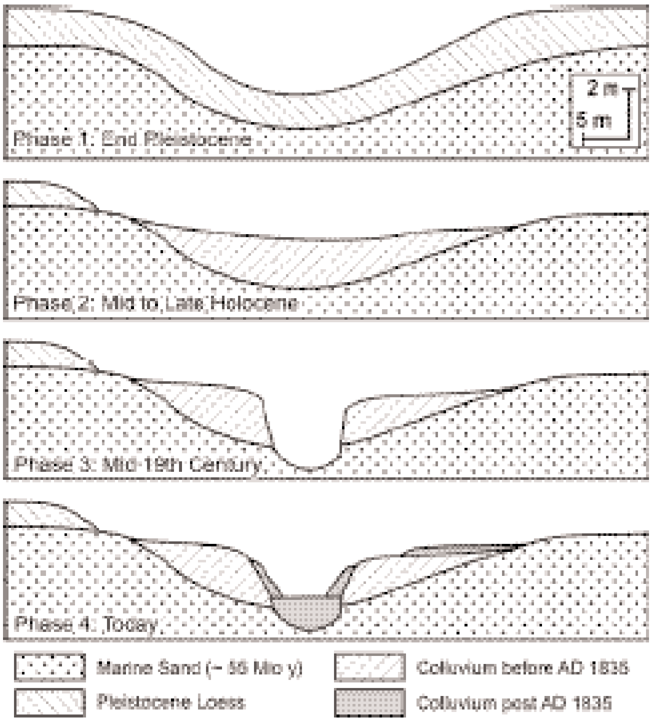

Fig. 5. Cross section through a sediment sequence at Charley Cooper Site

3. Conclusion

Intensive rainstorms and highly erodible material make the landscape in the uplands of North Mississippi extremely vulnerable to soil erosion. It might be possible that extensive land use by the Native Indians or / and natural wood fires cleared the vegetation so that soil erosion occurred. But for this period we haven't found any traces of gullying yet. The results give us a first idea that Native Indians triggered soil erosion. But their impact to the landscape and soil development is still unclear and much more research is needed to determine these interactions.

As White men came into this region in the early 19th century they found still highly fertile soils. Deforestation and farming caused intensive erosion and in a very short time nearly all the soil was eroded and the landscape was gullied into badlands.

AGRICULTURAL LAND USE, PIPING AND GULLIES ACTIVITY IN THE HUERVA LOWER VALLEY (SARAGOSSA, SPAIN)

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1. Introduction

The variations in the total amount of surface used for arable crops both for dry farming and fallow land, with regard to the different "agricultural policies", have modified the natural dynamics of some processes such as piping and gullies activity in the Huerva lower valley (Saragossa) over the last 50 years.

2. Study Area and Gully erosion

The area of study focuses in the lower stretch of the Huerva Valley, tributary of the Ebro River at its right bank, opened in the Neogene gypsum facies of the Saragossa Formation. The climatic conditions in this sector are clearly semiarid, with precipitations around 320 mm per year, which are significantly irregular (Fig. 1), potential evapo-transpiration values of 1,200 mm -200 mm during the summer-, and a contrasted thermal regime -maximum absolute temperatures reaching 45ºC and minimum temperatures of under -10ºC-. Vegetation consists of steppe plants: on the gypsum silt accumulations settle more or less dense herbaceous formations (*Lygeum spartum* and *Stipa lascae*) due to progressive dynamics from derelict land. The soil on these gypsum-silt materials is weakly developed, *Entisol* type, with a certain depth, a poorly differentiated profile and, in most farmed land cases, it is quite pervious, with a weak structure, abundance of nitrogenous matter and a high biological activity. Cereal is this soil's agricultural use and its prevailing crop is wheat.

The Huerva's tributaries along this stretch are *vales*, flat-bottom valleys, filled basically with Holocene gypsum silts, with some rows of gypsum and limestone boulders and crossed by gullies with vertical incisions (1500 BP, Peña et al., 2000). Gully development over the last 1500 years triggered by a combination of human-induced land cover changes and extreme rainfalls have been documented (Faulkner, 1995, in southern Spain; Peña et al. (2000) in the Ebro Basin; Poesen et al. (2000), in Belgium). In Northeast Spain, particularly in the almost completely cleared out cultivated steppe land of the Inner Ebro Basin, gullying is a characteristic and widespread phenomenon, incising and dissecting the flat valley bottoms built up by Quaternary sediments (Ries and Marzolff, 2003).

The Vales Gully presents a high erosive activity both in the headwaters of the main incision and in the secondary ones, which can be related to piping phenomena. In some cases the piping activity has been recognised as a importan process in the development of bandlands and gully systems in other semiarid areas -in Etiopía (Bull, 1977), in Southeast Spain in dispersive marls (Harvey, 1982; López Bermúdez and Romero, 1989; Faulkner et al., 2003) and in some flat bottom valleys (Ries and Marzolff, 2003) or in Bardenas (Desir y Marín, 2006) in the Ebro Basin-.

The presence of easily dispersible silty soil, of scarce plant cover, of flat topography accelerating water infiltration -favoured by surface cracks-, of a water gradient facilitating the mechanical erosion of water… are some of the factors that help understand the piping dynamics (Gutiérrez et al., 1988).

3. Results and conclusions

Aerial photographs have been analysed to measure temporal changel in length, area or volume of gullies (Burkard and Kostaschuck, 1995; Nachtergaele and Poesen, 1999; Gabris et al, 2003; Martínez Casasnovas, 2003; Vandekerckhove et al, 2003). Another solution consists of combining high altitude aerial photo data with field data (Vandaele et al, 2003). In the study area have been anlaysed aerial photos of three distinct dates, 1956, 1984 and 1991.

The evolution observed over the last 50 years in the total hectares intended for dry farming and fallow land in the municipality of Botorrita (Fig. 3) does not differ from the patterns followed by the Spanish dry farming cereal; the few changes that have been introduced are always due to incentives relating to the present moment that have been supported by the Public Administrations. Thus, the increase of the surface used for growing wheat during the 50's, for instance, was backed by this cereal's preferential price policy. Nevertheless, in the 50's, the pipes'activity is absolutely evident under natural conditions and in the Vales Gully a functional piping can be seen, which is responsible for the growth of the largest gullies of the studied period (Fig. 2, 1956). At the end of the sixties, the wheat production had largely exceeded the needs of the inner market, which oriented the agricultural policy towards other cereals. In 1967, a series of measures were implemented in order to subsidize the wheat replacement for forage and fodder grains, especially maize and barley. High prices were fixed to these, which every time became nearer to those of wheat. On the one hand, old wheat fields were being replaced for barley and, on the other hand, new lands were being ploughed and gullies and pipes were anthropically refilled. This situation lasts as far as the eighties (Fig. 2, 1984). The solid boost experienced by the cultivated surface from the decade of the seventies leads to thinking that the sealing was a standard practice.

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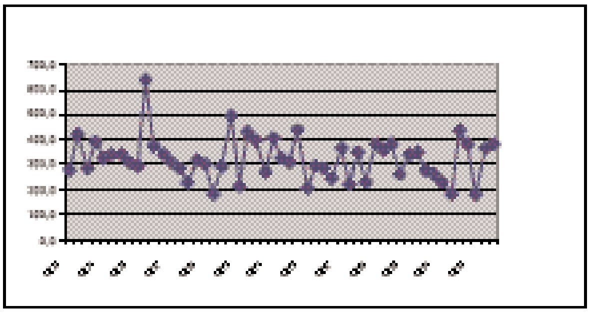

Fig. 1. Annual precipitation in mm (1950-2000)

The last stage starts with Spain's integration in the EEC, in which the markets'common organization is accompanied by a subsidies policy for those lands traditionally producing grain that should be left untilled for a five-year period, in an attempt to slow down the surplus of some products. This temporary dereliction of land reactivates the opening of pipes, which evolve naturally, without any anthropic intervention. Even though refilling may be done frequently, they are reformed during the next rainy season developping an incised channel with accelerated formation of lateral rills (Foster, 1986). The new incentives to compensate income losses (case of the hard wheat in Saragossa) result, only temporarily, in an increase of the cultivated land and in a brake on erosion. This fact can be confirmed in Figure 2 (1991), in which the potential activity of the process follows the gullies'beds in 1956, having broken the 1984 "sealing" and taking up again their natural dynamics (2,05m^2 in three months -Barrón et al., 1995-), which is periodically interrupted due to the increase of cultivated surface, coinciding with a certain dereliction of the farming.

Fig. 2. Gully activity evolution (1956-1991)

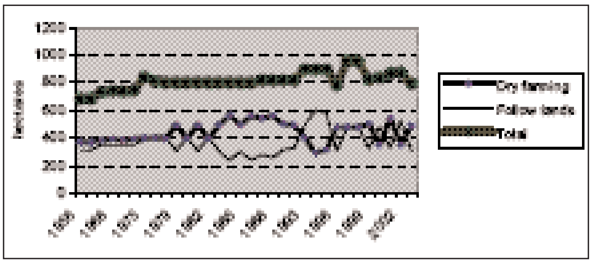

Fig. 3. Variations in the amount of surface used for arable crops both for dry farming and fallow land.

It can be therefore concluded that the piping dynamic and the gully erosion under the above-mentioned environmental conditions has been cyclically modified in connection with the different agricultural policies: from the pipe-sealing times -with rubble, plastics, earth…-, thus increasing the surface intended for crops, up to other stages in which the piping and gullying morphodynamic is clearly predominant.

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References

Barrón, G., Echeverría, MªT, Ibarra, P., Marco, P., Pérez, F., Sesé, P. 1995. Algunos datos sobre la evolución de los pipes en el bajo Valle del huerva (Zaragoza, España). *Actas del VII Coloquio Ibérico de Geografía*. Cáceres.

Burkard, M.B. and Kostaschuck, R.A. 1995. Initiation and evolution of gullies along the shoreline of Lake Hurón. *Geomorphology 14*: 211-219.

De Ploey, J. 1990. Threshold conditions for talweg gullying with special reference to loess areas. In Bryan, R.B. (Ed.) Soil Erosion. Experiments and Models. *Catena* Suppl.*,17*:147-151.

Desir, G. and Marín, C. 2006. Evolución y procesos de erosión en gullies. Bardenas Reales (Navarra, España). In Pérez Alberti, A. y López Bedoya, J. (Eds.. *Geomorfología y Territorio*. Actas de la IX Reunión Nacional de Geomorfología. 189-199. Santiago de Compostela

Faulkner, H. 1995. Gully erosion associated with the expansion of unterraced almond cultivation in the coastal Sierra de Lújar, S. Spain. *Land Degradation and Rehabilitation, 9*:179-200.

Gábris, Gy., Kertész, A., Zámbó, L. 2003. Land use change and gully formation over the last 200 years in a hilly cartchment. *Catena, 50*:151-164.

Gutiérrez, M., Benito, G., Rodríguez, J. 1988. Piping in bandlands areas of the middle Ebro basin. Spain. *Catena Suppl., 13*:49-60.

Harvey, A. 1982. The role of piping in the development of badlands and Gully systems in south-east Spain., 317-336 . In Bryan, R. & Yair, A. (Eds). *Badland. Geomorphology and Piping*. Geobooks.

López Bermúdez, F. and Romero, M.A. 1989. Piping erosion and badlands devellpment in Southeast Spain. In Yair, A. & Berkowitz, B. (Eds.) Arid and semiarid environments-Geomorphological and Pedological Aspects. *Catena Suppl., 14*: 59-73.

Martínez Casasnovas, J.A. 2003. A spatial information technology approach for the mapping and qualification of gully erosion. *Catena*, *50*: 293-308.

Nachtergaele, J. and Poesen, J. 1999. Assesment of soil losses by ephemeral gully erosion using high altitude (stereo) aerial photographs. *European Journal of Soil Science, 53 (3):* 449-463.

Peña, J.L., Echeverría, Mª T., Julián, A., Chueca, J. 2000. Processus d'accumulation et d'incision pendant l'Antiquité Classique dans la Vallée de la Huerva (Bassin de l'Ebre, Espagne). In Vermeulen, F. & De Dapper, M. (Eds). *Geoarchaeology of the landscapes of Classical Antiquity*. 151- 159. Gent

Poesen, J., Nachtergaele, J., Deckers, J. 2000. Gullies in the Tersaert Forest (Huldenberg, Belgium. climatic or anthroppogenic cause?. In Verstraten, G. (Ed.). *Gully erosion Proceses in the Belgian Loess Belt: Causes and Consequences. Excursion Guide.* International Symposium on Gully Erosion under global change, K.U. Leuveen, Belgium, 15-26.

Poesen, J., Nachtergaele, J., Verstraeten, G., Valentin, C. 2003. Gully erosion and environmental change: impotance and research needs. *Catena*, *50, (2-4):* 91-133.

Ries, J.B. and Marzolff, I. 2003. Monitoring of gully erosion in the Central Ebro Basin by large scale aerial lphotography taken from a remotely controlled blimp. *Catena*, *50*: 309-328.

Vandaele, K., Poesen, J., Marques de Silva, J.R., Desmet, P. 1996. Rates and predictability of ephemeral gully erosion in two contrasting environments. *Geomorphology (2):* 83-96.

Vandekerckhove , L., Poesen, J., Govers, G. 2003. Medium-term gully headcut retreat rates in Southeast Spain determined from aerial photographs and ground measurements. *Catena, 50*:329-352.

EVALUATING AIRBORNE LASER SCANNING FOR GULLY EROSION DETECTION AND BASELINE MAPPING IN THE FITZROY CATCHMENT, QLD, AUSTRALIA

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1. Introduction

Australia's climate and land management practises have resulted in an increased threat to land condition and water quality through sediment transported by gully erosion. The Fitzroy River catchment is located in Queensland and is the largest catchment on the east coast of Australia. It covers approximately 14.26 million hectares and drains into the Great Barrier Reef lagoon. Grazing is the major land use of the Fitzroy River catchment (80.93%), followed by cropping (6.2%) (Rowland *et al.*, 2006). Changes to land use over time as population has increased in the region has led to a decline in water quality (Dougall *et al.,* 2006).

Water quality modelling (Prosser *et al.*, 2001; Wilkinson *et al.*, 2004; McKergow *et al.*, 2005; Dougall *et al.*, 2005; Joo *et al.*, 2005;) has shown that gully erosion is likely to be the main source of sediment for the Fitzroy. However, the uncertainty in these models is substantial (Dougall *et al.,* 2006). A major limitation is that gully densities, volumes, types and locations have not been accurately mapped and modelled to date at an appropriate scale.

Two concurrent projects are in progress to improve the spatial information on gullies for the Fitzroy River catchment: The Short-Term Modelling Project (Dougall *et al.*, 2006) aims to refine estimates of gully density by digitising gullies on Quickbird satellite imagery for sample areas and to extrapolate across the catchment from the sample sites using a range of environmental variables. The second project, described in this paper, is developing methods to detect and map gullies using Light Detection and Ranging (LIDAR) technology in the form of an aeroplane mounted Airborne Laser Scanner (ALS). The expected outcomes are (i) improved information on gully volume for areas sampled with ALS data; and (ii) accurate baseline datasets for future monitoring for sampled gullies. The paper will briefly outline the methods and products created from LIDAR derived Digital Elevation Models (DEM) to date.

2. Methods

2.1. Airborne Laser Scanner data

LIDAR has the potential to map gullies at a fine yet precise and accurate resolution. The fact it can also accurately measure height means there is a potential for gully volume changes to be detected over time.

Five sites were chosen within the Fitzroy catchment (Fig. 1a,b), mainly within the Nogoa sub-catchment, a region found to have the largest gully density in previous sediment movement prediction models (Dougall *et al.*, 2006).

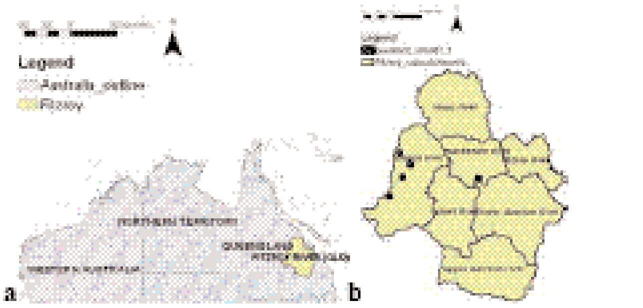

Fig. 1a: Location of Fitzroy catchment within Queensland, Australia. Only the northern states of Australia are shown.
Fig. 1b: Location of 5 study sites within the Fitzroy catchment, Queensland, Australia. Two LIDAR transects of 5km x 200m each were captured for each site.

On February 3-5, 2007 ten LIDAR transects were flown over five sites in total using an Optech ALS ALTM 3100 Enhanced Accuracy LIDAR scanner to capture easting (X), northing (Y) and height (Z) data. Two 5km x 300m transects in a cross design with an average laser point density of 30cm for each transect were captured. The transect design allows quantification of errors over time.

Quickbird imagery was also acquired over the five sites to optically validate and assess the LIDAR data. 3-D analysis in ArcScene 9.2 aided in the visual delineation of gullies.

2.2. Digital Elevation Model visualisation

We acquired the raw LIDAR data in the format of a *.las* file. The LIDAR data was classified into ground and non-ground returns by the 'Terrascan' classification system. The ground return files were imported into ArcMap 9 to create point files from text files and then Digital Elevation Models (DEMs) were created using the inverted distance weighted (IDW) interpolation algorithm in ArcMap 9.

2.3. Field validation

Surveyors recorded 118 measurements on February 7th, 2007 along one of the ten transects to assess the accuracy of the LIDAR captured. On March 5th, 2007, a field trip was conducted to validate the LIDAR transects. Photos, GPS points and bearings were recorded for four transects, with more field trips planned for additional validation. The field

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data was used to validate the ‘edge’ of the gullies and to assess the accuracy of the automated ‘Terrascan’ classification.

3. Results

3.1. Digital Elevation Model visualisation

DEMs with a 50cm spatial resolution (pixel size) were generated for each of the 10 transects. Two examples, clearly showing gullies are shown in Figures 2a,b representing two different 1500m subsets.

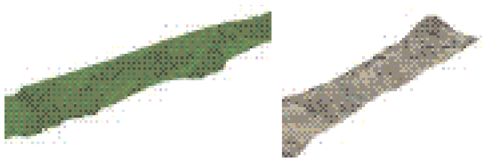

Fig. 2a: Gullies identified in the 30cm DEM over a 1500m subset created from LIDAR Transect 2 data (vertically exaggerated 5 times). **Fig. 2b:** Transect 3 DEM subset with a clipped Quickbird image draped on top (vertically exaggerated 2 times).

Cross-sectional analysis provides valuable information on gully status (Fig. 3). This product can be used to detect gully morphological changes over time.

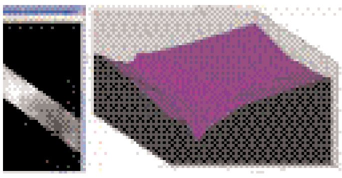

Fig. 3: Cross-sectional analysis of gullies within Transect 2. Elevations of 400 metres to 450 metres above sea level.

3.2. Field validation

Surveyors identified a vertical mean difference of 0.091m (0.045m RMS error) between the surveyed heights and the LIDAR heights. In the regions of overlap of the laser transects, no differences in elevation were recorded. Field photos were linked in ArcMap to points on the transects (Fig. 4). Field photos revealed the LIDAR was accurately classified, despite potential complications such low lying shrubs.

Fig. 4: Transect 3 field photos and coordinates mapped.

4. Discussion

4.1. Current research and future directions

We have established a methodology to capture LIDAR, and visualise the data to detect and measure gullies on an extremely fine scale. In addition, a baseline has been established for future research into sedimentation rates and gully morphology. This will contribute to understanding sedimentation rates in models applicable to the Australian environment and assist in land management and water quality decision making for sustainable use of our resources.

This project only recently commenced and is at an early stage. LIDAR data will be captured for a further ten transects to provide samples over land types not previously covered. The use of object-oriented classification software (Definiens, 2006) will be investigated in an effort to determine gully densities and establish an average density per land type per land use. Results will be published at a later date. Further aspects of this research will analyse 3-dimensional slope and cross-sectional gully types to gain an insight into whether a gully is active as a transport mechanism for sediment movement through the catchment.

We also aim to build on current gully density models and provide (i) improved estimates of gully volume across the catchment; and (ii) if possible, enhanced information on gully status or rate of change. This information will drastically improve sedimentation rate modelling techniques.

The longer term aim is to provide improved information on gully density, volume and status for other priority catchments in Queensland. Therefore it is critical that the approach developed is robust, repeatable and affordable.

References

Definiens, 2006, *Definiens Professional 5: User Guide*, document version 5.0.6.2, Definiens AG, Munich, Germany.

Dougall, C., Packett, R., Carroll, C., 2005, Application Of The SedNet Model In Partnership With The Fitzroy Basin Community, In Zerger, A. and Argent, R.M. (eds) *MODSIM 2005 International Congress on Modelling and Simulation*. Modelling and Simulation Society of Australia and New Zealand, December 2005, pp. 1119-1125

Dougall, C., Packett, R., Carroll, C., Sherman, B.S., Read, A., Chen, Y., and Brodie, J., 2006, Sediment and nutrient modelling in the Fitzroy NRM region. Volume 5 In: *The use of SedNet and ANNEX model to guide GBR Catchment sediment and nutrient target setting*. Ed A.L. Cogle, C. Carroll and B.S Sherman. Department of Natural Resources, Mines and Water.

Joo, M., Yu, B., Carroll C., Fentie, B., (2005) *Estimating and modelling suspended sediment loads using rating curves in the Fitzroy River catchment Australia.* International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2005.

McKergow, L.A., Prosser, I.P., Hughes, A.O., Brodie, J. (2005) *Sources of sediment to the Great Barrier Reef World Heritage Area. Marine Pollution Bulletin,* Volume 51, Issue 1-4, 2005, Pages 200-211

Prosser, I., Young, B., Rustomji, P., Moran, C. and Hughes, A. (2001) *Constructing River Basin Sediment Budgets for the National Land and Water Resources Audit*. CSIRO Land and Water Technical Report 15/01, Canberra. http://www.clw.csiro.au/publications/technical2001/tr15-01.pdf

Rowland, T., van den Berg, D., Denham, R., O’Donnell, T., Witte, C., 2006, *Mapping Landuse: Land Use Change Mapping from 1999 to 2004 for the Fitzroy River Catchment*, Department of Natural Resources and Water, Brisbane.

Wilkinson, S., Henderson, A., Chen, Y., (2004) *SedNet User Guide: Client report for the Cooperative Research Centre for Catchment Hydrology*; CSIRO Land and Water; Canberra. www.toolkit.net.au/sednet

HYDROLOGICAL EFFECTS OF THE SEDIMENTS DEPOSITED OFF A HILLSLOPE AFFECTED BY RILL EROSION: PROJECT OUTLINES AND PRELIMINARY RESULTS

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1. Introduction

Soil erosion by concentrated flow generates rill networks on hillslope areas which are equivalent to river streamline networks reduced to a field scale. This is a common phenomenon observed and documented in agricultural lands (e.g., Evans, 1995) and mainly studied under laboratory conditions (e.g., Bryan and Poesen, 1989; Favis-Mortolock, et al, 2000). Nevertheless, the way these networks emerged and developed is hitherto not fully understood.

Erosion models normally envisaged rills as planar channels with enough flow energy to transport much of the sediment off the hillslope, where rills are developed, towards sedimentation areas. Recent findings (Giménez et al., 2004), however, show that eroding rill has topographical and hydraulic characteristics different from those present in a flat channel. Rill topography is characterised by an alternation of planar reaches (*steps*) and relative large depressions (*pools*). Over *steps*, flow is shallow, unidirectional and rapidly accelerating. In the *pool*, instead, the flow is deep, multidirectional and complex. In addition, a strong interrelation between rill flow and bed topography has been observed (Giménez et al., 2004). This feedback is, for example, the responsible of the slope independence of flow velocity in eroding rills (Govers, 1992; Giménez and Govers, 2001). This complexity is not observed in a channel with a flat surface. Yet, most of the present rill erosion models are based on hydraulic formulae borrowed from flat channels.

During rill formation, rill flow competence is indeed large enough to detach and transport even relatively coarse sediments, such as soil aggregates, off the hillslope. After formation, a rill may remain in the field for weeks or months. During this time, the rill is still a preferential pathway for water and sediment, often at lower flow rates than the rill's formative discharge. Assuming that a less intense flow will not be able to erode the preformed rill, rill topography can remain invariant in the meantime unless sedimentation becomes important. Giménez et al. (2007) show that at lower discharges, rill macro-roughness dramatically reduces the flow's competence to transport coarse sediments. Differences of one order of magnitude in transport between a rill and a flat channel of the same micro-roughness were observed under the same slope and discharge (Giménez et al., 2007). Therefore, we hypothesise that within the sedimentation area of a hillslope, rill erosion is able to generate a layer of sediment whose granulometric characteristics should be different from that of the sediment produced by interill erosion (i.e., by overland flow). Now, to what extent these granulometric differences lead to local disparities in the hydrological behaviour of soil profile (e.g., infiltration rate), is much uncertain.

The main objectives of this project are then (i) to evaluate the sedimentation rate generated by rill erosion in a hillslope and the granulometric characteristics of the sediment deposited off this hillslope, and (ii) to determine the incidence of this sediment on the hydrological properties of the sedimentation area. In addition, an extra aim is to gain insight into the spatial and temporal evolution of a rill network under field condition.

2. Materials and methods

2.1. Selection of the experimental site

An essential part of the present work is to find a proper field place to run the experiments. We need a piece of land with at least the following characteristics [the below terminology follows the USDA's (1993) Soil Survey Manual]:

(i) Normal to excessive relief (i.e., a sloping upland with a medium to rapid runoff) with (ii) a nearly uniform soil surface, and a (iii) simple or somewhat convex slope (rilling is more likely in a convex slope). (iv) A clear sedimentation area which normally occurs when there is a sudden break in the slope towards a nearly flat relief, lowland. (v) An homogenous and deep topsoil in order that rills develop entirely within a single type of material. (vi) A well defined contributing area which is directly related to runoff discharge over this plot. (vii) Finally, a clear rill network must be, under natural conditions, easily developed, and the whole rill network must occupy a rather small area (around 100 – 200 m^2) in order to facilitate its monitoring. We found a plot with the aforementioned characteristics within the region of Pitillas (Navarre, Spain). This is 18 m long, 8 m wide and 12% steep (Fig.1).

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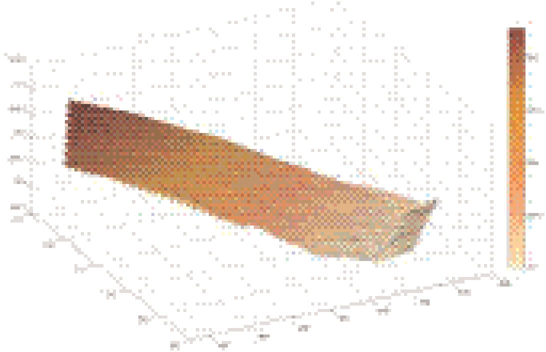

Fig. 1. Digital Elevation Model of the experimental plot.

2.2. Experimental protocol

Before starting the experiments, the whole plot was gently tilled with a disc plough in order to obliterate the pre-existing eroded rills. Then, it was surrounded by a wire fence to avoid soil disturbance by animal tramping.

Rainfall events are being measured every 10 min time by using an automatic pluviograph installed closed to the experimental plot. To measure soil moisture content, TDR probes were placed at the top, middle and bottom of the plot, at two different depths, i.e. 10 and 30 cm. Then, soil moisture content is being periodically measured using a portable TDR gauge that is connected in turn to each probe. In addition, continuous soil moisture content is being continuously registered by a soil water gauge connected to a datalogger. This last device is located at the middle of the plot and near to its lateral border, and at a depth of 25 cm

After any (important) rainfall event, the plot surface is being topographically surveyed by using a total station without using a prism located at around 8 m far from the low border of the plot (i.e., trampling over the plot is hence avoided). Rills (if any) are especially surveyed as in detail as possible. Besides, after a rainfall occurs, topsoil samples will be taken both in the rill and interrill sedimentation areas, and granulometric analysis of them will be carried out. In addition, in situ infiltration measurements will be made in both sedimentation areas by using a disk or tension infiltrometer. This allows to determined the infiltration rate (and characterize soil porosity) of few millimetres thin, sediment or soil layers by introducing water at subatmospheric pressure during just few minutes. Moreover, and again in both sedimentation areas, infiltration measurement of the whole soil profile will be carried out using a conventional double-ring infiltrometer.

3. Preliminary results

As preliminary results, Fig. 2 shows a plan view of the experimental plot with some incipient rills over it.

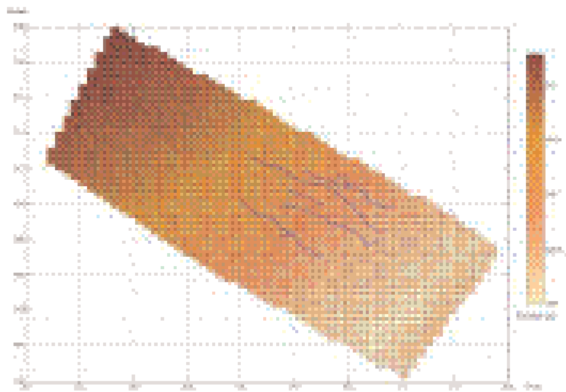

Fig. 2: Incipient rills observed in a plan view of the experimental plot.

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References

Evans, R.1995. Some methods of directly assessing water erosion of cultivated land-a comparison of measurements made on plots and in fields. Progress in Physical Geography 19 (1): 115-119.

Favis-Mortlock, D.T., Boardman, J., Parsons, A.J.Lascelles.B. 2000. Emergence and erosion: a model for rill initiation and development. Hydrological Processess, 14:2173-2205.

Giménez R., Govers G. 2001. Interaction between bed roughness and flow hydraulics in eroding rills. Water Resources Research, Vol. 37 Nº3, 791-799.

Giménez, R., Léonard, J., Duval, I., Richard, G. Govers, G. 2007. Effect of bed topography on soil aggregates transport by rill flow. Earth Surface Processes and Landforms, 32(4):602-611 .

Giménez, R., Planchon, O., Silvera, N., Govers, G. 2004. Longitudinal velocity patterns and bed morphology interaction in a rill. Earth Surf. Processes and Landforms 29, 105–114.

Govers, G. 1992. Relationship between discharge, velocity and flow area for rills eroding loose, non-layered materials. Earth Surface Processes and Landforms, vol.17, 515-528.

USDA. 1993. Soil Survey Manual. Handbook Nº 18. 503p.

MODELLING THE OCCURENCE OF GULLIES IN SEMI-ARID AREAS OF SOUTHWEST SPAIN

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1. Introduction

Modern methods and techniques of predictive modelling have rarely been applied to predict the location of geomorphic phenomena. In this paper we use a relatively new method, *Multivariate Adaptive Regression Splines* (Friedman 1991), in order to determine the potential distribution of gullying in silvopastoral systems of southwest Spain. We selected MARS instead of Neural Networks because the results are easily interpretable and they do not suffer from black box limitations.

In these areas gully erosion can be the most important process of soil degradation together with sheet erosion (Schnabel 1997).

2. Methodology

Multivariate Adaptive Regression Splines (MARS) is a non-parametric method for modelling the response of a dependent variable (gullying) from a set of independent variables. Gullies were located in the field within a selection of 54 farms distributed in Extremadura, Spain. With the help of a GPS and aerial orthophotographs of high resolution gullies were mapped. A set of 36 different maps of the study areas were used to define the independent variables reflecting topography, climate, soils, lithology, land use and vegetation cover.

2.1. Topography

To represent the topography of the study areas Digital Elevation Models (DEM) were elaborated with a resolution of 5 m, which is the best available. Furthermore the model is developed for being applied in large areas such as Extremadura with a surface area of 41,634 km^2. The resolution of the *DEM* can be considered as the error of prediction, i.e. whether a gully exists or not. This error is considered not significant for localizing a gully in the field. Starting from this *DEM* we generated maps of slope gradient, curvature (general, profile and plan), Roughness (using three different windows of three, seven and eleven pixels), catchment area, total upslope length and longest upslope length of flow path terminating at each grid cell.

2.2. Rainfall

From a large dataset of precipitation (1960-1991) for 222 meteorological stations in the study area, we generated maps of mean annual, seasonal and monthly rainfall.

2.3. Lithology and soils

Rock type was obtained from the geological maps of the study area (scale 1:50,000). Two soil maps using the FAO-WRB classification system were digitalized. (1:300,000).

2.4. Land use and vegetation cover

Five variables were used to represent land use and vegetation cover, each of them were obtained from the Forest Map of Extremadura (scale 1:50.000): land use and management of the farm, dominant tree species, tree cover, total vegetation cover and structure of vegetation cover.

The performance of the model was analyzed using the ROC curve (*Receiver Operating Characteristic*) that represents the ability of a predictive model to differentiate areas with and without gullies. The ROC curve represents the values of sensibility (true positives) and the complementary of specificity (false positives) across all possible thresholds. The threshold is defined as the value used for classifying a quantitative result of the model like gullied or ungullied. For an optimal model, the ROC curve must be fitted to the upper-left side of the graphic, and the value of the AUC (*Area Under the Curve*) must be approximately one. AUC is a measure of model accuracy, but it does not provide a rule (threshold) for the classification of areas with or without gullying. The optimal threshold was selected using the sum of the percentage of correct cases of presence and absences of gullies.

In addition to the ROC curve and AUC we carried out a validation of the model with an external dataset from five different areas. For these datasets a confusion matrix was obtained representing a comparison between reality and model results.

The contribution of each variable to explain the model was estimated from the Generalized Cross Validation algorithm (1) (Craven and Wahba 1979) which estimates the reduction of the goodness of fit when each variable is eliminated from the model (Table 1):

$$GCV(M) = \frac{1}{N} \frac{\sum_{i=1}^{N} (y_i - f_M(x_i))^2}{\left(1 - \frac{C(M)}{N}\right)^2} \qquad (1)$$

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where N is the number of cases of the initial dataset, y is the dependent variable, is the model and $C(M)$ is a measure of cost-complexity of the model with M terms.

Another possible output of predictive models is the generation of maps which present the risk or potential of gullying. The results were used to generate those maps for the study areas and analyze the surface area that can be potentially affected by gullies.

3. Results

The result of the ROC curve (Fig. 1) shows a model with a good performance and sufficient ability to differentiate gullied and ungullied areas, with values of the AUC of 0.98.

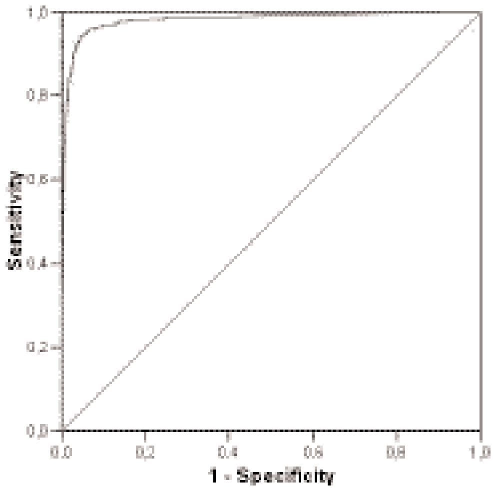

Fig. 1. ROC curve for the final model elaborated.

The threshold selected to classify the model results into gullied and ungullied areas was 0.45 which assures the highest percentage of areas being classified correctly.

The most important variables to support this model were lithology, vegetation structure and the average amount of autumn rainfall (September to November). Other important variables for explaining the model results were elevation, soil type, total upslope length of flow paths and average monthly precipitation of April, June, October and May (Table 1).

Table 1. Reduction of the goodness of fit of the model caused by eliminating each of the 10 most important variables.

Variable	-*GCV*
Lithology	0.075
Vegetation Structure	0.050
Autumn Rainfall	0.037
Elevation	0.034
Rainfall April	0.031
Soil type	0.031
Total upslope length	0.031
Rainfall June	0.031
Rainfall October	0.031
Rainfall May	0.031

Table 2. Summary of the importance of different factors in the gully model, where N is the number of variables, $-GCV$ is the sum of GCV of each group variables and $-GCV_{average}$ is the average GCV by group of variables.

Group of Variables	N	$-GCV$	$-GCV_{average}$
Topographic	11	0.358	0.033
Rainfall	17	0.513	0.030
Lithology-Soil type	3	0.135	0.045
Land Use and Veg.	5	0.167	0.033

The Generalized Cross Validation (GCV) parameter shows that by groups, the most important factors in determining the distribution of gullying are lithology-soil type and topographic factors (Table 2).

Five different datasets were used for an external validation of the obtained model. The results show a model efficiency in determining the location of gullies of 80 % and in 99.65 % of the cases the model determined correctly the absence of gullies (Table 3). For three of the five validation datasets the values of efficiency in classifying gullied areas were higher than 90%.

Table 3. Confusion matrix that presents the results of validation for five external datasets.

		Reality	
		Absence of Gullies (0)	Presence of Gullies (1)
Model	Absence of Gullies (0)	4822	91
	Presence of Gullies (1)	17	364
Percent Correct (%)		99.65	80.00

4. Conclusions

Modern predictive models represent a powerful tool for predicting and analyzing geomorphological phenomena like gullying. The model obtained presents a high percentage of success in classifying gullied and ungullied areas. Nevertheless, in some areas the prediction of the occurrence of gullying was worse. Further studies need to be carried out in order to understand the reasons for its poor performance in certain areas. However, an improved model could be an important management and planning tool for silvopastoral areas of southwest Spain.

References

Craven, P. and G. Wahba. 1979. “Smoothing noisy data with spline functions.” *Numerische Mathematik* 31: 377-403.

Friedman, J. H. 1991. “Multivariate adaptive regression splines.” *Annals of Statistic* 19: 1-141.

Schnabel, S. 1997. *Soil erosion and runoff production in a small watershed under silvo-pastoral landuse (dehesas) in Extremadura, Spain*. Logroño.

EPHEMERAL GULLY HEADCUT DEVELOPMENT AND MIGRATION IN STRATIFIED SOILS

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1. Introduction

Headcuts and knickpoints are step-changes in bed surface elevation where intense, localized erosion takes place. In upland concentrated flows such as rills, crop furrows, and ephemeral gullies, the formation of headcuts and their upstream migration have been linked to the concentration of overland flow, rill and gully development, and significant increases in sediment yield (see review and discussion in Bennett et al., 2000).

On natural landscapes and especially where ephemeral gullies are prevalent, soils display a clear stratification with depth. Due to cultivation and/or the presence of a fragipan, a resistant layer is often present at depth within the soil profile.

The objectives of the current study were: (1) to quantify the effect of an erosion resistant (ER) soil layer placed at various depths within a soil profile on headcut development and migration; and (2) to assess the effects of this ER layer on analytic formulations for headcut erosion based on jet impingement theory.

2. Experimental Equipment and Procedure

A tilting, non-recirculating flume (see Bennett et al., 2000) was used. A multiple intensity rainfall simulator was suspended above the flume. A sandy clay loam, comprised on average of 28% clay, 15% silt, and 57% sand, dried and sieved at 2 mm, was packed incrementally in ~2 cm layers at an average bulk density of 1538 kg m^{-3}. During bed preparation, when the target depth for the ER layer was reached, the soil surface was subjected to 300 s of simulated rain at 21 mm hr-1. This rainfall application and the packing of subsequent soil layers created a resistant layer at the prescribed depth for each experimental run. While packing the uppermost layers, an aluminum plate was installed to create a 3 cm vertical step (headcut) near the downstream end of the flume.

After soil bed preparation, 5 hr of simulated rainfall at 21 mm hr^{-1} was applied to the material at a bed slope of 5%. This rainfall created a thin, pliable soil surface seal. A subsurface drainage system prevented the development of a perched water table. At the conclusion of the 5 hr simulated rainstorm, the headcut forming plate was removed, the slope of the flume was adjusted to 1%, and an overland flow rate of 71.0 L min^{-1} was immediately released onto the soil material. As flow passed over the pre-formed step, a two-dimensional plane jet impinged the bed downstream causing surface seal failure within 10 to 20 s. Once seal failure occurred, a scour hole began to enlarge that was modulated by the presence of the ER layer (Figs. 1 and 2). The ER layer was never eroded by the impinging jet. Headcut migration began after about 30s.

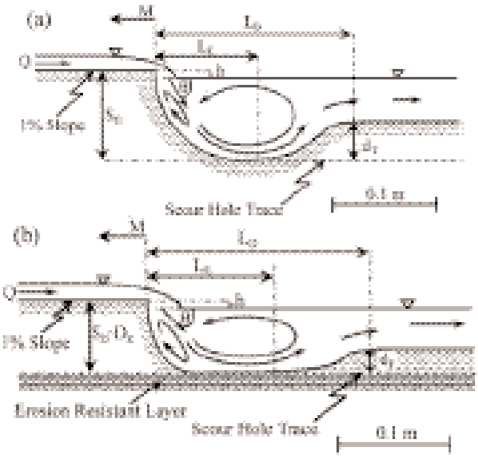

Fig. 1. Definition diagrams of water and bed surface profiles of steady state headcuts digitized directly from video images of (a) Run 1 with no ER layer and (b) Run 6 with an ER layer (D_R = 0.055 m)

3. Results

3.1. Steady State Erosion

As shown in the time-series plots of headcut scour depth S_D (Fig. 2), headcut brinkpoint position (Fig. 3a), and sediment discharge q_s (Fig. 3b), there is a time period when steady-state erosion is achieved. That is, a point in time is reached when an actively migrating headcut of similar form and sediment discharge translates upstream at a constant rate. The time and distance needed to reach steady-state erosion conditions were entirely controlled by that point in time and space when the bottom of the scour hole encounters the ER layer.

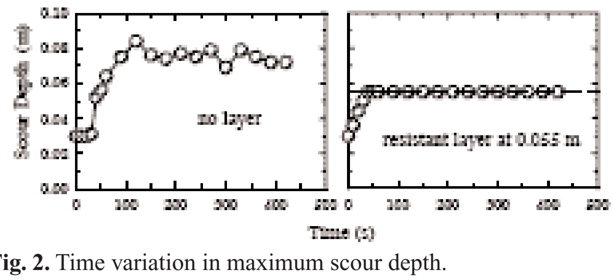

Fig. 2. Time variation in maximum scour depth.

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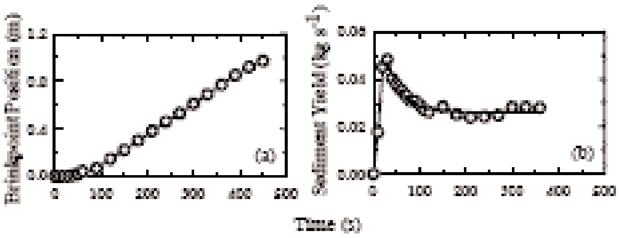

Fig. 3. Typical time variation in (a) headcut brinkpoint position and (b) sediment yield for ER layer depth = 0.055 m.

3.2 Sediment Sorting and Deposition

As the scour hole enlarges, the majority of detached sediment is transported out of the flume, sediment discharge is initially high, and the flow regime is capacitylimited. As deposition is initiated and sediment discharge approaches a steady-state condition, the flow transformed into a transport-limited regime. This transition is reflected in the textural composition of the sediment discharge, which shows that, in general, the amount of sand exiting the flume decreased with time whereas the amount of silt and clay increased with time

3.3 Effect of ER Layer Depth on Steady-State Parameters

As the depth of scour increased, or as the depth to the erosion resistant layer increased, both sediment discharge q_s (Fig. 4a) and the thickness of the downstream deposit d_T (Fig. 4b) increased significantly. Yet these deeper and more erosive headcut scour holes did not migrate at a different rate M (Fig. 4c). Thus, the higher sediment effluxes from the migrating headcuts were primarily due to the increased scour hole depth, as modulated by thicker downstream sediment deposits.

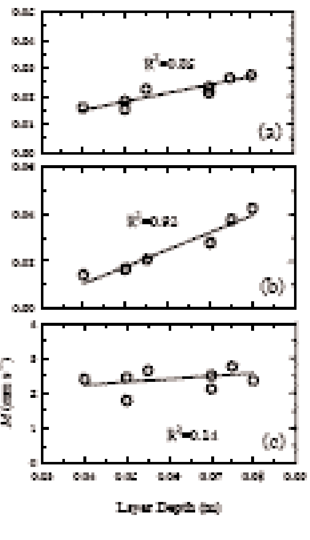

Fig. 4. Variation of steady-state soil erosion parameters as a function of the ER layer depth (steady-state scour depth S_D, m). Shown are (a) sediment discharge q_s, (b) headcut migration rate M, and (c) deposit thickness d_T.

4. Discussion

4.1. Comparison to an Analytic Model of Headcut Erosion

Using previous results of experiments involving headcuts in homogeneous soil materials, Alonso et al. [2002] derived predictive equations for the magnitude of headcut scour and the rate of headcut migration based on modified jet impingement theory. Alonso et al.'s (2002) model was used to predict the jet entry angle θ (Fig. 5a) and headcut migration rate M (Fig. 5b) in these stratified soils. Finally, the predicted erosion and deposition were compared with the measured sediment discharge at the flume outlet and this mass-balance comparison resulted in excellent agreement (Fig. 5cTime (s))

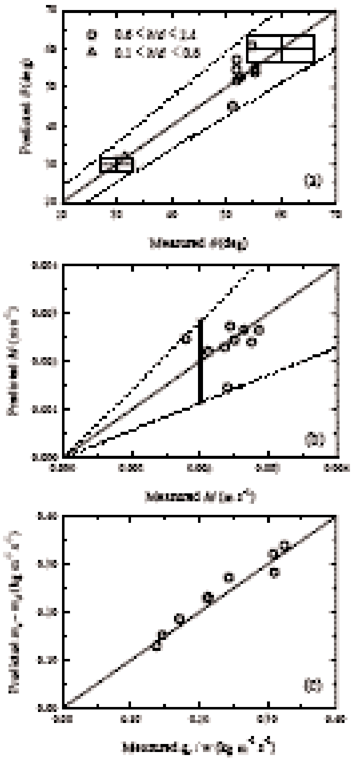

Figure 5. Comparison of (a) jet entry angle θ, (b) headcut migration rate M, and (c) the rate of sediment erosion m_e minus deposition m_d as computed using Alonso et al. (2002) versus measured values. The dotted lines represent the mean uncertainty range.

5. Conclusions

Mechanized tillage practices decrease significantly erodibility indices of the surface soil and arbitrarily create a non-tilled layer at depth which is often much less erodible than the overlying material. An experimental program was designed to examine the effects of an erosion resistant (ER) layer placed at depth on the growth and development of headcuts at the time and space scales of rills and ephemeral gullies.

When the ER layer was placed at or above the potential scour depth (verified by baseline runs), headcuts were limited in depth to this layer, and while their migration rates remained about the same, total sediment efflux was markedly reduced. These experimental observations were successfully compared to analytic expressions for jet entry angle, scour depth, migration rate, and sediment mass balance for headcuts in upland concentrated flows.

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References

Alonso, C.V., S.J. Bennett, and O.R. Stein. 2002. Predicting headcut erosion and migration in upland flows, Water Resourc. Res., 38, 39-1– 39-15.

Bennett. S.J., C.V. Alonso, S.N. Prasad, and M.J.M. Römkens. 2000. An experimental study of headcut growth and migration in upland concentrated flows, Water Resourc. Res., 36, 1911-1922.

EPHEMERAL GULLIES: TO TILL OR NOT TO TILL?

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1. Introduction

Ephemeral gully erosion is now recognized as a significant, if not dominant, source of sediment from agricultural lands worldwide. Ephemeral gullies are typically plowed in and tilled across annually or more frequently, thus restoring the original swale and allowing erosion processes to become reactivated. Mechanized tillage redistributes soil from convex areas to swales in amounts that may exceed soil losses due to water erosion (Van Oost et al., 2006). This 'conveyer belt' repeatedly resupplies concentrated flow zones with erodible material, potentially exacerbating the long-term impacts of ephemeral gully erosion on losses of soil material and crop productivity, as topsoil thickness is reduced not only in the location of the gullies themselves, but across entire fields.

Gordon et al. (2007) have extended the basic theoretical framework of the Ephemeral Gully Erosion Model (EGEM, Woodward, 1999) by refining existing components, incorporating additional components, and adapting the model to operate within the USDA Annualized Agricultural Non-Point Source model (AnnAGNPS, Bingner et al., 2003). Models of ephemeral gully erosion such as EGEM, and now AnnAGNPS, limit the depth of an ephemeral gully channel to the tillage depth or depth to a less-erodible layer (e.g. fragipan). Once evacuated to this depth (through incision and headcut development and migration), channel widening by sidewall erosion dominates and erosion decreases.

We hypothesize that by routinely introducing additional topsoil to areas susceptible to concentrated runoff, via tillage and repair of ephemeral gullies, soil losses will significantly increase over long time periods. The objective of this study is to use a recently developed ephemeral gully erosion model to test this hypothesis.

2. Methods and Data

2.1. Ephemeral gully technology

The ephemeral gully model can be conceptually presented as follows (see Gordon et al., 2007). For a given runoff event, a hydrograph is constructed at the edge or outlet of a field, and the flow rate at a given location within the field is proportional to the upstream drainage area, which depends upon the length of the gully. Thus flow is unsteady in time and spatially varied. Once the flow rate at the mouth of the field exceeds the erosion threshold of the soil, incision is initiated in the form of a headcut. This headcut first incises (scours) down to the tillage depth, an erosion-resistant layer. It then migrates upstream at a rate proportional to the flow rate. The distance the headcut travels defines the ephemeral gully length, which may not exceed a maximum length calculated as a function of the size of the field. The width of the gully downstream of the headcut and sediment transport, whether limited by sediment supply or flow capacity, is proportional to flow rate. Since flow is unsteady and spatially varied, the headcut migration rate, gully width, and rates of sediment entrainment, transport, and deposition vary accordingly in time and space. Erosion processes cease at any given location once the flow rate at that location drops below this same soil erosion potential. Following the runoff event, the field may be re-tilled, thus obliterating the developed gully and reactivating initial erosion processes at the field outlet. If tillage does not occur, the physical characteristics of the existing gully are carried forward in time until another runoff event occurs, which may or may not modify the gully.

2.2. Study locations

Comprehensive datasets for ephemeral gully erosion containing measured input data, including measured soil erodibility factors, currently are not available. A literature review was conducted to determine: (1) locations where ephemeral gully erosion has been reported to contribute significantly to total soil losses; and (2) measured parameter values that may be used to compile complete input datasets for select locations. See Gordon et al., 2007 for model input requirements. Four study sites were chosen for simulation and include Belgium, Mississippi, Iowa, and Georgia.

2.3. Simulations

Ten years (1992 to 2002) of simulations were limited to five months per year (May 1 to September 1, 153 days), representing an approximate summer growing season. Field size (5.0 ha) and soil roughness (Manning's n = 0.40) were held constant throughout all simulations. In the first scenario, a tillage event (conventional moldboard plowing to 0.275 m, considered to be the maximum ephemeral gully depth) is simulated at the start of each growing season (May 1), which fills any ephemeral gully channel that may have developed during the previous year, and after which erosion begins at the field outlet. In the second scenario, a field is considered freshly tilled only at the start of the ten year simulation. At the end of each year, gully dimensions and

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erosion rates are recorded and carried over into the next growing season. These gullies are never filled by tillage and are allowed to freely develop over a ten year period.

3. Results and Discussion

3.1. Long-term erosion rates

Erosion rates (sediment delivery to the gully mouth, Mg ha^{-1} yr^{-1}) for simulated ephemeral gullies over the ten-year time period were 326% greater on average when the gullies are filled annually by tillage as opposed to those gullies left untilled. These erosion rates do not include sheet and rill erosion. When gullies are filled in by tillage, erosion processes are reactivated and erosion potential is maximized, as the entire channel may be eroded again. In this case, cumulative erosion rates are continuously increasing (Fig. 1c). In contrast, after several storms, gullies left untilled generally approach some maximum dimension related to the size of the field, the erodibility of the soil material, and the frequency and magnitude of runoff events. Once these dimensions are attained, erosion potential is minimized and erosion rates are greatly reduced, as cumulative rates of erosion increase only slightly due to gully widening or the removal of deposited material from the gully bed. In Belgium, cumulative erosion rates for the two tillage scenarios diverge after six years of simulation and for a ten year period, the untilled gullies conserve 3.1 Mg ha^{-1} yr^{-1} of soil material. For the remaining study sites, cumulative erosion amounts diverge after the first year or two and over a ten-year period in Mississippi (Fig. 1), Iowa, and Georgia, no-till soil conservation rates amount to 7.6, 7.7, and 9.0 Mg ha^{-1} yr^{-1}, respectively.

3.2. Implications for ephemeral gully management practices

The negative effects of tillage with regard to ephemeral gully erosion further demonstrate the advantages of soil conservation technologies such as no-till planting and installation of best management practices (BMPs). No-till practices increase the stability of the soil, allow for greater retention of moisture, and promote residue cover that protects the soil from detachment by raindrop impact, and the beneficial hydrologic impacts of no-till agriculture have been shown to increase over time (Dabney et al., 2004). Installation of BMPs such as grassed waterways in concentrated flow zones has been shown to reduce flow erosivity and induce deposition, thereby preventing erosion of natural drainageways by ephemeral gully incision (Fiener and Auerswald, 2003).

When ephemeral gullies are present, land managers should acknowledge the implications of repairing ephemeral gullies during tillage and consider alternate approaches to mitigating ephemeral gully erosion and ensuring the long-term productivity of their land.

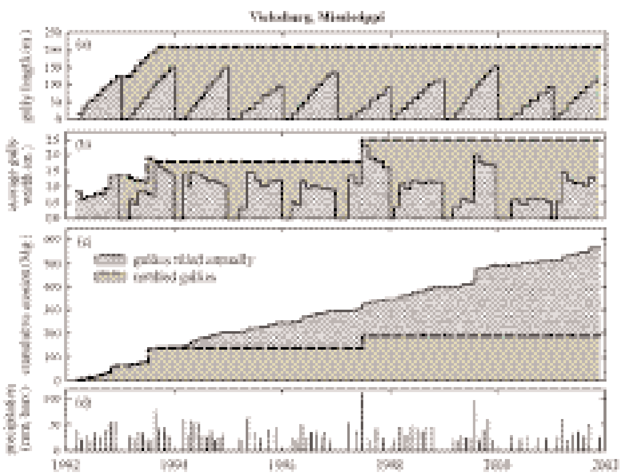

Fig. 1. Time evolution of (a) ephemeral gully length (m), (b) ephemeral gully width (m), and (c) cumulative erosion (Mg) for annually tilled and untilled gullies resulting from (d) rainfall events producing concentrated flows exceeding the soil's critical shear stress at Vicksburg, Mississippi. Note that gully dimensions and erosion rates are identical during the first simulation year.

4. Conclusion

While the perceived magnitude of ephemeral gully erosion may be masked after gullies are repaired, the action of plowing in these channels reduces topsoil thickness and crop productivity over a much wider area than the channel itself. This study demonstrates that filling ephemeral gullies on an annual basis during tillage operations may be more destructive than realized. These results should provide land managers an additional incentive for adopting soil conservation practices such as no-till.

Acknowledgements: This work was funded by the USDA-ARS.

References

Bingner, R.L., F.D. Theurer, and Y. Yuan. 2003. AnnAGNPS Technical Processes. Washington, D.C.: USDA-ARS. Avaliable at: www.ars.usda.gov/Research/docs.htm?docid=5199. Accessed 3 April, 2007.

Dabney, S.M., G.V. Wilson, K.C. McGregor, and G.R. Foster. 2004. History, residue, and tillage effects on erosion of loessial soil. Transactions of the American Society of Agricultural Engineers. 47(3): 767-775.

Fiener, P. and K. Auerswald. 2003. Effectiveness of grassed waterways in reducing runoff and sediment delivery from agricultural watersheds. Journal of Environmental Quality. 32: 927-936.

Gordon, L.M., S.J. Bennett, R.L. Bingner, F.D. Theurer, and C.V. Alonso. 2007. Simulating ephemeral gully erosion in AnnAGNPS. Transactions of the American Society of Agricultural and Biological Engineers. IN PRESS.

Van Oost, K., G. Govers, S. de Alba, and T.A. Quine. 2006. Tillage erosion: a review of controlling factors and implications for soil quality. Progress in Physical Geography. 30(4): 443-466.

Woodward, D.E. 1999. Method to predict cropland ephemeral gully erosion. Catena. 37: 393-399.

IMPLICATIONS OF RECENT EXPERIMENTAL FINDINGS FOR RILL EROSION MODELING

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1. Introduction

Several relationships that describe flow hydraulics and sediment detachment within an eroding rill/gully have been proposed. Often, concepts were taken from literature on alluvial rivers and directly applied to these eroded channels. However, there are both similarities and discrepancies between flow and sediment detachment and transport in rivers (or gullies) and rills. Rills are small, concentrated flow paths where typical water depths are of the order of millimetres to several centimetres running over steep slopes. In such shallow flows, the effect of the bed topography on flow hydraulics cannot be neglected. In addition, rills actively erode and thus evolve morphologically over very short timescales. In contrast, water depth is usually much larger than the bed roughness in alluvial rivers (or gullies) and their morphological evolution is relatively slow. It can therefore be questioned whether concepts that were developed for rivers or big channels can directly be applied to rills. Rill flow and rill detachment experiments provide an opportunity to investigate to what extent the concepts used in models are a truly valid description of the erosion processes occurring. Field observations allow a further test of model concepts: a strong deviation between observed and predicted tendencies points to a significant deficiency in the model. Unfortunately, the reverse is not true: due to equifinality problems, good results can often be produced for the wrong reasons. The major aim of this paper is to critically review the theoretical concepts that are underpinning current models of rill flow and sediment detachment in the light of recent experimental results and, when necessary, to propose modifications to the theoretical formulations so that they are in agreement with experimental evidence. We also investigate to what extent a detachment model of reduced complexity, which is based on experimental observations, is consistent with field observation on the effect of topography on rill erosion.

2. Rill erosion models: an overview

Here, we present a description of both the hydraulic principles and the representation of detachment processes which are frequently used in current models.

Most erosion models use Manning's equation as a fundamental equation for the relationship between the velocity of water in a channel (m s^{-1}), v, and the geometry of that channel :

$$v = (R^{2/3} S^{1/2}) / n \tag{1}$$

Where, R = hydraulic radius (m); S = slope gradient (sin); n = Manning's number (s $m^{-1/3}$). The value of n is normally obtained by experimentation and is generally assumed to be independent of flow conditions. The different components of the hydraulic roughness are assumed to be additive. In order to calculate flow velocity and depth using flow resistance equations information on rill geometry is also needed. In most models values for geometric variables such as rill width are either provided by the user or are calculated using empirical relationships.

Several approaches have been used to estimate soil detachment in rills. Probably the most commonly used relationship to predict rill detachment capacity is based on the excess of shear stress (τ) over a critical value (τ_c) applied by the concentrated flow:

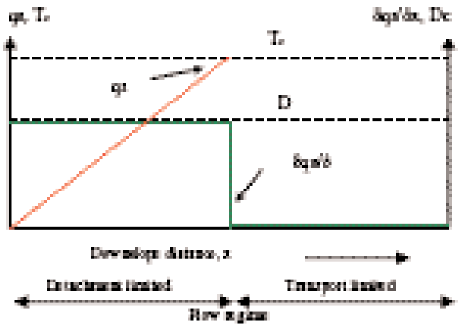

Fig. 1. Variation of sediment load with distance downslope assuming a constant discharge over a rectilinear slope (after Kirkby, 1980).

$$[Dr = K\,(a\,\tau - \tau_c)^b] \tag{2}$$

This assumes that sediment detachment (D_r) is a separate phase of the soil erosion process and that soil detachment is independent of the magnitude of the sediment load (q_s) (Fig. 1). Assuming a constant discharge over a rectilinear slope, sediment discharge will then increase linearly with distance downslope until sediment transporting capacity (T_c) is reached (Fig. 1). On the other hand, Foster and Meyer (1972) proposed a first-order detachment-transport coupling, which states that, the detachment rate (kg m^{-2} s^{-1}), Dr, is proportional to the difference between transporting capacity (kg m^{-1} s^{-1}), T_c, and sediment load (kg m^{-1} s^{-1}), q_s:

$$Dr = \delta q_s / qx = \alpha\,(T_c - q_s) \tag{3}$$

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Where, α = rate control constant (m^{-1}), x = distance (m). As sediment concentration increases downstream, detachment rate decreases accordingly. Under transport limited flow conditions the detachment rate is zero (Fig.2).

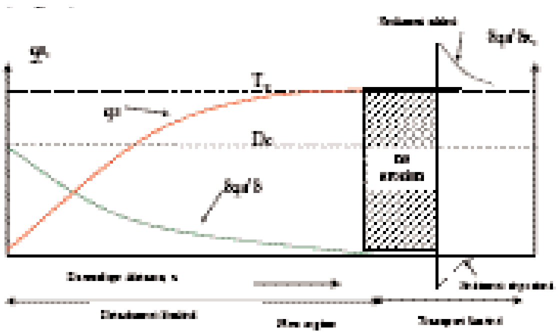

Fig. 2. Transport/detachment models following Foster and Meyer's approach. *Dc* = Detachment capacity (kg m^{-2} s^{-1}) (after Foster and Meyer, 1972).

3. Rill modeling: state of the art

Govers (1992) noticed that rill flow velocities tended to be independent of slope. This is due to a feedback between rill bed morphology and flow conditions that, besides, leads to a constant average (near-critical) Froude number (Giménez and Govers, 2001). This finding shows that assuming a constant hydraulic roughness [e.g., *n* in (1)] is clearly inappropriate for eroding rills. In addition, a simple power equation to estimate velocity, *v* (m s^{-1}) directly to discharge, *Q* (m^3 s^{-1}) and independent of slope was proposed by Govers:

$$v = 3.52\ Q^{0.294} \qquad (4)$$

On the other hand, Giménez and Govers (2002) showed that several flow hydraulic parameters can be related to flow detachment. However, only if shear stress or the unit length shear force, Γ (kg s^{-2}) (5) is used to predict sediment detachment, it is possible to directly account for beds with different roughness.

$$\Gamma = \tau\ Wp \qquad (5)$$

Where, *Wp* is wetted perimeter (m)

After making a correction, these variables can also be related to flow detachment when a vegetation or residue cover is present (Giménez and Govers, in press). Thus, these flow variables (i.e., τ, Γ) appear to be more 'universal' than other hydraulic variables which were used to predict sediment detachment. With respect to the formulation of the detachment-transport coupling model (3), recent findings (e.g., Giménez and Govers, 2002) show that flow detachment and sediment transport are not necessarily controlled by the same hydraulic parameters. This implies that sediment detachment cannot simply be described as a function of sediment transporting capacity deficit as is proposed in the original Foster and Meyer model (3). Other studies suggest that the effect of sediment load on detachment may be more important in high-energy flow conditions.

While it is clear that a full physical description of flow detachment and transport in rills is still beyond reach, we can use the available experimental information to construct a simple model of rill flow detachment:

$$\Gamma = \rho\ g\ (0.34\ Q^{0.732})\ S \qquad (6)$$

In order to investigate to what extent this (6) is in agreement with field observations, a comparison with published data was made. We attained a good agreement between field observations and model predictions. This detachment model (6) is definitely too simple to be applicable in all circumstances, but at least it explains the basic relationship between erosion rate, slope gradient and discharge for rills eroding cohesive materials.

4. Conclusions

Currently used approaches to model rill flow hydraulics and sediment detachment in rills are not always in agreement with available experimental evidence. The experimental data that are at present available suggest that rill flow hydraulics is not well described by the Manning's equation. Furthermore, experimental data suggest that the Foster-Meyer model for sediment load and transport interaction may need modification. A simple model that can be proposed for sediment detachment in rills and that is consistent with experimental evidence relates sediment detachment per unit length to unit length shear force. The exponents for discharge and slope in the expression resulting from this analysis are in good agreement with field data. A simple expression such as the one derived in this paper is certainly not capable to describe sediment detachment in all cases, as it does not allow to take into account size-selectivity, nor the interaction between sediment load and sediment detachment. Care should be taken however that the behaviour of more sophisticated models is consistent with existing experimental data. Using models that are consistent with experimental data will not necessarily directly improve model performance. However, it may ultimately lead to models that are more generally applicable and also produce meaningful results outside of the domain for which original calibration and validation was carried out.

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References

Foster, G. R. and Meyer, L.D. 1972. A closed-form equation for upland areas. In Sedimentation, Symp. to Honour Prof. H.A. Einstein, Fort Collins, (ed. H. Shen), 12.1-12.17.

Giménez R.; Govers G. 2001. Interaction between bed roughness and flow hydraulics in eroding rills. Water Resources Research, Vol. 37 Nº3, 791-799.

Giménez, R.; Govers, G. 2002. Flow Detachment by Concentrated Flow on Smooth and Irregular Beds. Soil Sci. Soc. Am. J. 66:1475–1483.

Giménez and Govers. Incorporated straw residue effects on rill erosion and hydraulics. Catena. In press.

Govers, G. 1992. Relationship between discharge, velocity and flow area for rills eroding loose, non-layered materials. Earth Surface Processes and Landforms, vol.17, 515-528.

Kirkby, M.J. 1980. Modelling water erosion processes. In Soil Erosion (Kirkby, M.J. and Morgan, R.P.C. Morgan, Eds. Johan Wiley & Sons. 312p.

URBAN GULLIES IN SÃO LUÍS CITY, MARANHÃO STATE, BRAZIL

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1. Introduction

Urban gully erosion is a serious problem in São Luís City, Maranhão State, Brazil. São Luís Municipality covers 831.7 km? and is situated in west-central Maranhão Island (2º19’09”-2º51’00” S; 44º01’16”-44º19’37” W). The Municipality is bounded by: São José de Ribamar (east); the Atlantic Ocean (north); Paço do Lumiar (west) and Rosário (south). The total population of the Municipality is 867,968; the vast majority being resident in urban areas (867,690) (IBGE, 2001).

The occurrence of soil erosion involves a series of inter-related contributory factors, including: rainfall erosivity, soil erodibility, slope characteristics and vegetation cover. Urban gully erosion in São Luís City has resulted in loss of lives and property. Environmental conditions (soil properties, soil use, rainfall regime and slope characteristics) combined with deforestation and unplanned and unauthorized urban settlement expansion has promoted land degradation and initiated gully formation (Guerra and Hoffman, 2006). The lack of basic urban infrastructure, especially sanitation, adequate road drains and paved roads, has exacerbated the problem.

In São Luís, a research project commenced in 2000, in which actively eroding gullies were identified and their evolution subsequently monitored. These gullies are in the districts of *Salina*, *Sacavém, Araçagi*, *Castelão*, *Bequimão*, *Coeduc* and *Jaracaty*.

2. Factors affecting gully erosion

Areas where people build houses in a high-density and irregular way are more susceptible to land degradation and particularly gully erosion. In São Luís there are several contributory physical factors, including the friable nature of sedimentary rocks, steep local slope angles and rainfall seasonality. Combined with poorly planned and rapid urban growth, these factors have contributed to the onset of severe accelerated erosion.

Local geological formations are composed of sedimentary rocks, dominated by permeable and generally friable and porous sandstones and shales of the Tertiary *Barreiras* Formation. Weathering on these rocks produces erodible soils, including lithosols, latosols, concretionary red/yellow clay soils and concretionary plinthosols (Maranhão, 1998). Thus, erodible soils and regolith are subject to high erosion rates, especially on steeper slopes subject to additional human interventions. Furthermore, although regional slopes are quite gentle, there is localized high relative relief.

Local vegetation consists of mangrove swamps, riparian forests, secondary mixed forest (*capoeira*), brushwood and water meadows. Secondary mixed forest and brushwood are the dominant vegetal cover adjacent to the urban gullies.

The local climate is humid tropical, with average annual temperatures of 26ºC, reaching higher values in October to December and lower from April to June (Fonseca, 1995). Rainfall distribution throughout the year is irregular, marked by two very distinct seasons (rainy and dry). The highly seasonal erosive rains incise a complex series of soil erosion landforms (including rills, gullies, pedestals, alcoves, grooves, pipes, sand-falls, clod-falls, ribs, fissures, and mass movements).

The settlement of São Luís was established in 1612 and has evolved in distinct phases. Rapid urban growth was associated with industrialization in the second half of the 18th Century. Rapid population and urban growth has intensified problems, compounded by poor planning and improper soil use. São Luís, like many other Brazilian cities, has experienced rapid population growth in recent decades, which has created a series of socio-economic and environmental problems, including accelerated soil erosion.

3. Monitored gullies

The selected monitored gullies are located in four points in the urban area of São Luís, representing specific land use types. These are: adjacent to irregular settlement (*Sacavém* District), coastal areas (*Ponta da Areia* Beach), a protected environment area (*Sítio Santa Eulália*) and next to *Castelão* Football Stadium (*Barreto* District).

The gullies have been monitored following the method of Guerra (1996), which employs stakes around the gullies, measuring tapes to measure the distance between stakes and gully edges and a Brunton compass to orientate measurements.

Monitoring at three selected gullies (Castelão, Sacavém and Salina) shows that the rainfall regime strongly

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contributes to gully evolution rates and gully retreat. Most erosion is attributable to erosive rains during and after the rainy season (Mendonça *et al*., 2005). Deforestation and burning of vegetation exposes soil to the direct impact of rain drops, causing soil crusting, decreasing infiltration and thus increasing runoff and accelerating erosion rates.

Sacavem Gully has the highest erosion rate of the monitored gullies, with a gully head retreat rate of ~1 metre per year. The other gullies have smaller retreat rates of ≤0.5 m per year. The main explanation is the high population pressures adjacent to Sacavem Gully. These pressures include a dense and intensively used network of footpaths (which form important source areas for runoff and sediment) and extraction of sand and gravel for building material.

4. Strategies for erosion control

In association with the ongoing programme of gully monitoring (Guerra *et al.*, 2004), efforts are in progress to rehabilitate degraded areas using bioengineering techniques. These techniques have been applied in different situations, with positive results from the use of biodegradable materials (e.g. vegetal fibres, wooden stakes and re-vegetation). These techniques stabilize the soil at low cost and improve the environment. Bioengineering involves the planned, strategic and phased application of selected materials, involving biodegradable materials, often in combination with 'hard engineering' structures constructed from stone, concrete and steel.

Currently, particular attention is focused on the use of biodegradable geotextiles made from the fibre or straw of some native palm trees, such as Buriti (*Mauritia flexuosa*). The use of these biogeotextiles is an adaptation of techniques used in other places with similar vegetation. For instance, in The Gambia (West Africa) the native palm tree Borassus, which is similar to Buriti, is being used in a similar fashion. Currently, a project is rehabilitating degraded areas in the Sacavém gullies, using bioengineering techniques. Preliminary evaluation suggests the approach has considerable potential as an efficient, effective and viable technique that offers environmental and financial advantages for the local people (Furtado *et al*., 2005).

The use of palm-geotextiles is a good solution for the environmental problems associated with soil degradation by gully erosion. The Buriti palm was selected due to its abundance in Maranhão, particularly in Barreirinhas Municipality, where the fibre is harvested to produce the mats. Furthermore, the Buriti fibres are similar to Borassus. However, the potential of other species of Brazilian palm to control urban gully erosion is also being evaluated in São Luís.

After engagements with community leaders, weekly classroom and field-based lessons have been provided for children and youths from impoverished backgrounds. A 'learn-whilst-doing' methodology is applied, which includes art-design lessons and theatrical performances, to underpin the theme of the classes and promote interesting and practical sustainable remediation techniques. This is enhancing the personal development of the young people (notably, technical training, behavioural improvements, improvement in self-esteem and self-belief, plus the development of a teamwork ethos), which has widened community participation by attracting other family members to attend project events and develop an affiliation with the sustainable development and remediation of degraded areas.

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References

Fonseca, M.J.B. 1995. A Invasão como Processo de Ocupação dos Espaços Urbanos Vazios: o caso Vila Lobão - São Luís - MA. São Luís, 51p.

Furtado, M.S., Lima, N.F.C., Sousa, U.D.V., Mendonça, J.K.S., Guerra, A.J.T. and Feitosa, A.C. 2005. The use of biotextiles to recuperate degraded areas by erosion. International Symposium on Land Degradation and Desertification. Special Issue, Uberlândia, Brazil.

Guerra, A.J.T. 1996. Processos Erosivos nas Encostas. In: Geomorfologia: exercícios, técnicas e aplicações. Cunha, S.B. & Guerra, A.J.T. (Eds), RJ Bertrand, p. 139-155.

Guerra, A.J.T. and Hoffman, H. 2006. Urban gully erosion in Brazil. In: Geography Review. Vol. 19, Number 3, 26-29.

Guerra, A.J.T, Mendonça, J.K.S, Rêgo, M. and Alves, I.S. 2004. Gully Erosion Monitoring in São Luis City - Maranhão State - Brazil. In: Yong Li; Jean Poesen; Christian Valentin. (Eds). Gully Erosion under Global Change. 1 Chengdu: Sichuan Science and Technology Press, v. 1, p. 13-20.

IBGE. 2001. Instituto Brasileiro de Geografia e Estatística. Recenseamento de 2000.

Maranhão, 1998. "Secretaria de Estado do Meio Ambiente e Recursos Hídricos". Diagnóstico ambiental da Microrregião da Aglomeração Urbana de São Luís e dos municípios de Alcântara, Bacabeira, Rosário e São Luís.

Mendonça, J.K.S., Bezerra, J.F.R, Gonçalves, L.D.P., Gonçalves, M.F.P., Guerra, A.J.T. and Feitosa. A.C. 2005. Study of rainfall rates and erosive processes in the urban area of São Luís – MA. International Symposium on Land Degradation and Desertification. Special Issue, Uberlândia, Brazil.

GULLIES ON MARS: THE DEBATE ABOUT FORMATIVE PROCESSES
(Keynote)

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1. Introduction

The discovery of very young gully systems on Mars has occasioned a lively debate about the processes and materials involved in their formation (Malin and Edgett, 2000). The strong interest in these features results because the majority of studies have concluded that flowing liquid water has been involved in their formation and the possible implications for past or present microbiotic life on Mars. This paper reviews the occurrence and morphology of the gullies and the range of hypotheses about their formation.

2. Present and past Martian environments

Early in martian history an active hydrological cycle eroded extensive valley networks and infilled craters with eroded sediment. This period of intensive fluvial activity stopped about 3.7 billion years ago due to the loss of the most of the atmospheric gasses, possibly as a result of the loss of the magnetic field. Since that time the atmospheric pressure has been only a few tens of millibars and average surface temperatures have been well below freezing. Subsequent fluvial activity has generally been limited to occasional floods from subsurface sources (outflow channels) and possibly to melting of snow accumulations on major volcanoes and gully formation elsewhere.

3. Morphology and occurrence of gullies

The gullies that have been the focus of intensive recent study are noteworthy because of their youthfulness, indicated by the lack of superimposed impact craters. The density of impact craters is the primary means of relative age dating on planetary surfaces. Features of appreciable size that lack craters are estimated to be no older than tens of millions of years.

The arrival of the Mars Observer Camera (MOC) high resolution camera into orbit in 1997 permited recognition of features on the surface as small as a few meters in size, resulting in the first definitive recognition of the gully features. The gullies occur primarily on steep slopes in the mid to polar latitudes, generally on the walls of relatively young impact craters or tectonic scarps. A typical setting for gullies is a scarp or interior crater wall that is 200-500 m tall and averages 20° in steepness. The gullies typically display an upper *alcove* incised into the slope, often with crudely dendritic channels merging downslope to a well-defined throat below which is a conical *apron* on the lower part of the host slope (Fig. 1). The apron often displays well-defined distributary channels that have a straight to modestly sinuous planform and often narrow gradually downslope. Although quantitative measurements have not been possible to date, the volume of the apron seems commensurate with the size of the alcove. The close association and similar size of alcove and apron indicate that erosion of the alcoves and downslope transport and deposition of the erosional debris has created the aprons.

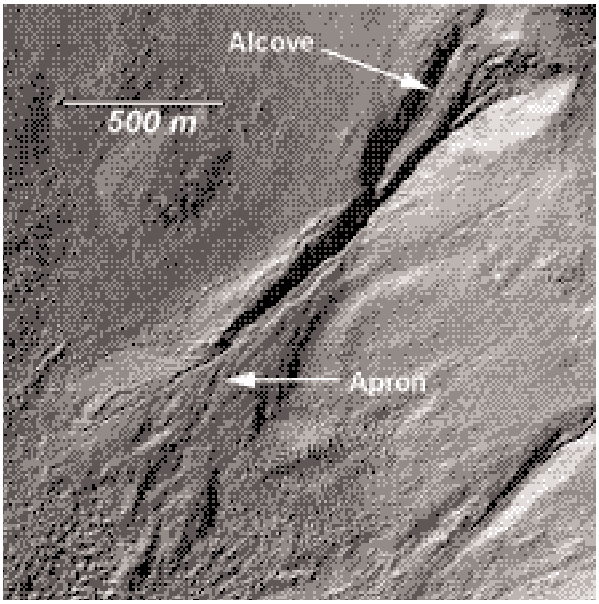

Fig. 1. Part of HiRISE image PSP_001368_ 1400 showing a typical gully system on a Martian Crater wall.

Although there is a wide range of gully morphologies, a few generalizations are possible:

1). The gullies are most common at mid-latitudes, with a preferance toward occurrence on pole-facing slopes, at higher latitudes the orientation bias is less strong (Berman et al., 2005).

2). Gully alcoves generally originate at a consistent elevation on crater or scarp walls, sometimes exposing layered or bouldery rocks (Fig. 2). (Malin and Edgett, 2000; Gilmore and Phillips, 2002). In a few cases gullies occur at multiple elevations. Smaller gullies are often incised solely into thick, fine grained, and possibly volatile rich "pasted-on" terrain on crater walls and scarps, as in the gully at the lower right of Fig. 1 (Mustard et al., 2001; Bleamaster and Crown, 2005).

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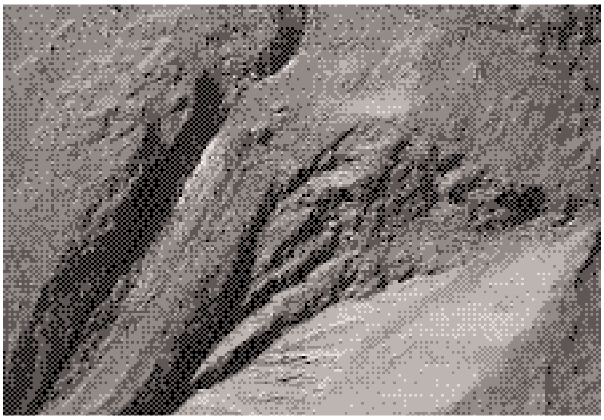

Fig 2. Inset of Fig. 1 showing alcove.

3). Aprons are surprisingly free of coarse debris (>1 m in size) (Fig. 3). Most aprons appear to be steeper than 10°, and many are probably steeper than 20°. Aprons often have sinuous feeder channels and multiple distributaries, and hints of depositional lobes (although levees are rare).

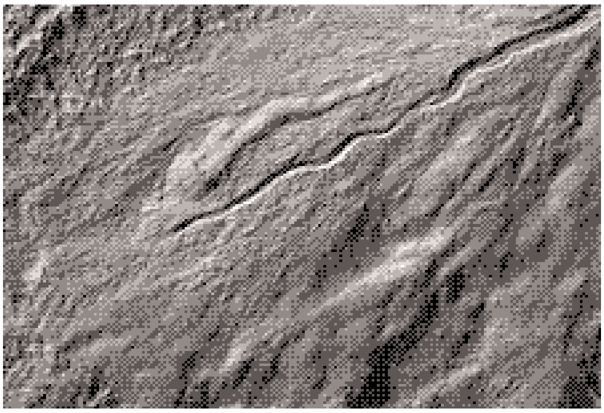

Fig. 3. Inset of Fig. 1 showing apron.

4). Aprons almost always terminate abruptly downslope. Channels extending beyond the apron are rare.

5). Gully systems often show a complex history. For example, in Fig. 1 the apron apex has been deeply entrenched, and multiple ages of debris emplacement are shown in Fig. 3. In some cases alcoves show recent entrenchment into larger, older alcoves that appear to have "healed" by deposition or mass wasting (Fig. 2).

6. Patchy albedo brightening during the past few years on two aprons suggests recent gully activity (Malin et al., 2006).

3. Formation mechanisms

A wide range of formation mechanisms have been proposed. These include:

- Flow from groundwater (Malin and Edgett, 2000; Gilmore and Phillips, 2002; Heldmann and Mellon, 2004; Márquez et al., 2005). Observations supporting this are the common elevation of alcoves on crater walls or cliffs, exposure of layered rocks in alcoves, and difficulties mobilizing liquid water in the modern surface environment.
- Explosive eruptions of water or CO_2 (Mellon and Phillips, 2001; Musselwhite et al., 2001).
- Melting of water from seasonal or epochal accumulations of frost, or from melting of "pasted-on" mantles (Costard et al., 2002; Hecht, 2002; Christensen, 2003; Mangold et al., 2003).
- Formation by dry mass wasting or by CO_2 gasses from seasonal sublimation (Treiman, 2003; Shinbrot et al., 2004; Ishii et al., 2006; Bart, 2007).

Distinguishing between these hypothesis is difficult because the steepness of the features means only slight stresses in excess of gravity are required to initiate and maintain flows. The limited mobility of the flows is also indicated by the steepness of the aprons and lack flows beyond the aprons. Examples of possible terrestrial analogs will be presented.

References

Bart, G.D., 2007. Comparison of small lunar landslides and martian gullies. *Icarus, 187*: 417-421.

Berman, D.C., Hartmann, W.K., Crown, D.A. and Baker, V.R., 2005. The role of arcuate ridges and gullies in the degradation of craters in the Newton Basin region of Mars. *Icarus, 178*: 465-486.

Bleamaster, L.L.F. and Crown, D.A., 2005. Mantle and gully associations along the walls of Dao and Harmakhis Valles, Mars. *Geophysical Research Letters, 32*(20): L20203.

Christensen, P.R., 2003. Formation of recent martian gullies through melting of extensive water-rich snow deposits. *Nature, 422*: 45-48.

Costard, F., Forget, F., Mangold, N. and Peulvast, J.P., 2002. Formation of Recent Martian Debris Flows by Melting of Near-Surface Ground Ice at High Obliquity. *Science, 295*: 110-113.

Gilmore, M.S. and Phillips, E.L., 2002. Role of aquicludes in formation of Martian gullies. *Geology, 30*(12): 1107-1110.

Hecht, M.H., 2002. Metastability of Liquid Water on Mars. *Icarus, 156*: 373-386.

Heldmann, J.L. and Mellon, M.T., 2004. Observations of martian gullies and constraints on potential formation mechanisms. *Icarus, 168*: 285-304.

Ishii, T., Miyamoto, H., Sasaki, S. and Tajika, E., 2006. Constraints on the Formation of Gullies on Mars: A Possibility of the Formation of Gullies by Avalanches of Granular CO2 Ice Particles, *37th Annual Lunar and Planetary Science Conference*, pp. 1646.

Malin, M.C. and Edgett, K.S., 2000. Evidence for Recent Groundwater Seepage and Surface Runoff on Mars. *Science, 288*: 2330-2335.

Malin, M.C., Noe Dobrea, E.Z., Edgett, K.S., Posiolova, L.V. and McColley, S.M., 2006. Present-day impact cratering rate and contemporary gully activity on Mars. *Science, 314*(5805): 1573-1577.

Mangold, N., Costard, F. and Forget, F., 2003. Debris flows over sand dunes on Mars: Evidence for liquid water. *Journal of Geophysical Research (Planets), 108*: DOI: 10.1029/2002JE001958.

Márquez, A., de Pablo, M.A., Oyarzun, R. and Viedma, C., 2005. Evidence of gully formation by regional groundwater flow in the Gorgonum Newton region (Mars). *Icarus, 179*: 398-414.

Mellon, M.T. and Phillips, R.J., 2001. Recent gullies on Mars and the source of liquid water. *Journal of Geophysical Research, 106*: 23165-23180.

Musselwhite, D.S., Swindle, T.D. and Lunine, J.I., 2001. Liquid CO2 breakout and the formation of recent small gullies on Mars. *Geophysical Research Letters, 28*(7): 1283-1285.

Mustard, J.F., Cooper, C.D. and Rifkin, M.K., 2001. Evidence for recent climate change on Mars from the identification of youthful near-surface ground ice. *Nature, 412*: 4111-4114.

Shinbrot, T., Duong, N.-H., Kwan, L. and Alvarez, M.M., 2004. Dry granular flows can generate surface features resembling those seen in Martian gullies. *Proceedings of the National Academy of Science, 101*: 8542-8546.

Treiman, A.H., 2003. Geologic settings of Martian gullies: Implications for their origins. *Journal of Geophysical Research (Planets), 108*: DOI: 10.1029/2002JE001900.

PROPOSED METHODOLOGY TO QUANTIFY EPHEMERAL GULLY EROSION

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1. Introduction

Ephemeral gully erosion is the main source of sediment from the agricultural landscape, unfortunately, it has been overlooked in traditional soil erosion assessment (Poesen et al., 2003). Since an ephemeral gully, by definition, can be easily alleviated or filled by normal tillage, the difficulty in making the ephemeral gully erosion assessment is the lack of well-defined channel morphology such as classical gullies and river channels. Additionally, the width and depth of the ephemeral gully are too small (+/- 0.5 m) to be detected by general topographic surveying and mapping.

There are two general approaches used in assessing ephemeral gully erosion. The widely known and used Ephemeral Gully Erosion Model (EGEM) and some current process-based water erosion model (e.g., WEPP, Nearing et al., 1989) simulate the gully as a concentrated flow channel, hence, requires input for channel geometry and length (Woodward, 1999; Nachtergaele et al., 2001; Capra et al., 2005). This model may be useful once the gully has been formed. The other approach uses a topographic threshold concept based on extensive field surveys on existing gullies to back track significant topographic attributes contributing to gully initiation. For the second approach, critical slope steepness and contributing area relationship has been found for ephemeral gully initiation (Vandekerckhove et al., 1998; Vanwalleghem et al., 2005). Despite the differences, both approaches focus on hydraulic shear stress as the main factor without considering the subsurface hydrology of the soil which may have inherently caused 'weak' spots on the landscape for gully initiation.

Research conducted in the Belgian loess belt identified different hydrologic conditions for summer vs. winter gullies with surface shear under intensive storms being the main driving factor for the summer gully and profile saturation or subsurface flow the cause for winter/spring gully development (Nachtergaele et al., 2001). From a geomorphic point of view, if ephemeral gully is the transition between a hillslope and a permanent drainage channel, it can be argued that both surface and subsurface flow may also converge at locations that become initiating points of the gullies.

In this paper, we report our proposed methodology to include subsurface hydrology to develop a landscape model for ephemeral gully erosion assessment.

2. Research Objectives and Methodology

The overall objective of the proposed research is to identify and quantify landscape attributes and hydrologic conditions that can be used to assess hillslope seepage and ephemeral gully erosion. We propose to use three different methodologies to study ephemeral gully development, i.e., 1) laboratory rainfall simulation to quantify seepage and hydraulic shear effects on rill or gully initiation; 2) digital photogrammetry from low altitude aerial photography to quantify ephemeral gully development; 3) topographic threshold based ephemeral gully erosion model with subsurface hydrology.

2.1. Laboratory Experiments

The laboratory study is designed to quantify the critical conditions for rill or ephemeral gully initiation under surface flow and subsurface seepage. The process we are interested in is the initial down-cutting from an un-eroded surface instead of channel deepening, widening or sidewall sloughing on existing rill or gully channels. Prior research showed that seepage conditions greatly enhanced rill erosion (Fig. 1). The proposed laboratory study will further place the seepage induced erosion in a landscape context by quantifying the critical drainage area relationships (Kirkby, 1994) which contain terms such as rainfall intensity, soil infiltration, slope, critical shear stress, internal friction and effective cohesion.

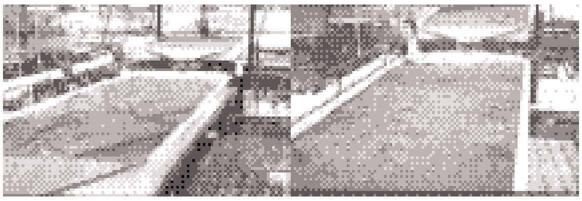

Fig. 1. Severe rilling under seepage (left) in contrast to surface scour (right) for the same soil, slope and rainfall.

Three experiments are planned. Experiment 1 will be conducted in small soil boxes (0.3 m (w), 0.45-m (l) and 0.3-m (d)) set to 5% slope and with free drainage, -10cm, -5 cm water table (tension or drainage) and 0 cm (saturation) and +5 cm, +10 cm (seepage) gradient and exposed to 25, 50 and 75 mm/h simulated rainstorms for rainfall dominated erosion assessment.

Experiment 2 will use a mini-flume, measuring 0.2m (w), 1m (l), 0.1m (d) with the same hydraulic gradient and slope treatments as the rainfall study, to quantify concentrated flow detachment under 10, 20, 40, and 80 l/min inflow. These two experiments will produce adjustment functions

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for soil erodibility and critical shear stress under saturation and seepage conditions.

Experiment 3 will be conducted in a multiple box system that consists of three soil boxes in an up and down slope cascade each measuring 1.2 m (w) by 1.8 m (l), 1.2 m (w) by 5 m (l), and 0.6 m by 4.5 m (l) with 0.3m (d) for all three boxes. Since each box has separate rainfall simulator and seepage/drainage control, we can simulate different upslope contributing areas with different levels of run-on and adjust slope and surface hydraulic gradient (seepage vs. drainage) at the down slope test box to quantify the critical area for rill or gully initiation.

2.2. Low altitude digital photogrammetry

The analysis of time lapsed aerial photos or DEM to quantify gully erosion has been well documented, especially aided by geo-spatial data processing techniques in recent years (Martinez-Casanovas, 2003). These studies are mainly on well-developed gullies with depths in the order of 1 to 10 meters or greater. There is still a need to develop an accurate and rapid tool to assess rill or ephemeral gully erosion in the order of 0.5-1.0 m wide and 0.1 to 0.2 m deep in cultivated fields.

Using low cost digital cameras to acquire 8 to 10 mega pixel images has made photogrammetry a much more feasible technique to generate DEM for gully erosion assessment. Although a remote controlled blimp has been successfully used to acquire low-attitude photo images, it is not a technique that can be easily adopted (Ries and Marzolff, 2003).

We have made progresses in developing software that will merge overlapping digital photos with ground control points to estimate DEM. Planned work include 1) testing this photogrammetry software and comparing generated DEM's with laser scanned DEM's in meter size areas; 2) testing different unmanned aerial vehicles (UAV) to acquire photographs at 10 to 100 m altitude; 3) testing alternative ground-based photographic approaches .

2.3. Modelling Ephemeral Gully Erosion

The proposed modelling approach will first to analyze the subsurface factors for potential hillslope seepage. This subsurface hydrology analysis will combine detailed digital elevation model, soils database, topographic attributes, i.e., slope shape, length and steepness, upslope contributing area, and soil profile properties to develop a spatially distributed data layer for potential hillslope seepage and ephemeral gully erosion.

Soil profile properties to be evaluated for seepage potential include soil texture and depth to impervious horizon. The seepage potential map will be superimposed onto the landscape threshold model that uses localized slope steepness and contributing area to account for the surface hydraulic shear potential for a combined surface and subsurface hydrologic model for ephemeral gully initiation. Climatic factors, such as rainfall amount and distribution and potential evapotranspiration will be used to quantify climatic potential for summer storm-driven (surface shear) vs. winter/spring soil saturation controlled ephemeral gully initiation. This spatially distributed, process-based seepage and ephemeral gully erosion model will be compared to field observations.

The field observation will be initially focused at central Indiana in conventionally cultivated fields. Ephemeral gullies will be mapped for their channel geometry using a differential GPS total station as well as the aerial photogrammetry technique once it is developed. The mapping will be done in early spring before spring cultivation and in the fall after harvest. Any tillage operation that may obliterate the ephemeral gully will be recorded. For each ephemeral gully, geo-referenced soil probing will be conducted in the contributing area, with 1-2 m grid near the gully channel and 20-50 m grid for the rest of the area, to obtain depth to impervious horizon data.

The field survey will be used to create a data layer and compared to the same attributes derived from available DEM and soil survey map. We plan to test the topographic threshold concept for the combined surface-subsurface hydrology model for ephemeral gully initiation. Where gully channels already exist, we plan to test the EGEM and develop a process where both topographic threshold and EGEM-based channel hydraulics can be combined in the ephemeral gully erosion model. Since ephemeral gully is a feature resulting from processes at the 2-dimentional landscape, we anticipate the outcome will be incorporated into a process-based model such as the Water Erosion Prediction Project (WEPP) model.

References

Capra, A., Mazzara, L.M., Scicolone, B. 2005. Application of the EGEM model to predict ephemeral gully erosion in Sicily, Italy. *Catena,* 59: 133–146.

Kirkby, M.J. 1994. *Process models and theoretical geomorphology*, 11, p 221-246. John Wiley & Sons, Chichester, U.K.

Martínez-Casasnovas, J.A. 2003. A spatial information technology approach for the mapping and quantification of gully erosion. *Catena,* 50:293– 308.

Nachtergaele, J., Poesen, J., Vandekerckhove, L., Oostwoud Wijdenes. D., Roxo, M. 2001. Testing the ephemeral gully erosion model (EGEM) for two Mediterranean environments. *Earth Surf. Processes Landforms,* 26: 17–30.

Nearing, M. A., Foster, G.R., Lane, L.J., Finkner, S.C. 1989. A process-based soil erosion model for USDA-Water Erosion Prediction Project technology. *Trans. ASAE,* 32: 1587-1593.

Poesen, J., Nachtergaele, J., Verstraeten, G., Valentin, C. 2003. Gully erosion and environmental change: importance and research needs. *Catena,* 50: 91– 133.

Ries, J.B., and Marzolf, I. 2003. Monitoring of gully erosion in the Central Ebro Basin by large-scale aerial photography taken from a remotely controlled blimp. *Catena,* 50:309-328.

Vandekerckhove, L., Poesen, J., Oostwoud Wijdenes, D., de Figueiredo, T. 1998. Topographical thresholds for ephemeral gully initiation in intensively cultivated areas of the Mediterranean. *Catena,* 33: 271–292.

Vanwalleghem, T., Poesen, J., Nachtergaele, J., Verstraeten, G. 2005. Characteristics, controlling factors and importance of deep gullies under cropland on loess-derived soils. *Geomorphology,* 69: 76– 91.

Woodward, D.E. 1999. Method to predict cropland ephemeral gully erosion. *Catena,* 37: 393 – 399.

GULLY DYNAMICS: INITIATION AND MORPHOLOGY

(Keynote)

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1. Introduction

The paper reviews general conditions for initiation and maintenance of gullies.

Channel initiation is seen as a balance between infilling by diffusive processes and excavation by water-driven sediment transport. Where all material is coarse, and therefore governed by transport limited removal, then incision does not generally produce the sharp headcuts and deep incision associated with gullies. The concept of the effective bedload fraction (ebf), defined below, can be used to describe the proportion of the total sediment transport that is transport limited, and therefore acts as bedload that constrains the gully sediment budget. Where the ebf is small, gullies can cut channels at gradients less than those of the surrounding hillsides or fans into which they are cut, since they are able to remove most of the material eroded, allowing the development of characteristic sharp headcuts. Where the ebf is locally higher, for example where the gully cuts through a gravel lens, then gully gradient rises, and the depth of incision is reduced, in some cases preventing further headward extension of the gully.

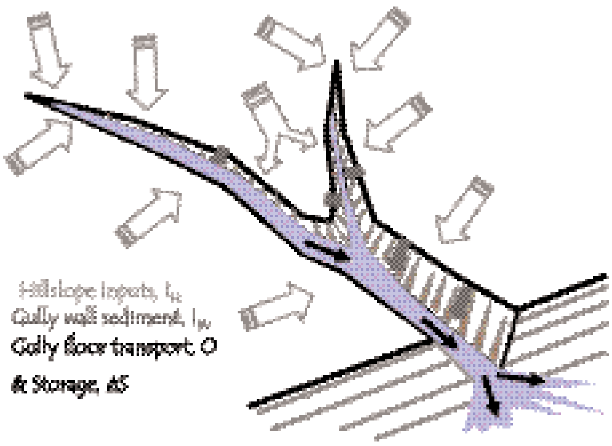

Fig. 1. Gully sediment balances: $I_H + I_W - O = \Delta S$. Sediment Delivery Ratio (SDR) = $O/(I_H+I_W) = 1/(1+\Delta S/O)$

Gullies can be initiated only where there is instability, in the sense of Smith and Bretherton (1972). For this to occur, any local incision will grow if and only if the additional flow converging on the incision is able to transport more than the additional sediment that is brought in, so that the local rate of incision exceeds the local rate of infilling. This Instability criterion can be expressed in the form:

$$\partial Q_S/\partial a > Q_S/a$$

where Q_S = sediment transport per unit width and a = area drained per unit width. In practice this criterion defines a critical distance or catchment area, beyond which fluvial transport can enlarge a proto-gully faster than rainsplash and rainwash can fill it in, coming back to Horton's (1945) critical x_c distance. However, it is also clear that this threshold distance varies from storm to storm, with smaller threshold distances in larger events, so that any current gully head position partly reflects the history of recent storms.

In addition, to form a gully, there must be accommodation space for removal of the eroded material, associated with available relief, commonly growing headward from a free face downstream/downslope; and a suitable material that can be transported by the processes active, usually sediment transport by overland flow.

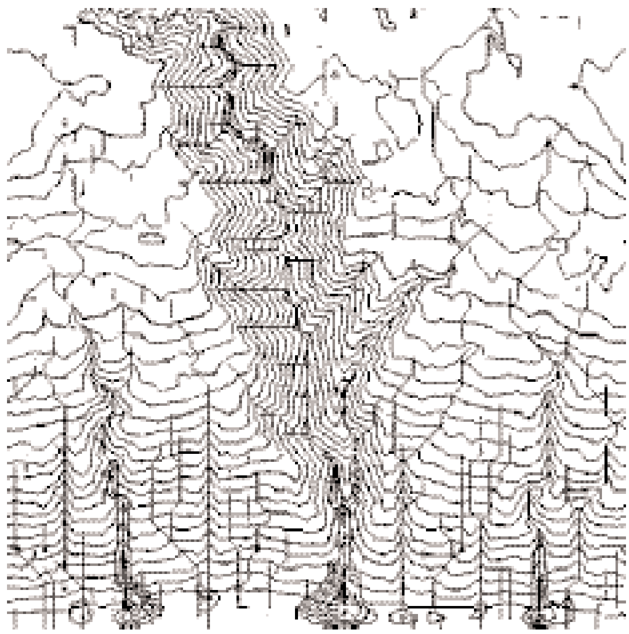

Fig. 2. Modelled gully evolution using the ebf concept (from Kirkby and Bull, 2000). Contours along bottom edge show fan deposition.

Actual sediment transport may be limited by the transporting processes, being carried at the transport capacity, and this is commonly the case for the coarsest fractions. Alternatively material may be limited by available supply, when transport is at much less than the transporting capacity, and this is commonly the case for the fines. These two concepts may be combined through defining the transport process through the two parameters of travel distance, h, and detachment rate, D. In a given flood flow, equal mobility suggests that

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the bed material is detached as a sheet, so that *D* is in proportion to the different size fractions present, but that *h* is roughly inversely proportional to grain size. The transporting capacity, *C*, for each grain size is then given by the product $C = D.h$, and can be compared with the composition of the source material, distinguishing the coarse transport-limited material from the finer supply-limited material, and so defining the (dynamically varying) effective bedload fraction. This concept is explored more fully in Kirkby & Bull, 2000., and used as a consistent basis for modelling gully evolution.

The stability criterion can then be approximately re-written as:

$$1/ebf.\ \partial C/\ \partial a > C/a$$

and this criterion becomes progressively less demanding for smaller ebf, allowing gullies to form closer to the divide, and with more pronounced headcuts (figure 2).

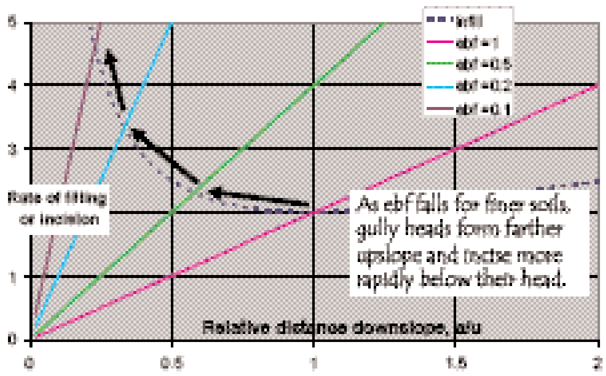

Fig. 3. Rates of initial gully enlargement for C ~ Ks. $(1+a^2/u^2)$ where s is gradient, and K, u are empirical parameters

In rough terms, the threshold grain size distinguishing bedload is usually in the range 1-5 mm, offering a rule of thumb for susceptibility to gullying.

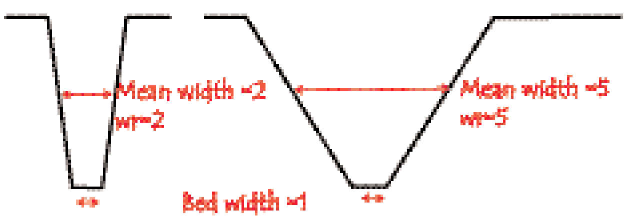

Fig. 4. Gullycross-section factors and the width ratio.

Away from the gully head, the contribution of sidewalls becomes increasingly important to the overall sediment budget, and incision is clearly limited where sidewalls have a low angle of stability. Where the ratio of average gully width to bed width is large, the much greater volumes removed during incision partially counteract the effect of a low ebf, and may prevent incision. At one extreme, the erosional feature takes the broad cross-sectional form associated with 'ephemeral gullies'. It is suggested that the product of the ebf and the width ratio (wr) of mean gully width to gully channel width (Fig 4) provides an index of overall gully response, explaining some of the features of their distribution. Differences in substrate as a gully cuts down can also be important. In some environments, the surface layers are tougher than those below. This may be due to duricrusting and/or the accumulation of a lag deposit. The effect is to provide an initially high ebf, from the surface layer, but one that drops once the surface layer is breached, and erosion in predominantly in the finer material beneath. It may therefore require an exceptional storm to breach the surface layer initially, but then allow much more rapid subsequent incision.

In conclusion, it is argued that an understanding of gully dynamics has to be based on the hydraulics of flow and sediment transport and on a consideration of grain-size specific sediment budgets, taking into account material supplied at gully heads and from their sidewalls. From these considerations, it is argued that differences in the properties of the materials incised can help us to understand the spatial distribution of gullies and their morphology.

References

Horton, R.E., 1945. Erosional development of streams and their drainage basins: hydrophysical approach to quantitative morphology. *Bulletin of the Geological Society of America*, 56, 275-370.

Kirkby, M.J. and L.J. Bull, 2000. Some factors controlling gully growth in fine grained sediments: A model applied to south-east Spain. *Catena*, 40 (2), 127-46

Smith, T.R. and Bretherton, F.P., 1972. Stability and the conservation of mass in drainage basin evolution. *Water Resources Research*, 8(6), 1506-29.

CONCENTRATED FLOW ERODIBILITY OF LOESS-DERIVED TOPSOILS: THE IMPACT OF RAINFALL-INDUCED CONSOLIDATION AND SEALING

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1. Introduction

Soil surface sealing and soil consolidation are recognized to considerably affect soil loss rates. The effect of these rainfall-induced processes on soil erosion by concentrated flow is twofold. Firstly, it is well documented how the development of a soil surface seal and the increase in soil bulk density over time reduce the saturated hydraulic conductivity and the surface roughness of the soil. As a result, both the volume and the erosivity of runoff to concentrated flow zones increases and hence sealing and consolidation are generally considered to enhance the propensity for soil erosion. Less attention has been paid to the second and counteracting effect of soil consolidation and sealing, the reduction of the soil's erodibility during concentrated runoff. Ouvry (1990) proposed the compaction of thalwegs in small agricultural catchments that are vulnerable to rill or gully incision as a low-impact soil conservation measure. The efficiency of this technique has not been tested. This study investigates the impact of rainfall-induced soil consolidation and soil surface sealing processes over time after tillage on soil erosion during concentrated flow. The soil erodibility (Kc) and critical flow shear stress (τ_{cr}) were examined for identical, artificially created soil samples under simulated rainfall. As these rainfall-induced soil structural changes are inseparably related to soil moisture variations, the effects are evaluated for different soil moisture conditions.

2. Materials and methods

Flume experiments (2 m long by 0.10 m wide) simulating concentrated runoff were carried out on remoulded, artificially created silt loam soil samples (0.36 m x 0.09 m x 0.09 m) to measure the effect of rainfall-induced soil consolidation and soil surface sealing on rill and gully initiation on loess-derived soils and to establish a relationship between soil erodibility and soil bulk density. Soil consolidation and sealing were simulated by successive simulated rainfall events (0 to 600 mm of cumulative rainfall) alternated by periods of drying (48 h).

The rate at which concentrated runoff detaches soil particles from the soil surface (Dr, kg s^{-1} m^{-2}) is usually described as a function of the shear stress applied on the soil surface by the flow (τ, Pa):

$$Dr = Kc\ (\tau - \tau_{cr})$$

where both Kc (soil erodibility during concentrated flow, s m^{-1}) and τ_{cr} (critical flow shear stress, Pa) represent the soil's erosion resistance. Soil detachment measurements at the outlet of the flume for five different applied flow shear stress levels at the inlet (3-30 Pa) were repeated for four different soil moisture contents (0.04, 0.14, 0.20 and 0.31 g g^{-1}). Kc and τ_{cr} were then derived from the regression of Dr versus τ.

3. Results

Whereas no effect of soil consolidation and sealing is observed for critical flow shear stress (τ_{cr}), soil erodibility (Kc) decreases exponentially with increasing cumulative rainfall depth (figure 1).

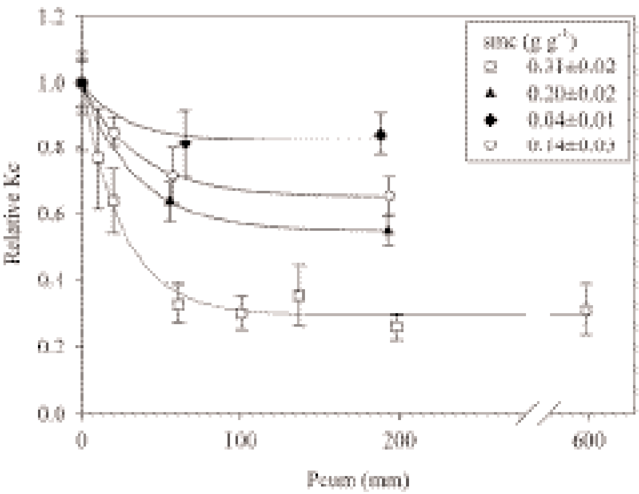

Fig. 1. The effect of cumulative rainfall depth (Pcum) on relative soil erodibility (Kc) compared to the no rainfall-treatment for four different soil moisture treatments (smc). Whiskers represent standard error of the mean.

The erosion-reducing effect of soil consolidation and sealing decreases with a decreasing soil moisture content prior to erosion due to slaking effects occurring during rapid wetting of the dry soil. Therefore, when rainfall causes erosive concentrated runoff on a consolidated soil after a dry period, the stabilizing effect of rainfall consolidation is almost nullified. After about 100 mm of rainfall, Kc attains its minimum value for all moisture conditions, corresponding to a reduction of about 70 % compared to the initial Kc value for the moist soil samples and only a 10 % reduction for the driest soil samples.

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An equation to adjust Kc values of freshly tilled soils (K_i) for the effect of cumulative rainfall depth (Pcum, mm) is developed based on the experimental results:

$$AdjKc = \frac{K_{cons}}{K_i} + \left(1 - \frac{K_{cons}}{K_i}\right) e^{-0.03 Pcum}$$

where

$$\frac{K_{cons}}{K_i} = -2.0 \ smc + 0.93$$

where AdjKc is the relative Kc value that can be used as an adjustment factor to account for consolidation and sealing, subscripts cons and i refer to respectively consolidated and initial soil conditions immediately after tillage and smc is gravimetric soil moisture content (g g^{-1}).

This relationship is validated with field data and flume measurements of soil detachment for a gradually consolidating cropland field in the Belgian loess belt. The relationship predicting relative Kc values from soil moisture content and cumulative rainfall depth predicts Kc values measured in a conventionally tilled field reasonably well (Model Efficiency=0.54; Fig. 2). For the conservation tilled field (ST in Fig. 2), the equations overestimate the consolidation effect on relative Kc values because the crop residue on the soil surface protects the soil surface from rainfall impact.

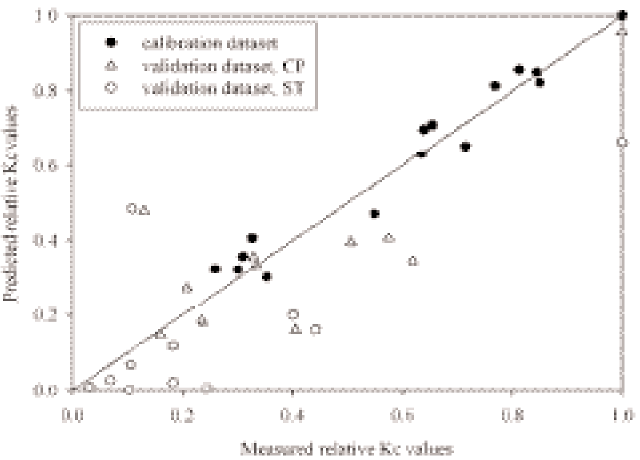

Fig. 2. Predicted versus measured relative Kc values for field data on a conventionally ploughed (CP) and shallow non-inversion tilled plot (ST).

As soil bulk density increases asymptotically with cumulative rainfall depth, Kc is also shown to decrease linearly with increasing soil bulk density (DBD) for all moisture treatments (Fig. 3):

$$Kc = 0.65 - 0.49 \ DBD \qquad (R^2 = 0.73)$$

4. Conclusions

Our results confirm a sharp decrease in soil erodibility during concentrated runoff (Kc) with increasing bulk density (Fig. 3). Yet, it is shown (Fig. 1) that the effect of soil consolidation and soil surface sealing on soil stability is largely erased when a rain event causes concentrated runoff on dry topsoil and slaking occurs. The effectiveness of thalweg compaction in reducing concentrated flow erosion rates as proposed by Ouvry (1990) thus depends on the soil moisture content prior to erosion and hence on rainfall history.

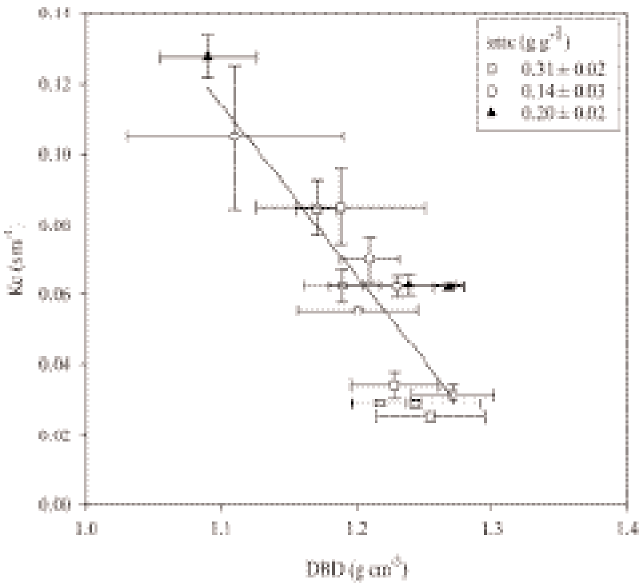

Fig. 3. Soil erodibility (Kc) as a function of dry bulk density (DBD) for different soil moisture contents (smc) prior to erosion.

Therefore, we suggest that soil compaction by multiple vehicle passages after sowing in concentrated flow zones, which can be done with low financial and labor efforts, might be used as an additional soil erosion control measure without restrictions based on catchment-characteristics. Soil bulk densities do not need to be extremely high to have a significant effect on Kc (Fig. 3) and therefore compaction can be applied without jeopardizing the viability of root penetration and vegetation development. Nevertheless, as the effectiveness of soil compaction depends on the antecedent soil moisture conditions when concentrated flow erosion occurs, it can only be considered in addition to other erosion control measures in concentrated flow zones such as establishment of grassed waterways and double drilling of the thalweg (Gyssels et al., 2007).

References

Ouvry J-F., 1990. Effet des techniques culturales sur la susceptibilité des terrains à l'érosion par ruissellement concentré. Expérience du Pays de Caux (France). AREAS-Association régionale pour l'Etude et l'Amélioration des Sols. Cah. ORSTROM, sér. Pédol 15 (1-2), 157-169.

Gyssels, G., Poesen, J., Knapen, A., Van Dessel, W., Léonard, J., 2007. Effects of double drilling of small grains on soil erosion by concentrated flow and crop yield. Soil and Tillage Research 93 (2), 379-390.

LONG TERM EVOLUTION OF INCISED COASTAL CHANNELS ON THE ISLE OF WIGHT, UK: INSIGHTS FROM NUMERICAL MODELLING

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1. Introduction

Incised coastal channels or coastal gullies are found in numerous locations around the world where the shoreline morphology consists of cliffs. The coastal gullies found on the Isle of Wight are known locally as 'Chines' and debouche (up to 45m) through the soft cliffs of the south west coast. The base level of the Chines is highly dynamic, with episodes of sea cliff erosion causing the rejuvenation of the channel network. Consequently a key factor in Chine evolution is the relative balance between rates of cliff retreat and headwards incision caused by knickpoint migration. Specifically, there is concern that if contemporary coastal retreat rates are higher than the corresponding rates of knickpoint recession, there will be long-term a reduction in the overall extent of the Chines and their associated habitats.

Despite the wealth of literature concerning incised channels in general (e.g. Schumm et al. 1984; Darby and Simon, 1999) there are only a few studies that focus on coastal incised channels (e.g. Schumm and Phillips, 1986; Burkard and Kostachuk, 1995) and only one (Flint, 1982) that specifically focuses on the incised coastal channels found on the Isle of Wight, which are the subject of this study. The lack of scientific literature concerning such features is somewhat surprising given that they are of great geomorphological significance and exhibit fundamental differences in their development compared to other incised channels. In an attempt to provide a long-term context for these issues, in this paper we explore the Holocene erosional history of the Chines using a numerical landscape evolution model. Of particular interest is the question of whether the channels are relic components of an incised channel system that has now been truncated by coastal erosion during Holocene sea-level rise, or whether the channels are actively incising in response to base-level changes forced by shoreline cliff retreat. In the case of the former scenario, ancillary questions relate to the extent to which the incision was associated with low sea-level stands or climatic shifts.

2. The study site

The incised coastal channels that are the focus of this study are located along the south west coast of the Isle of Wight, located just off the southern coast of England. The shoreline consists of soft cliffs of sands, shales and marls which vary in height from 15m to 100m and which are retreating at rates of up to 1.5m a^{-1} due to a combination of wave erosion and landslides. This coast is divided into several low-order drainage networks that flow to the sea through deeply incised valleys, known locally as 'Chines'. The combination of deep incision, which provides a sheltered environment, and unstable side-wall surfaces provides unique habitats that support a diverse range of rare flora *(Philonotis marchica, Anthoceros punctatos)* and fauna *(Psen atratinus, Baris analis, Melitaea cinxi)*. An understanding of the historical geomorphic evolution of the Chines therefore underpins the long term management of the associated biodiversity.

3. Modelling

Current landscape evolutions models do not include process representation of the interactions occurring at the terrestrial-marine boundary. In the case of the Chines it has been established that cliff retreat and sea-level change have important implications for the development of the features (Leyland and Darby, 2005), although the long term connotation of these relationships is not known.

3.1. Process representation and parameterisation

In an effort to explore these drivers of development the model GOLEM (Tucker and Slingerland, 1994, 1996, 1997) was used in conjunction with custom codes that perform the various supplementary functions of interest. These included a cliff recession function that controls the position of the Chine outlet boundary, a sea level change routine and a climate change module, observable in the model as a dynamic effective precipitation value. Although cliff retreat rate is governed by a mean user defined value, actual recession events occur stochastically. Sea-level rise in the area is well documented throughout the Holocene (e.g. Waller and Long, 2003), however climate change is not and in order to obtain a dataset spanning the Holocene, average rainfall from the last 50 years was multiplied by a normalised climate index as derived by Coulthard et al. (2002). GOLEM simulates knickpoint recession in the Chines using a detachment-limited channel erosion law (1) wherein erosion rate (E) is a power function of drainage area (A) and stream gradient (S) with model parameters (k, m and n) defined using empirically-derived data.

$$E = kA^{m}S^{m} \quad (1)$$

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The model also includes representation of mass wasting processes such as threshold landsliding, a mechanism of widening observed to occur in the Chines as a response to channel incision.

3.2. Model setup

A MATLAB script was written that controlled the run time and parameter setup for GOLEM, as well as calling a user defined combination of the custom process functions. A typical model loop thus consisted of running GOLEM for a short time (e.g. 50 model years), then operating a combination of one, two or all of the custom functions before running GOLEM again with the updated inputs and parameters. The loop was then repeated until a pre-defined model run time (in the following scenarios 10,000 years) was reached.

4. Results

In order to explore the Holocene evolution of the Chines a range of scenarios relating to the key drivers (cliff recession and climate change) of their development were modelled. The simulation in which realistic conditions were reproduced (Fig. 1) broadly replicated observed incised coastal channel morphologies. This suggested that a degree of confidence could be placed in the modelling process and the next stage was to begin to elucidate which of the combined drivers exerted the most significant control on the formation of the features.

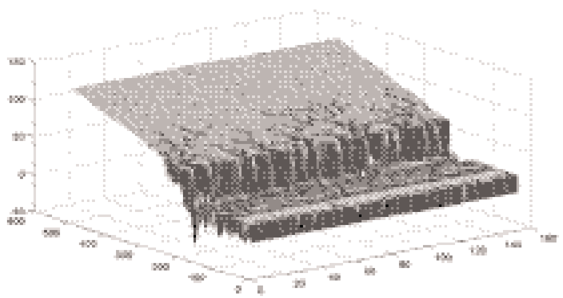

Fig. 1. Scenario 1: Realistic Holocene changes in sea-level rise, cliff retreat and climate variation.

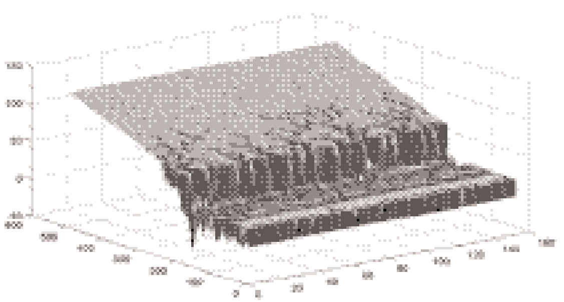

Fig. 2. Scenario 2: No coastal erosion and half the realistic effective precipitation.

A scenario matrix was devised that allowed the effects of parameter value changes in a single process function and across a combination of the three to be evaluated. Fig. 2 reveals that a 50% reduction in the effective precipitation throughout the Holocene inhibits the development of the gully network, as does an increase in the rate of cliff recession (Fig. 3). In the latter case the gullies are destroyed as they cannot incise at a rate equal to or greater than that of the cliff recession.

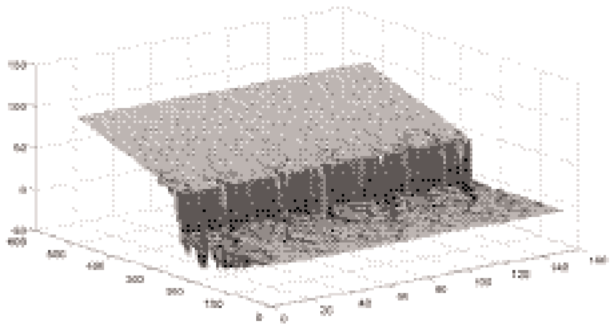

Fig. 3. Scenario 3: Constant effective precipitation of 10^3mm a^{-1} with cliff erosion of 1m a^{-1}.

5. Conclusions

Moderate rates of effective precipitation induce a realistic incised channel network, providing there is a step cliff profile present. Such a step profile is shown to be produced by sea-level rise and associated cliff retreat, however the modelling reveals that high rates of cliff retreat destroy the networks.

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References

Burkard, M.B. and Kostaschuk, R.A., 1995. Initiation and evolution of gullies along the shoreline of Lake Huron. *Geomorphology, 14*: 211-219.

Coulthard, T., Macklin, M.G. and Kirkby, M.J., 2002. A cellular model of Holocene upland river basin and alluvial fan evolution. *Earth Surface Processes and Landforms, 27*: 269-288.

Darby, S.E. and Simon, A., 1999. *Incised river channels: Processes, forms, engineering and management.* Wiley, Chichester, 424 pp.

Flint, K.E., 1982. Chines on the Isle of Wight: Channel adjustment and basin morphology in relation to cliff retreat. *The Geographical Journal, 148*(2): 225-236.

Leyland, J. and Darby, S.E., 2005. An empirical-conceptual model for the formation and evolution of incised coastal channels: The `Chines' of the Isle of Wight, England. *Eos Trans. AGU, Fall Meeting Supplement*, H53D-0513, 86(52).

Schumm, S.A., Harvey, M.D. and Watson, C.C., 1984. I*ncised channels: Morphology, dynamics and control.* Water Resources Publications, Chelsea, Michigan, 200 pp.

Schumm, S.A. and Phillips, L., 1986. Composite channels of the Canterbury Plain, New-Zealand - a Martian analog. *Geology, 14*(4): 326-329.

Tucker, G.E. and Slingerland, R., 1994. Erosional dynamics, flexural isostasy, and long-lived escarpments: A numerical modeling study. *Journal of Geophysical Research- Solid Earth, 99*(B6): 12,229-12,243.

Tucker, G.E. and Slingerland, R., 1996. Predicting sediment flux from fold and thrust belts. *Basin Research, 8*(3): 329-349.

Tucker, G.E. and Slingerland, R., 1997. Drainage basin responses to climate change. *Water Resources Research, 33*(8): 2031-2047.

Waller, M.P. and Long, A.J., 2003. Holocene coastal evolution and sea-level change on the southern coast of England: A review. *Journal of Quaternary Science, 18*(3-4): 351-359.

GULLY EROSION IN MOUNTAIN AREA OF SW-CHINA, ASSESSED USING ^{137}CS AND ^{210}PBEX TRACERS AND GPS SURVEY

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1. Introduction

Gullies are extensively distributed in the Upper Yangtze River Basin, SW-China. But the impact of these gullies on total sediment output is still not clear because there is no reliable technique for quantifying this issue. The target areas of our research are the dry-valleys located in the upper Yangtze River Basin, SW-China. Our study objectives are to: a) quantify gully erosion rates as affected by land use change over the last 100 years, and b) to assess relative importance of different erosion types including gully and rill or sheet erosion in sediment production in selected gully catchments.

2. Study area and methods

Our investigations were carried out in the Anning Warm-Dry Valley of southern Sichuan in the territory of Xichang. We selected Changshanling catchment for our objectives. We measured the gully system using RTK-GPS and established Digital Elevation Mode (DEM) of the gully catchment, and proposed a method for extract the active gully system from the established DEM in frame of GIS (See Fig. 1). Sediment production by gully was estimated from DEMs based on RTK-GPS survey data. By establishing a sediment chronology within the gully systems using 137Cs and 210Pb dating we intended to develop a relationship between gully development and the history of gully catchment land use. Sediment production by rill or sheet erosion on slope of the catchment was estimated by the combined use of fallout ^{137}Cs and ^{210}Pb measurements.

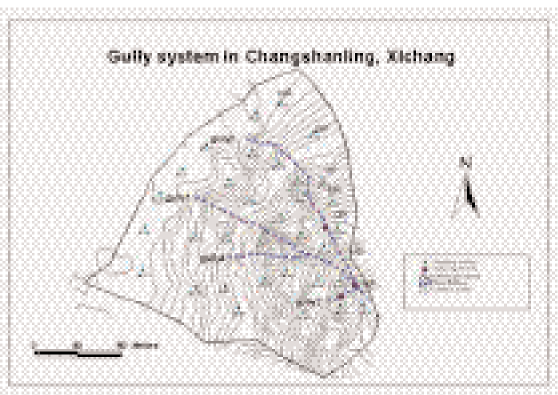

Fig. 1. Field sampling map in Changshanling of SW-China.

3. Results and conclusions

Reference values of ^{137}Cs and ^{210}Pbex inventories were calculated to 802±49 Bq/m2 and 7823±1382 Bq/m^2, respectively, for the Majiasongpo catchment, and 916±75 Bq /m^2 and 6642±1303 Bq/ m^2, respectively, for the Changshanling catchment (Figs. 4-5). The coefficients of variation (CV, %) for 25 sampling sites were in range of 23-33% for ^{137}Cs and 21-25 for 210Pbex in the upper Yangtze River Basin, SW-China. The depth-incremental profiles of both fallout ^{137}Cs and ^{210}Pbex in reference sites shows a typical exponential decrease with soil depth, and majority of the 137Cs and 210Pbex is concentrated within the top layers of 0-10 cm.

Our results from caesium-137 and unsupported lead-210 dating provide direct evidence that gully initiation occurred in 1920's, which consistent with extensive deforestation by fire in the study area. Caesium-137 and only existed only in top 5 cm soils and ^{210}Pbex only in topsoil of 15 cm measured in the hillslopes suggested that the study gully catchment have not been cultivated over the last 200 years. The accelerated gully erosion may therefore arise from intensive grazing activities. This finding is opposite of the assumptions made by Bork et al (2001). Bork et al (2001) proposed that the grazed hill slopes were replaced by agricultural terraces in 1965. Evidently, fallout radionuclide dating may provide an independent tool for identification of past land uses. Local culture and history records were also analyzed, interviewing senior experts and farmersto givea more detailed reconstruction of land use history.

Results indicated that the gully density in Changshanling was 46.7m/hm^2, and annual sediment production by gully erosion ranged from 6 to 110 t/ha, averaging 61 t/ha/yr. Average sediment yield by sheet erosion was 26.42 t/ha/yr, nearly three times lower than gully erosion in the study catchment Gully erosion with 12% of total area represented 87% of total sediment yield whereas sheet erosion with 87% of total area accounted for 13% of the total soil loss in the study catchments (Tables 1-2). Our results suggested that gully erosion is the major sediment sources and the dominant water erosion process in the Upper Yangtze River Basin, SW-China.

The following conclusions could be drawn from our investigation: a) Stable gullies widely distributed in Changshanling mountain areas of .SW-China occurred in

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the years between 1930 and 1950, b) Gullies presented 80-90% of total sediment production, suggesting the dominance of water erosion processes in contributing sediment for SW-China, c) The active gullies on the planted forestland without understorey primarily result from intensive grazing and water buffalo trampling in the last 50 years, and d) Topographic threshold conditions for gully initiation in forest and grassland can be described using the following relation of a critical upslope drainage area (A) and a the critical slope gradients (S): $S\ A^{0.4145} > 0.1585$. These results provide reliable data on the long-term impacts of land use on soil erosion in western China, and add a new issue for global change studies.

Table 1. Gully parameters of Cahngshanling gully catchment estimated from ^{137}Cs and excess ^{210}Pb dating and RTK-GPS survey.

Gully Parameters	Unit	Gully 1	Gully 2	Gully 3	Gully 4	Total
Volume	m^3	5841	327	4560	844	11572
Gully area	ha	0.26	0.04	0.23	0.07	0.60
Length	m	212	36.3	137	51	436
Average depth	m	2.44	1.24	3.43	1.49	--------
Max. depth	m	11	4.1	22.1	6.53	--------
Average width	m	12	11	17	14	--------
Max. width	m	26	19	27	18	--------
Catchment area	ha	0.72	0.53	1.1	1.15	3.5
Average slope	degree	37.62	21.21	24.71	36.56	------
Max. slope	degree	72.4	30.1	47.54	57.6	--------
Sediment yield	t	7709	432	6019	1114	15275
Eroded time	yr	70	70	50	50	
Gully erosion	t/ha-yr	110.14	6.17	109.44	19.38	60.76

Note: An average bulk density of 1.32 g cm^{-3} from measurements was used for calculation of sediment yields and gully erosion rate, and small gullies were not included in this calculation.

Table 2. Relative contribution of gully erosion derived from ^{137}Cs and excess ^{210}Pb dating and GPS-survey for Cahngshanling gully catchment

		Area ha	Contribution to total area (%)	Contribution to total sediment (%)
Gully		0.6	11.90	87.02
Sheet erosion	Loss	2.65	52.58	12.98
	Gain	1.79	35.52	

Note: Several major gullies in Changshanling catchment were not included in this calculation for gully erosion.

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References

Bork, H.R., Li, Y. Zhao,Y. 2001. Land use changes and gully development in the Upper Yangtze River Basin, SW-China. Journal of Mountain Science, 19: 97-103.

Cheng, H., Wu,Y.Q., Zou,. X.Y. Study of ephemeral gully erosion in a small upland catchment on the Inner-Mongolian Plateau. Soil & Tillage Research 90 (2006) 184–193.

Desmet, P.J.J., Poesen, J., Govers, G.. and Vandaele, K., 1999. Importance of slope gradient and contributing area for optimal prediction of the initiation and trajectory of ephemeral gullies. Catena, 37:377-392.

Fu, B., Chen, L., Ma, K., Zhou, H., Wang, J., 2000. The relationships between land use and soil conditions in the hilly area of the loess plateau in northern Shaanxi, China. Catena 39, 69 –78.

Li. Y., Poesen, J., Valentin, C. (eds.) 2004. Gully Erosion Under Global Chang .Sichuan Science Technology Press, Chengu ,China .354 pp.

Li, Y., Zhang, Q. W., Reicosky, D. C., Lindstrom, M. J., Bai, L. Y,.and Li L. 2007. Changes in soil organic carbon induced by tillage and water erosion on a steep cultivated hillslope in the Chinese Loess Plateau from 1898–1954 and 1954–1998, J. Geophys.Res., 112, G01021, doi:10.1029/2005JG000107.

Li, Y., Poesen, J., Yang, J. C., Fu, B., and Zhang, J. H. 2003. Evaluating gully erosion using 137Cs and $^{210}Pb/^{137}Cs$ ratio in a reservoir catchment, Soil Tillage Res. 69, 107– 115.

Nachtergaele, J. & Poesen, J. 1999. Assessment of soil losses by ephemeral gully erosion using high altitude (stereo) aerial photographs. Earth Surface Processes and Landforms, 24:693-706.

Poesen, J., Nachtergaele, J., Verstraeten, G. & Valentin, C. 2003. Gully erosion and environmental change: importance and research needs. Catena 50 (2-4):91-133.

Poesen, J.W.A. & Hooke, J.M. 1997. Erosion, flooding and channel management in Mediterranean Environments of southern Europe. Progress in Physical Geography 21 (2):157-199.

Ritchie, J.C. and J.R. McHenry. 1990. Application of radioactive fallout 137Cs for measuring soil erosion and sediment deposition rates and patterns: A review. J. Environ. Qual. 19: 215-233.

Valentin, C. J. Poesen and Y. Li. (Eds.) Gully erosion: A Global Issue. Catena 63 (2005) 129–330. (Special Issue)

A PROPOSAL TO STUDY GULLY EROSION ON SILICA SAND AND ARKOSE SLOPES IN CENTRAL SPAIN

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1. Introduction

A research project to be developed, granted by the Spanish Minister of Education and Science (project CGL2006-07207), aims to investigate gully erosion on silica sand and arkose slopes in Central Spain. The period of the study is from January 2007 to December 2009. In this abstract, we present the objectives and beginning of the this research project.

2. Geology and landforms

Two areas have been chosen to study gully erosion and sediment movement at the North Slope of the Guadarrama Mountains, in the Central System of the Iberian Peninsula (Segovia Province, Castille and Leon Region, Spain).

The first area is underlain by silica sand, shale and gravel sediments of Upper Cretaceous age. They form a depositional sequence, approximately 70 m thick, bounded by two erosional surfaces. The silica sands consist, mainly, of quartz, with a less proportion of feldspar and mica, these latter transformed to kaolin and smectite. These sediments are described as braided fluvial deposits and coastal fan deltas deposits (ITGE, 1991). The landforms under study are gullies and badlands underlain by the sediments above described. They occur on slopes of mesas and cuestas, capped by more resistant rocks, limestones and dolostones. Platforms and slopes of these mesas and cuestas are covered by a mixed holm oak and juniper forest, which is now recovering from centuries of overgrazing (Fig. 1).

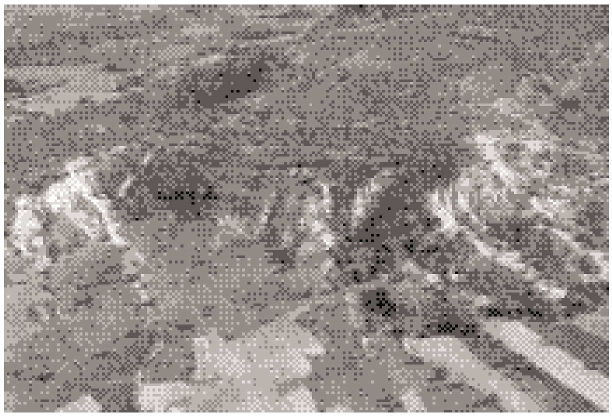

Fig 1. Aerial view of the gullies developed on silica sand slopes (in: Díez and Martín Duque, 2006).

The second area is underlain by arkosic sand sediments, with pebbles, cobbles and boulders of granite, gneiss and quartz, of Miocene age (ITGE, 1990). These sediments were formed in alluvial fan systems, emerging from the uplifting of the Guadarrama Mountain range to the south (ITGE, 1991). The landscape is characterized by dry cereal crops on rolling uplands, only dissected by the actual fluvial system. At the slopes of the valleys, gullies are developed (Fig. 2).

Fig 2. Aerial view of the gullies developed on arkosic slopes (in: Díez and Martín Duque, 2006).

3. Research proposal

With this project, we mainly intend to characterize and quantify, in terms of type of activity, velocity and frequency, the active geomorphologic processes operation in the referred gullies. Specifically, we aim to:

1) Understand the origin and development of these gullies, and their evolution in historical times, since it has no been explained yet if they have a natural or human-induced origin.
2) Study their evolution in recent times (1946 to the present, through series of aerial photographs), in order to determine if the gullies are growing, shrinking, or have stabilized.
3) Characterize and quantify their current functioning, by establishing which geomorphologic processes are eroding and mobilizing the sediments within the gullies. What is the degree of activity, and the speed at which the processes of water erosion, piping, mass movements, and sediment transportation operate? To

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do so we intend to follow these approaches: (1) various dendrogeomorphic techniques to measure the amount and rate of both erosion of the interfluves and sedimentation in the collector drainages. In this respect, our team has already the experience and expertise of quantifying sheet erosion rates from the analysis of exposed Scots pine roots (Bodoque et al., 2005). (2) Installation of rods, erosion pins, pedestals and micro-profile devices to measure small changes in the topography of the gullies by both water erosion and mass movement. (3) Installation of sediment traps in the dry washes, to measure the amount of sediment yield. (4) Instrumentation to measure knickpoint migration within collector washes. (5) Detailed topographical surveys to quantify the modification of the area of the gullies' watersheds and mass movement processes within the gullies.

4) Identify the effects that the various distinct meteorological regimes have on the movement of sediment. By installing weather stations, and modelling the watersheds, to investigate the causes and frequencies of geomorphic activity. What season of the year produces the most erosion and transportation of sediment? What is the relation between meteorological conditions and distinct geomorphic processes and rates?
5) Determine how these processes affect vegetation dynamics. The presence of unstable substratum and the variation that occurs on the nature of the soil, once the gullies are formed, have striking effects on the vegetation.
6) As the main conclusion of the project, we intend to propose a model for the origin and development of the gullies, to explain in detail their geomorphic activity, and to determine the implications for the environmental management of the area.
7) Last but not least, we are interested on obtaining applicable conclusions for the land reclamation of mines and quarries on these terrains. Moreover on silica sand mines, common in the region. In the first area, there is a reclaimed silica sand mine, benefited from existing gullies, which reclamation project was developed by us, based on a geomorphic approach (Martín-Duque et al., 1998). Being able to integrate the knowledge of the gully dynamics with the reclaimed mine system would result in a highly potential for ecological restoration applications of this type of mining.

4. The beginning of the research project

It is our intention to start monitoring the geomorphic activity in the first place (objective 3), so that we can start gathering data, systematically, at the beginning of the 2007-2008 hydrological year (October 1st, 2007). In parallel with the gathering of the data, objectives 1 and 2 will be tackled. In order to assess the most suitable locations for starting the systematic monitoring of the geomorphic activity and sediment movement within the gullies, a detailed inventory of landforms and processes is being carried out during the first months of 2007. The inventory is being conducted by: (1) using a specific form, which includes information on physiography, morphometry, signs of active geomorphic processes, signs of stability (description of soils and vegetation) and the potential for installing devices to measure geomorphic activity (all that for each gully); (2) depicting detailed geomorphological sketches of the gullies. Simultaneously, a relational database connected to a geographical information system (GIS) is being constructed. The database provides the form information, along with graphical images (photos and sketches).

5. First assessment of scale of sediment movement

During the time that this proposal was elaborated, and during the beginning of the project, a first assessment of geomorphic activity within the gullies has been studied. The aim was to see what scale of sediment movement we will be working with. Therefore, a series of rods were driven into the ground of different dry washes of both areas, each one with washers levelling the bottom of the dry wash. Measurements were carried out after each storm or precipitation event. A two-year observation period now shows the following pattern of sediment movement: (a) *winter*, snowmelt processes are able to move high amounts of sediment trough the dry washes, with the deepening of the bottom of the gullies reaching depths up to 20 cm; (b) *spring*, hardly sediment movement through the beginning of the season, but the storms of May and June trigger the most intense geomorphic activity and sediment movement processes; intense storms on May 2007 produced the deepening of some drywashes up to 50 cm, and the formation of alluvial cones in almost each silica sand gully, some of them filling local roads with sand; (c) *summer*, general geomorphic inactivity; (d) *autumm*, low intensity of erosion and sediment movement.

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References

Bodoque, J.M., Díez, A., Martín Duque, J.F. et al. 2005. Sheet erosion rates determined by using dendrogeomorphological analysis of exposed tree roots: two examples from Central Spain. *Catena, 64*:81-102.

Díez, A. and Martín Duque, J.F. 2006. *Las raíces del paisaje.* Junta de Castilla y León, Valladolid.

ITGE, 1990. *Mapa Geológico de España 1:50.000 (El Espinar, 507)*. Instituto Tecnológico Geominero de España, Madrid.

ITGE, 1991. *Mapa Geológico de España 1:50.000 (Pradena, 458)*. Instituto Tecnológico Geominero de España, Madrid.

Martín-Duque, J.F., Pedraza, J., Díez, A., Sanz, M.A. and Carrasco, R.M. 1998. A geomorphological design for the rehabilitation of an abandoned sand quarry in central Spain. *Landscape and Urban Planning*, *42*:1-14.

A COMPARISON OF ANTHROPOGENIC AND LONG-TERM SOIL EROSION ON BANKS PENINSULA USING ^{137}CS AND KAWAKAWA TEPHRA

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1. Introduction

The task of this study is to assess the severity of anthropogenically induced soil erosion on a loess-mantled hillslope on the foothills of Banks Peninsula, South Island, New Zealand. The analysis is restricted to a slope segment representative for the soil creep-type processes that dominate on convex soil-mantled hillslopes which satisfy the assumptions of the soil erosion measurement techniques employed.

Convex hillslopes evolve through slope-dependent transport processes, such as creep, resulting from disturbance by expansion and contraction due to freeze-thaw, wet-dry and hot-cold cycles, by biologic activity, or – perhaps most significant for the current processes – by rain splash. The region has experienced climate changes and, consequently, changes in vegetation cover from forest to shrub vegetation and grassland (Shulmeister, 1999).

To quantify long-term (natural) and short-term (anthropogenically induced) erosion rates tracers within the soil are used. The thickness of soil above a ca. 26,500 year old tephra and an inventory of the amount of that tephra are used to determine the long-term rate across a convex hillslope, from the interfluve to the midslope. An inventory of bomb-fallout ^{137}Cs is used to determine short-term rates over the same hillslope. A slope dependent transport model is parameterised to encapsulate transport efficiency relevant to the short and long time scales, and the parameters used as a basis for comparing soil erosion rates at different time scales. Comparing the results of the two different surveys, a statement is made whether the actual occurring erosion of soil under grass vegetation cover is higher than that under natural vegetation of the last 26,500 years.

2. Study Area

The hillslope chosen for this project is located on the loess-covered foothills in the west of Banks Peninsula, in the surroundings of Taitapu, in the South Island of New Zealand. The peninsula has been heavily eroded, and along the outer flanks steep-sided valleys have been incised and/or exhumed. These valleys, in combination with big gullies cut into the hillslopes, give Banks Peninsula the appearance of a largely dissected surface with a general radial drainage pattern. Thereby, the rather low gradients of the radially diverging ridges contrast with the steep walls of the valleys.

The study site is a convex hillslope situated on a north aspect of a long ridge running in NE-SW direction. The hillslope transect studied was restricted to the upper convex slope segment from the interfluve to the upper backslope. This section of the slope is characterised by low profile curvature and limited micro-topography. This restriction has been made because the soil creep-type processes presumed to dominate here (Gilbert, 1909; Dietrich et al., 2003) satisfy the assumptions of the ^{137}Cs erosion measurement techniques employed. Below the upper backslope, tunnel-gully erosion predominates and soil erosion rate is likely to be highly spatially and temporally variable.

3. Methodology

Long- and short-term erosion rates for the study area were quantified as follows:

- The hillslope transect was surveyed topographically at high resolution.
- Five sites were sampled along the transect and analysed for ^{137}Cs and tephra distribution and concentration. ^{137}Cs reference sites (uneroded) were sampled on the interfluve.
- Short-term and long-term erosion rates were calculated for each site, using ^{137}Cs profile inventory, tephra grain inventory, and depth to tephra emplacement horizon.
- A slope dependent transport model was parameterised to encapsulate transport efficiency relevant to the short and long time scales, and the parameters used as a basis for comparing soil erosion rates at different time scales.

4. Modelling soil transport and erosion rate

The convex form of soil-mantled hillslopes results from slope-dependent soil transport (Gilbert, 1909), modelled one-dimensionally as

$$q_s = -K \cdot \frac{\partial z}{\partial x}, \qquad (1)$$

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where $\vec{q}_s$ is sediment flux [m² m⁻¹ yr⁻¹], K the transport rate constant [m² yr⁻¹], $\partial z/\partial x$ the local hillslope gradient, z is elevation [m], and x the horizontal distance [m]. The one-dimensional form of the equation is used for clarity. The argument can be extended simply to the two-dimensional case.

As sediment flux on steep slopes tends to increase nonlinearly (Roering et al., 1999), this model is appropriate only for low-gradient (< 0.4) hillslopes (Roering et al., 2002). Combining equation (1) with the one-dimensional continuity equation,

$$E = \frac{\partial z}{\partial t} = \frac{\partial \vec{q}_s}{\partial x}, \qquad (2)$$

where E is erosion rate [m yr⁻¹], z is elevation [m], t is time [yr], $\vec{q}_s$ the sediment flux [m² m⁻¹ yr⁻¹], and x is horizontal distance [m], gives

$$\frac{\partial z}{\partial t} = K * \frac{\partial^2 z}{\partial x^2}, \qquad (3)$$

where $\partial^2 z/\partial x^2$ is local hillslope curvature.

This relationship indicates that erosion is proportional to local hillslope curvature, enabling to quantify variability in erosion rates, when coupled with the topographic survey of the hillslope. Thereby K is a constant of proportionality, the transport coefficient. This coefficient captures the efficiency of soil erosion, or the power of transport processing acting on the slope. A change in this parameter over different time scales is, therefore, a reflection of changes in intensity of erosion, as long as the slope dependent transport model is appropriate.

K can be estimated from the slope of a best fit line to a plot of erosion rate versus local hillslope curvature, or alternatively multiple values of K can be estimated from differences in erosion rates and curvatures from pairs of sites:

$$\Delta E_{ij} = K * \Delta C_{ij}, \qquad (4)$$

where ΔE_{ij} is the difference in erosion rate between sites i and j [m yr⁻¹] and ΔC_{ij} the difference in curvature between sites i and j [m⁻¹].

5. Results and discussion

Long-term erosion rates, as quantified by tephra distribution along the hillslope, appear to be proportional to hillslope curvature, confirming the appropriateness of a slope dependent transport model. The transport coefficient calculated over the long term ($K_{long} = 0.0032 \pm 0.0007$ m² yr⁻¹) is in the range of the estimates in similar studies (Roering et al., 2002; Walther, 2006).

Any difference between long- and short-term erosion rates would be captured in differences in K_{long} and K_{short}. Unfortunately, the level of variability of the ^{137}Cs-based short-term erosion rates does not allow an assessment of the appropriateness of the slope-dependent transport model over the short term, and it prevents a meaningful estimate of K_{short} being made. An analysis of power of the regression analysis suggests as many as 20 observations would be necessary to determine a statistically significant slope (at 95 % confidence) when K_{short} is approximately equal to K_{long}. If K_{short} was higher, fewer observations would be necessary.

Actually, rather than on the upper part of convex hillslopes, significant erosion processes seem to be concentrated in areas of tunnel-gullies on the lower backslopes and incised valleys on the ridges of Banks Peninsula. These tunnel-gullies are propagating back up and lead to evident soil loss. To quantify the dimension of this soil loss, further studies either on the same ridge or on similar ridges should be carried out using e.g. the above mentioned techniques or the volumetric analysis of the sediment fan at the outlet of a gully. This would also enable to get more insights in the sediment yield of such a ridge and probably in the quantitative relation between soil loss on the upper backslope and in the gullies.

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References

Dietrich, W.E., Bellugi, D.G., Heimsath, A.M., Roering, J.J., Sklar, L.S., Stock, J.D. 2003. Geomorphic transport laws for predicting landscape form and dynamics. Prediction in Geomorphology. *Geophysical Monograph 135*, © 2003 by the American Geophysical Union.

Gilbert, G.K. 1909. The convexity of hilltops. *Journal of Geology 17*:344-350.

Roering, J.J., Kirchner, J.W., Dietrich, W.E. (1999). Evidence for nonlinear, diffusive sediment transport on hillslopes and implications for landscape morphology. *Water Resource Research 35*(3):853-870.

Roering, J.J., Almond, P., Tonkin, P., McKean, J. 2002. Soil transport driven by biological processes over millennial time scales. *Geology 30*(12):1115-1118.

Shulmeister, J., Soons, J.M., Berger, G.W., Harper, M., Holt, S., Moar, N., Carter, J.A. 1999. Environmental and sea-level changes on Banks Peninsula (Canterbury, New Zealand) through three glaciation-interglaciation cycles. *Palaeogeography, Palaeoclimatology, Palaeoecology 152*:101–127.

Tufts University (2006). *Banks Peninsula*. Photo retrieved September 26, 2006, from http://www.tufts.edu/~crogers/NZ/Akaroa.png.

Walther, S.C. 2006. *Quantifying biogenic sediment transport on a forested, loess- mantled hillslope in the Blue Mountains, eastern Washington*. Masters Thesis, University of Oregon, U.S.A..

GULLY DEVELOPMENT IN AGRICULTURAL FIELDS: INSIGHTS FROM CATCHMENT SCALE ANALYSIS

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1. Introduction

In recent years, soil erosion has become an important topic in the local, national and international decisions maker's agenda (Van Rompaey et al. 2003). Specifically, soil erosion by water is a major environmental problem (Fernandez et al. 2003), that worsens through intensive agricultural activity, soil degradation and heavy rainfall events (Amore et al. 2004). Gully erosion is one of the most effective mechanisms that cause damage to agricultural areas all over the world (Casalí et al. 2006), especially in Mediterranean and semiarid environments (Poesen et al. 2003). The need to estimate soil loss potential due to gully erosion, in large agricultural areas, is therefore well recognized (Amore et al. 2004). However, reliable estimations of gully development require understanding of the factors that influence gully development including physical conditions and human activities (Valcárcel et al. 2003). The effect of physical factors on gully head position and gully development is widely studied (Valentin et al. 2005) while most of these studies have used empirical approaches mainly in the plot/local scale. However, despite the fact that human activities have become the key contributing factor to regional soil erosion, still, most current prediction models have been unable to discern this effect on gully development (Ni and Li 2003).

Our *aim* is to study the combined effect of human-induced activity and the physical environmental conditions on gully development in a small agricultural catchment in Northern Israel. More specifically we address the following objectives: 1) to test inter-correlation between physical factors and human activities; 2) to quantify effects of physical and human factors on gully development; 3) to use GIS-based model to predict gully development; 4) to test our model against existing topographic threshold model.

2. Study area

The study area is a sub-catchment in the Harod River Basin, located in Northern Israel (Fig. 1). Catchment area is 13 km^2 and the slope range of cultivated fields is 0-28°. Agricultural land-uses are mainly field crops and orchards. The climate is of a transition zone between Mediterranean and semi arid with annual rainfall depth of 450 mm and potential evaporation is 170 cm. The soils are alluvials (vertisols) in the center of the study area and colluviums in the margins. Topsoils texture is generally clay. Organic matter ranges between 4.8 and 7.6%.

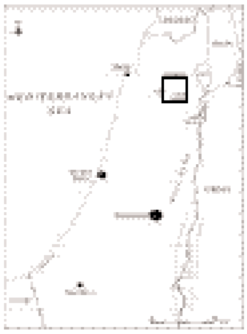

Fig. 1. Location of the study area.

3. Methods

3.1. GIS database design

Five physical and human activity factors were selected.

Physical environment: A contour-based digital elevation model was extracted from a topographic map of the Survey of Israel with 5-meters interval. Three layers were calculated from the DEM: slope, aspect and upslope contributing area. Saturated hydraulic conductivity was measured in a field survey: 72 Samples were analyzed for particle size distribution using hydrometer method and texture data were calculated. Organic matter for each soil sample was determined by LOI method. Texture data and organic matter placed into a SPAW Hydrology program, to determined soil water characteristics. The saturated hydraulic conductivity data was interpolated as raster layer based on the study area soil formation map.

Human activities: Tillage directions were coded from January 2003-air photo. To express their effect on erosion potential, we used Ganskopp cosine cost function (Ganskopp et al. 2000):

$$\cos t = \text{slope}^{f} \quad (1)$$

$$f = \cos^2 a \quad (2)$$

where *f*- is the effective friction, *a*- is the angle between the aspect and tillage direction. The unpaved roads were digitized from 2003 air photo. Tripled rings buffer of 30, 60 and 90 meters were produced down-slope to the unpaved roads.

3.2. Model approach

We used fuzzy logic (Openshaw & Openshaw 1997) to model vulnerability to gully development. For each variable, membership function (MF) was selected to express its effect on vulnerability (Table 1).

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Table 1. The variable and the matching memberships' functions and relevant weights for the linear joint membership function. Where P_{min} and P_{max} are the minimum and maximun threshold values and x is the value at the i,j location.

Attribute	Id	MF type	MF	Weight
Saturated Hydraulic Conductivity	MF1	Sigmoidal	$\cos^2\left(\left(\frac{x-P_{min}}{P_{max}-P_{min}}\right)\cdot\left(\frac{\pi}{2}\right)\right)$	0.33
Slope	MF2	Sigmoidal	$1-\cos^2\left(\left(\frac{x-P_{min}}{P_{max}-P_{min}}\right)\cdot\left(\frac{\pi}{2}\right)\right)$	0.34
Flow Accumulation	MF3	Linear	$1-\frac{P_{max}-x}{P_{max}-P_{min}}$	0.33
Tillage direction	MF4	Sigmoidal	$1-\cos^2\left(\left(\frac{x-P_{min}}{P_{max}-P_{min}}\right)\cdot\left(\frac{\pi}{2}\right)\right)$	0.5
Roads	MF5	Categorial		0.5

To produce a vulnerability map, for each of the factors (physical environment, human activities, and combined model), we used the convex combination operation (Svoray et al. 2004). Equation (3) shows predictions for the combined effect of the two factors (values between 0-1):

$$JMF = MF1\cdot 0.2 + MF2\cdot 0.2 + MF3\cdot 0.2 + MF4\cdot 0.2 + MF5\cdot 0.2 \qquad (3)$$

3.3. Model validation

Visual interpretations of air photos, field and laboratory measurements were used to validate and test the models.

Air-photos were interpreted to identify gullies and gully heads from 2003 and 2006 and maps were digitized. Buffers around the gullies and the gully heads were operated and local slope, contributing area and length were calculated. Depth and width were measured in the field for a sample of 21 gullies.

4. Results

Fig. 2a shows that in the physical model even areas of low scores are still covered by large number of gullies. The model that reflects the effect of human activities alone (fig. 2b) can not fully explain the phenomena either. However, the combined model (fig. 2c) could produce better predictions of both initial points and gully development.

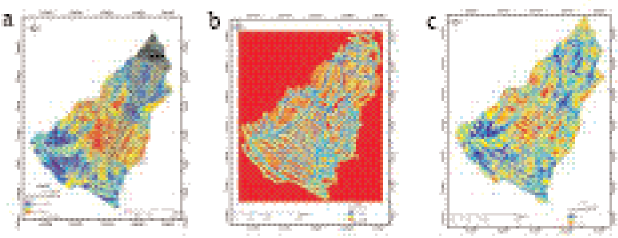

Fig. 2. The sub-models (a- physical; b- human; c- combined). Results and the existing gullies in the study area, that were generated from 2003 air-photo.

Visual interpretation of 76 gully heads was used to test the models by comparing their fuzzy membership scores (fig. 3). The results show that by adding the human activity to the physical properties, higher percentage of gully heads, can be explained.

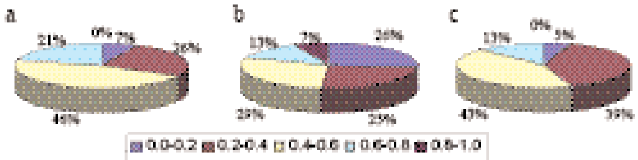

Fig. 3. Frequencies of initial points that were identified in the area according to each sub-models (a- physical; b- human; c- combined). The groups are following the fuzzy membership scores: 1-highest risk; 0-the lowest.

5. Conclusion

The integration of the physical properties and the human activity in the catchment explained the observed gullies in the area. By getting accurate and updated results, we will be able to produce prediction maps for gully development risks and to quantify the effects of each human and physical factor.

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References

Amore, E., Modica, C., Nearing, M.A., and Santoro, V.C. 2004. Scale effect in USLE and WEEP application for soil erosion computation from three Sicilian basins. *Journal of Hydrology*, 293: 100-114.

Casalí, J., Loizu, J., Campo, M.A., De Santisteban, L.M., and A'lvarez-Mozos, J. 2006. Accuracy of methods for field assessment of rill and ephemeral gully erosion. *Catena*, 67:128-138.

Frenandez, C., Wu, J.Q., McCool, D.K. and Stockle, C.O. 2003. Estimating water erosion and sediment yield with GIS, RUSLE, and SEDD. *Journal of Soil and Water Conservation*, 58 (3): 128-136.

Ganskopp, D., Cruz, R. and Jounson, D.E. 2000. Least-effort pathways?: a GIS analysis of livestock trails in rugged terrain. *Applied Animal Behaviour Science,* 68: 179-190.

Ni, J.R. and Li, Y.K. 2003. Approach to soil erosion assessment in terms of land-use structure changes. *Journal of Soil and Water Conservation*, 58(3): 158-169.

Openshaw, S. and Openshaw, C. 1997. *Artificial intelligence in geography*. Joun Wiley & Sons, Chichester, England.

Poesen, J., Nachtergaele, J., Verstraeten, G., and Valentin, C. 2003. Gully erosion and environmental change: importance and research needs. *Catena*, 50: 91-133.

Svoray, T., Bar-Yamin Gancharski, S., Henkin, Z. and Gutman, M. 2004. Assessment of herbaceous plant habitats in water-constrained environments: predicting indirect effects with fuzzy logic. *Ecological Modeling,* 180:537-556.

Valcárcel, M., Taboada, T., Paz, A., and Dafonte, J. 2003. Ephemeral gully erosion in northwestern Spain. *Catena*, 50: 199-216.

Valentin, C., Poesen, J., and Li, Y. 2005. Gully erosion: Impacts, factors and control. *Catena*, 63:132-153.

Van Rompaey, A., Bazzoffi, P., Dostal, T., Verstraeten, G., Jordan, G., Lenhart, T., Govers, G., and Montanarella, L. 2003. Modeling off-farm consequences of soil erosion in various landscapes in Europe with a spatially distributed approach. *In proceedings of the OECD Expert Meeting on Soil Erosion and Soil Biodiversity Indicators.* 25-28 March, Rome, Italy.

DOES VEGETATION COVER SUPPOSE GULLY EROSION STABILIZATION?

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1. Introduction

Vegetation cover is one of the factors affecting sidewall stability. Apparently, the presence of vegetation cover on gully sidewalls contributes to their stabilization. However, observations in gullies of some study areas, as the Penedès – Anoia region (NE Spain), evidence that the presence of vegetation is not sufficient to avoid gully retreat.

Gully erosion research has been traditionally addressed to determine retreat and sediment production rates (Poesen et al., 2003). Few research works have been addressed to analyze the influence of vegetation cover in gully erosion or sediment production within gullies, concluding that vegetation cover is important to reduce gully erosion and for sidewall stabilization (Rey, 2001). The present research is addressed to study the evolution of vegetation cover on gully sidewalls and its influence on sediment production due to gully erosion and on gully walls' stabilization. A sample gully system of the Penedès – Anoia (NE Spain) was selected as study area (Fig. 1). In this region, gully erosion is a problem which affects 23 - 32% of the land. It is part of the Penedès Tertiary Depression, where calcilutites (marls) and, occasionally, sandstones and conglomerates outcrop.

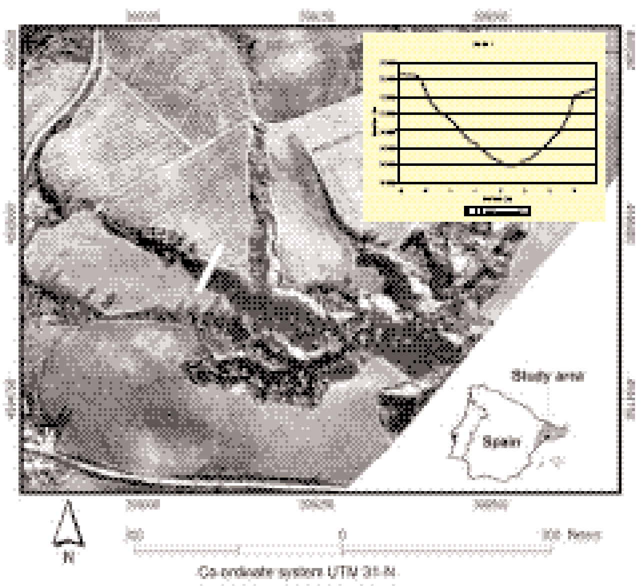

Fig. 1. Location of the study area. The white line indicates the cross-section in the upper-right part of the figure.

2. Methods and material

The analysis of the vegetation cover changes within the sample gully system of the Penedès – Anoia region was based on the use of multi-temporal and detailed aerial photographs: 1975 (1:7,000), 1995 (1:5,000) and 2002 (1:5,000). Those photographs were rectified to produce 1:1,000 orthophotos and digital elevation models (DEM) of 1 m resolution. From that material, vegetation cover was characterized for the respective years. Field work was carried out as ground truth to classify 2002 vegetation cover and to get photo-interpretation guidance to train the interpretation of the 1975 and 1995 vegetation cover maps.

The vegetation cover maps of 1975, 1995 and 2002 at 1:1000 scale were overlaid to produce change maps for each period. The geographic information system software ArcGIS 8.1 was used for that purpose. The vegetation cover change results were compared to catchment land use changes and gully erosion (sediment production rate) in both periods (1975-1995 and 1995-2002).

3. Results

The analysis of Table 1 reveals that in the period 1975-1995 there is an important diminution of the scrubland cover of 20.8% and an increase of coniferous forest of 21.5%. In addition, a reduction of the non-vegetated gully walls is observed (-4%). In the period 1995-2002 the same trend was observed: the scrubland decreased by 4.3%, the coniferous forest increased by 5.8% and the non-vegetated walls decreased by 1.6%.

These changes could be indicating stabilization of gully walls and a decrease of sediment production rates in the study area. In this respect, the second period (although shorter) could have a more favourable rate of vegetation cover increase. The vegetation cover class of greatest interests from the point of view of gully wall stabilization, the coniferous forest, increased by 14.7% from 1975 to 2002, with a rate of 0.15 ha per year (1.7%). The major growth occurred in areas previously covered by forested scrubland.

Regarding the relation of vegetation cover changes with respect topographic factors, mainly aspect, the results show that coniferous forest has mainly growth in north and east oriented walls, while non-vegetated areas are mainly south oriented. In these last walls, an opposite effect has been observed. On one hand, a certain increase of vegetation cover in non-vegetated walls in the period 1975-2002 was

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observed due to the growth of herbaceous and scrubland vegetation. However, the main vegetation cover decrease occurred on south oriented walls due to higher gully retreat rates of those walls.

Table 1. Vegetation cover changes in the sample gully area (Years 1975, 1995 and 2002).

Vegetation cover class	Percentage with respect total gullied area 1975	1995	2002
Coniferous forest	14.7	36.2	42.0
Scrubland	53.7	33.0	28.7
Forested scrubland	4.6	6.1	7.1
Herbaceous cover	0	0	0.8
Non-vegetated gully walls	27,0	23.0	21.4
No described	0	1,7	0

Table 2. Vegetation cover changes in the catchment of the sample gully system (Years 1975, 1995 and 2002).

Vegetation cover class	Percentage with respect total catchment area		
	1975	1995	2002
Traditional vineyard	24.5	16.1	12.3
Mechanized vineyard	0	18.9	18.9
Winter cereals	31.2	0	3.9
Urban area	0.2	2.7	2.7
Infrastructures	1.8	2.9	2.9
Scrubland	14.2	8.9	8.9
Unproductive	2.2	6.3	5.9
Forest	4.6	23.3	23.7
Orchards	1.6	2.6	2.6
Buffer between gully and fields	2.4	1.8	2.1
Gully area	17.3	16.5	16.2

The analysis of land use changes in the catchment of the gully systems indicates main changes in the vineyard and cereal classes (Table 2). In 1975 traditional vineyard and cereals occupied 90% of the total agricultural land, while in 1995 the first class decreased by 18.9% to favour the implantation of mechanized vineyards. Winter cereals were reduced from 31.2% in 1975 to 0% in 1995 and then to 3.9% in 2002. This is due to the higher profitability of mechanized vineyards in front of traditional cultivation. These land use changes produced a significant increase of overland flow from the fields to the gully walls, as consequence of the field restructuring carried out in the period 1975-1995 (including land levelling). This fact influenced higher moisture contents on gully walls and, as consequence, better conditions for vegetation development.

The subtraction of multi-temporal DEMs allowed to analyze the relationship between vegetation cover development and gully erosion. The most significant is the increase of vegetation cover in sedimentation areas within the gully (mainly gully bottom and walls' lower section): 62.7% of vegetation cover increase occurred in sediment deposition areas and in particular the development from scrubland to coniferous forest.

In the period 1975-1995 gully sidewall failures were observed, mainly located in the vicinity of the gully-wall border, where tension crack development is the main process promoting wall collapse. However, in the period 1995-2002, some wall failures also occurred near the gully bottom, indicating active undercutting by water and debris flow due to the important and high intensity rainfalls in this period (Martínez-Casasnovas et al., 2004).

4. Discussion and conclusions

The results suggest that gully sidewall processes in the study area, similar to other landslide activities do not depend on wall vegetation cover but are determined by two types of interrelated factors. The first type of factors express the progressive preparation of gully-wall materials, acting against the shearing resistance of the soil, e.g. tension crack development in the vicinity of the wall's border area by saturation of the materials and by changes in wetting-drying conditions. In those cases, wall slope and height also influence gully-wall stability. The other type of factors express a local short-duration drop in slope stability, such as large and high intensity rainfalls, that generate important runoff and provoke undercutting by concentrated runoff. In those cases, sidewall failures are not so dependent on slope angle, bank height or vegetation cover, but merely on material cohesion and runoff flow intensity (Martínez-Casasnovas et al., 2004).

Acknowledgements: This study was undertaken with funding from the Spanish Inter-ministerial Commission for Science and Technology (CICYT), as part of the projects REN2002-00432 and AGL2005-00091/AGR.

References

Martínez-Casasnovas, J.A., Ramos, M.C., Poesen, J., 2004. Assessment of sidewall erosion in large gullies using multi-temporal DEMs and logistic regression analysis. *Geomorphology* 58: 305–321.

Poesen, J., Nachtergaele, J., Verstraeten, G., Valentin, C., 2003 Gully erosion and environmental change: importance and research needs. *Catena* 50: 91-133.

Rey, F., 2001. Influence of vegetation distribution on sediment yield in forested marly gullies. *Catena* 50, 549-562.

SIDEWALL EROSION CONTROL STRATEGIES IN GULLIES OF THE THE PENEDÈS – ANOIA VINEYARD REGION (NE SPAIN)

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1. Introduction

The Penedès-Anoia (NE Spain) is a well know region because its dedication to vineyards for production of high quality vines and "cavas" (sparkling wines produced by the champagnoise method). It is part of the Penedès Tertiary Depression, where calcilutites (marls) and, occasionally, sandstones and conglomerates outcrop. One of the main characteristics of this area is the dissection of the landscape by a dense and deep network of gullies (Fig. 1), which have been object of different research works to determine the retreat and sediment production rates at regional as well as detailed scales (Martínez-Casasnovas, 1998; Martínez-Casasnovas, 2003; Martínez-Casasnovas et al., 2003). Those works have shown that the area affected by gullies reach up to 23 - 32% of the land, with average retreat rates of 0.1 m year^{-1} and sediment productions rates of 846±40 Mg ha^{-1} year^{-1}. Frequent failure of gully-walls and the retreat of sidewalls towards vineyard drainage outlets are usually observed (Fig. 1), being necessary the implementation of control measures to avoid the retreat of walls to vineyard fields that cause damages in the fields and infrastructures.

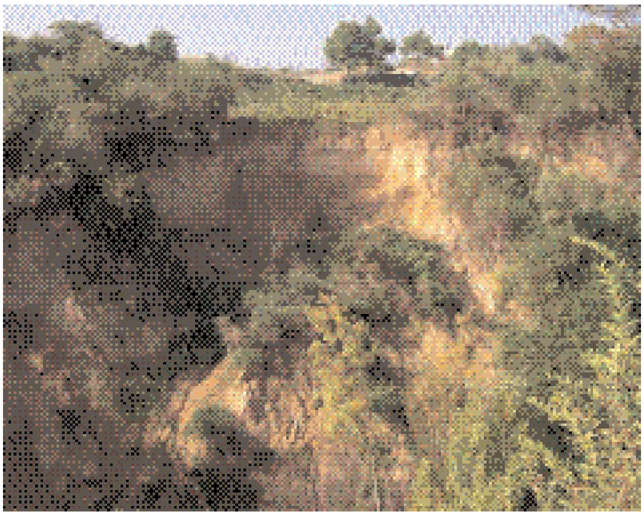

Fig. 1. Sidewall erosion in a sample gully of the Penedès-Anoia region.

In this respect, recent research by Martínez-Casasnovas et al. (2004) carried out in this study area has suggested that gully sidewall processes are determined by two types of interrelated factors. The first type of factors express the progressive preparation of gully-wall materials, acting against the shearing resistance of the soil, e.g. tension crack development in the vicinity of the wall's border area by saturation of the materials and by changes in wetting-drying conditions. The second type of factors express a local short-duration drop in slope stability, such as large and high intensity rainfalls, that generate important runoff and provoke undercutting by concentrated runoff. In those cases, sidewall failures are not so dependent on slope angle and bank height, but merely on material cohesion and runoff flow intensity.

According to this background, the objective of this work is to formulate different sidewall erosion control strategies to reduce retreat and sediment production rates in the gullies of the study area.

2. Methods and material

The determination of sidewall erosion control strategies has been based on both field observations and farmers' survey and research on the processes determining sidewall processes (Martínez-Casasnovas et al., 2004). The survey has been addressed to know the manner that runoff and infiltration water is managed from the fields to the gullies.

3. Results and discussion

Field observations and research conducted to know the processes associated to the development of sidewall erosion revealed that the retreat of gully walls is mainly caused by mass movements, which mainly occur in the saturated zone of sidewalls. This is caused by the infiltration and the accumulation of water in the lower parts of the fields (Fig. 2.A). To intercept the excess ob subsurface water flow going to gully walls, a belt drainage system along the border between the parcel and the gully is proposed. It would avoid the saturation of water in gully bordering areas (Fig. 2.B). The distance of the drain from the gully border as wells as its depth should be studied for each case. No less than 3 m from the sidewalls is recommended to avoid the collapse of the wall during the drainage installation. This is usually the distance between the last vineyard row and the gully border. The recommended depth should vary according to the depth to the lutite layer, installing the drains above the upper boundary of the impermeable layers.

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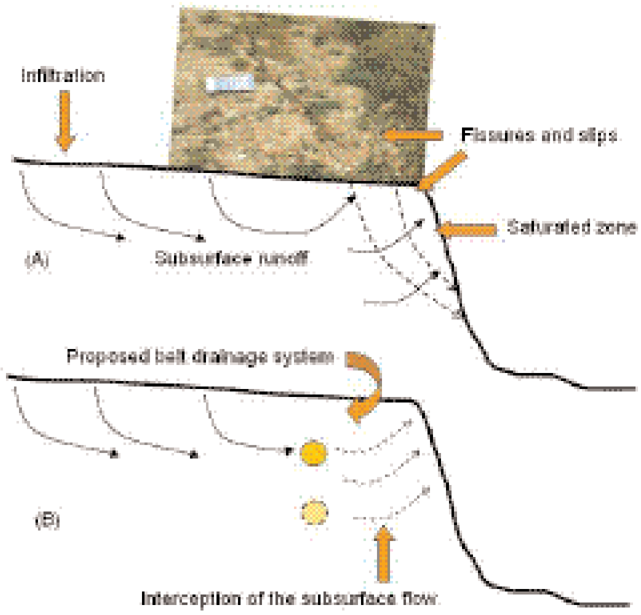

Fig. 2. (A) Process in the neighbour of gully walls determining tension crack development and wall failure and (B) proposed solution to avoid the saturation of field-gully contact areas by subsurface runoff.

Another observed process of gully wall retreat is caused by the concentration of water in drainage channels (Fig. 3). The outlets of these channels are located in the border between the fields and gullies. During high intensity rainfalls, the strength of the water flow in the outlet of drainage channels produces the erosion of the gully wall border and the development of new gullies towards headwater areas. These new gullies usually experiment a rapid growth thanks to the high relative relief with respect to the base level of the main gully. The free fall of water in the border of fields may constitute truly waterfalls. This erodes the base, and the upper part of the wall finally falls by gravity (Fig. 3A). The proposed solution is the canalisation of runoff water from the present outlets to the gully water courses (Fig. 3C).

These measures should be complemented with other, as for example the stabilisation of the gradient of the large gullies with structures as check dams, or the implementation of drainage terraces to conduct the runoff excess originated in the fields to specific outlet points. In those points the proposed tubes to conduct the water to the gully bottom should be implemented.

The field work has shown that none of the above mentioned control measures are usually implemented in the study area. Farmers conduct runoff water to the border of their fields and they fill ephemeral gullies that appear after high intensity rainfalls. When a gully wall falls and part of a field goes away, farmers fill the gully with soils or parent materials, which are moved from other parts of the field. It involves big investments and it does not avoid gully erosion. At present, this is in most of the cases the erroneous idea that many farmers have about the problem of gully erosion and its solutions.

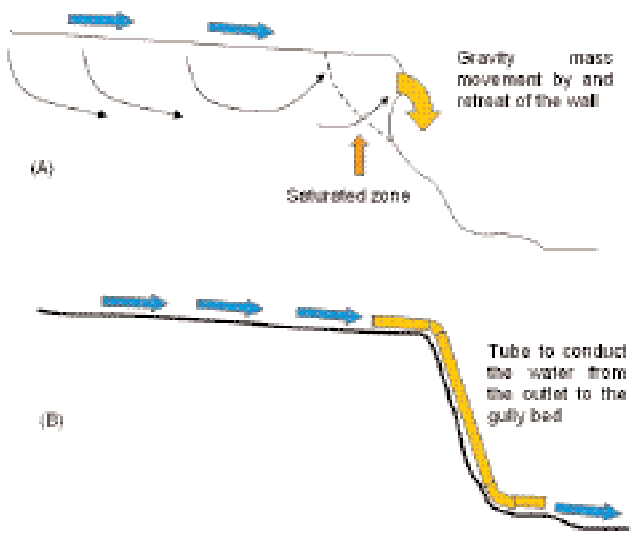

Fig. 3. (A) Concentration of runoff water in drainage channels and free fall of water on the gully walls, erosion of the gully walls and gravity mass movements, and (B) proposed solution by means of the canalisation of runoff water from fields to gully beds.

4. Conclusions

A change in the manner water is managed in the Penedès – Anoia vineyard region (NE Spain) must be considered to reduce gully erosion rates and to avoid further field and infrastructure damages. It is very important to persuade farmers to implement those control measure to secure the agricultural land uses as in its present form in decades to come.

Acknowledgements: This study was undertaken with funding from the Spanish Inter-ministerial Commission for Science and Technology (CICYT), as part of the projects REN2002-00432 and AGL2005-00091/AGR.

References

Martínez-Casasnovas, J.A., 1998. Soil – landscape – erosion. Gully erosion in the Alt Penedès – Anoia (Catalonia, Spain). A spatial information technology approach: spatial databases, GIS and remote sensing. PhD Thesis, University of Lleida, Lleida, Spain.

Martínez-Casasnovas, J.A., Ramos, M.C., Poesen, J., 2004. Assessment of sidewall erosion in large gullies using multi-temporal DEMs and logistic regression analysis. *Geomorphology* 58: 305-321.

Martínez-Casasnovas, J.A., 2003. A spatial information technology approach for the mapping and quantification of gully erosion. *Catena* 50: 293-308.

Martínez-Casasnovas, J.A., Antón-Fernández, C., Ramos, M.C., 2003. Sediment production in large gullies of the Mediterranean area (NE Spain) from high-resolution digital elevation models and geographical information systems analysis. *Earth Surface Processes and Landforms* 28: 443–456.

WHEN DID GULLY EROSION START TO BE ACCELERATED IN THE PENEDÈS – ANOIA VINEYARD REGION (NE SPAIN)?

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1. Introduction

Gully erosion in the Penedès – Anoia region (NE Spain) is a regional problem, affecting between 23 to 32% of the land. This region is part of the Penedès Tertiary Depression, where calcilutites (marls) and, occasionally, sandstones and conglomerates outcrop. The depression has and age of between 25 to 2 millions of years (Oligocene to High Neogene).

One of the main characteristics of this area is the dissection of the landscape by a dense and deep network of gullies (Fig. 1). According to Martínez-Casasnovas (1998), the total volume excavated the gully network in the incoherent materials is about 466 hm^3 and a maximum depth of 60 m. The density of gullies reaches 4.8 km km^{-2}, being this value considered as very severe.

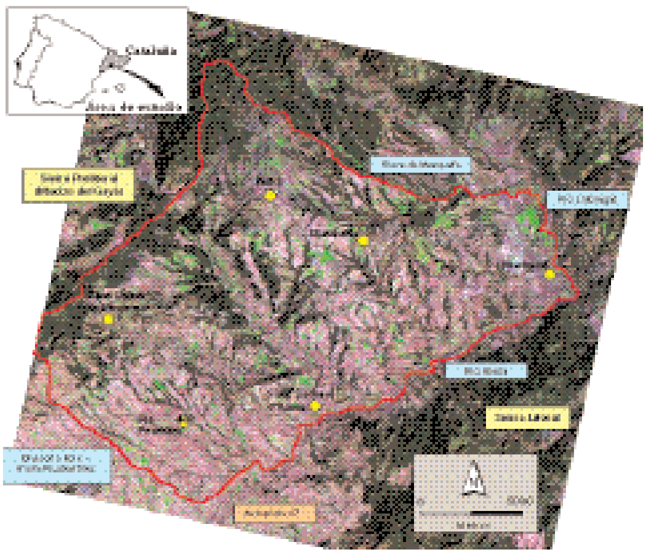

Fig. 1. Location of the study area. A dense drainage network mainly formed by deep gullies can be observed. Landsat TM image, RGB 543, March 1993.

Gully erosion in this region is not a past phenomenon. In this respect, recent research by Martínez-Casasnovas et al. (2003) has shown that neat erosion rates in gullies reach 576±58 Tn ha^{-1} $year^{-1}$ in the most active heads. However, some research questions arise about the magnitude of this problem: When did gully erosion start? When did it was accelerated? Is this acceleration related to the main land use in the region (vineyards)? The present work addresses those questions by analysing multitemporal remote sensing data in order to determine historic gully retreat rates and to relate them to documented land use changes in the region.

2. Methods and material

The research was based on a multi-temporal analysis of aerial photograph stereo pairs from 1957 (1:30,000 scale) and aerial photographs and orthophotos from 1993 (1:25,000 scale). From this information, the gully retreat rate was computed for the period 1957-1993. The gullied area for 1957 was mapped by means of airphoto interpretation. The boundary of the eroded area was drawn along convex slope break lines that mark the incision of gullies in the unconsolidated Tertiary deposits. The result of the airphoto interpretation for 1957 was restituted by means of a digital photogrammetric process at scale of 1:25,000. The gullied area for 1993 was drawn on a 1:25,000 orthophoto produced by the Cartographic Institute of Catalonia and digitised as an ArcInfo polygon coverage. Both coverages were geo-referenced according to the UTM 31N co-ordinate system.

The coverages were overlaid using ArcInfo's Union command. A contingence matrix was derived from the Union coverage. This matrix gives information about the area covered by each mapped class at the respective dates as well as about two-dimensional or planimetric changes among the classes in the considered period. From this matrix the rate of gully walls retreat was computed.

3. Results and discussion

The total area affected by the retreat of gullies in the period 1957 – 1993 was 76.5 ha (in 36 years) (Fig. 2). This represents a rate of 2.1 ha $year^{-1}$ or, in terms of the catchment area, 0.9‰ m^2 $year^{-1}$. The linear retreat of gully walls occurred at an average retreat rate of 0.2 m $year^{-1}$ along the perimeter of the gullies of the study area. However, this represents default rates since areas that were both eroded and filled within the studied period, and therefore not detected in the image interpretation process, may be included.

If this computed retreat rate was maintained over the time to come, it would last 840 years to erode the whole gully catchment. This is only a very hypothetical prediction, since only the last 36 years were considered to compute the

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erosion rate. On the other way around, if the retreat rate is applied in a reverse way, the hypothetical start of the gully development in the study area could be estimated. Accordingly, it indicates that gully erosion would have started 320 years ago. This date is again very few probable, since the start of the incision of the gully system is most sure contemporary to the incision of the Anoia river (main river in the area). However, it reflects that the rate of gully erosion in the study area has not been always the same. In the recent past, the study area suffered one of the highest gully erosion rates of its history. It seems to be the consequence of a break in the equilibrium of the landscape system, which could have started four centuries ago.

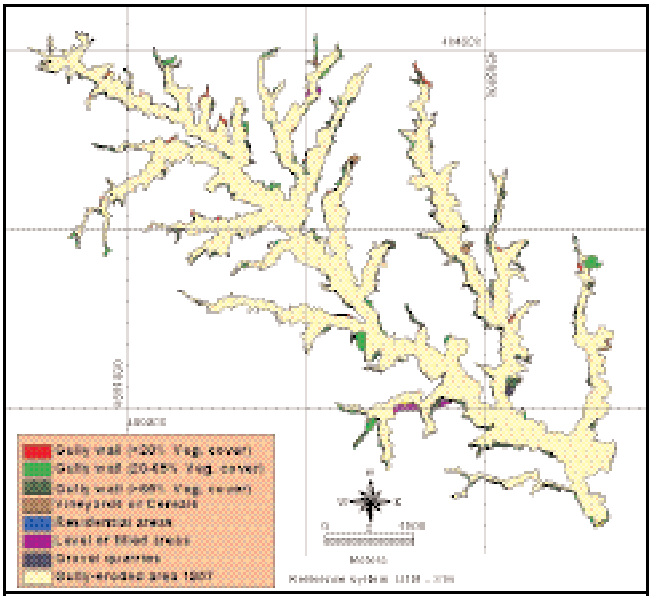

Fig. 2. Areas of the sample area in the Penedès-Anoia region (Rierussa catchment) affected by gully erosion in the period 1957-1993.

What happened four centuries ago? Balcells (1980) reports that in the XVI century started in the Penedès region the massive plantation of vineyards under the protection of temporary contracts called *Rabassa Morta*. This supposed the clearing of shrublands and forested areas, which seems the most probable cause of the land use/cover disequilibrium responsible for the higher runoff and erosion rates. Particularly important seems to be the studied period (1957-1993), after the advent of the mechanisation. Other aspects different from the traditional soil and water conservation measures have been priority in this period (Porta et al. 1994, Poch et al. 1996).

Therefore, and although the measured rate of gully retreat is a measure of the past erosion and it could not have to be the same for the future, it is a measure of the very recent past erosion. Then, since the land use system has not changed towards implementing more soil and water conservation measures, similar, accelerated, gully erosion rates can be expected for the near future in the study area.

4. Conclusions

The present research reveals the accelerated rates of gully erosion that the Penedès – Anoia vineyard region suffers, at least, since three centuries ago. This is consequence of a disequilibrium caused by an important and progressive (since that moment) land use/cover change that has favoured partial cover crops (vineyards) instead the original land cover vegetation. The acceleration of gully erosion could have been accentuated from the advent of mechanization, which also produced a removing of soil conservation measures to achieve larger fields for easier labour mechanization.

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References

Balcells, A., 1980. El problema agrario en Cataluña. La cuestión rabassaire (1890-1936). Serie de Estudios. Ministerio de Agricultura, Madrid.

Martínez-Casasnovas, J.A., 1998. Soil – landscape – erosion. Gully erosion in the Alt Penedès – Anoia (Catalonia, Spain). A spatial information technology approach: spatial databases, GIS and remote sensing. PhD Thesis, University of Lleida, Lleida, Spain.

Martínez-Casasnovas, J.A., Antón-Fernández, C., Ramos, M.C., 2003. Sediment production in large gullies of the Mediterranean area (NE Spain) from high-resolution digital elevation models and geographical information systems analysis. *Earth Surface Processes and Landforms* 28: 443–456.

Poch, R.M., Martínez-Casasnovas, J.A., Usón, A., Ramos, M.C., 1996. Conservació de sòls en vinyes de l'Anoia – Penedès: un enfoc cap a la sostenibilitat. *Actes de les Jornades sobre Agricultura i Medi Ambient*. Mollerusa, 16 March 1996.

Porta, J., Ramos, M.C., Boixadera, J., 1994. Mechanical measures for runoff management and erosion control in the vineyards of North East Spain. In R.J. Rickson (eds.), *Conserving soil resources: European perspective*, CAB International, Wallingford, pp. 369-378.

ANALYSIS OF WATER EROSION USING GIS AND REMOTE SENSING FOR THE MANAGEMENT OF PROTECTED NATURAL ENVIRONMENTS IN THE SOUTH OF THE PROVINCE OF SALAMANCA (SPAIN)

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1. Introduction

The soil is a natural resource that must be conserved in protected natural areas since it is one of the determinant physical supports in territorial planning because it governs its different uses. Accordingly, specific studies must be carried out aimed at estimating soil losses at individual project level and at the general level of Natural Environments in order to establish methodologies for the control and ordering of activities, above all in protected environments whose focus is on sustainable activities. The basic objective should delimit different erosive forms where best it reflects the risk of water erosion (gullies, rills) and the degree (weak, light, important, and burden) and the processes induced (slides, scarp, remontant erosion...) in addition the evolution with time.

2. Methodology

The study zone is the Protected Natural Space of "Batuecas-*Sierra de Francia"* and the Community interest site (LIC) of Quilamas: both sectors are included in the National Topographic Map (MTP) at 1/50,000 scale corresponding to Serradilla del Arroyo (526), Tamames (527) NE Martiago (551), Miranda de Castañar (552) and N of Hervás (575).

In the first phase, Geographic Information Systems (GIS- ArcGis 9) were used to determine the potential risk of erosion and generate models and cartographies of erosive risk by means of the analysis of a relational database, which allows classifications, map algebras etc., to be elaborated. Integrated in this database are the basic thematic parameters: the R, K and LS factors -of the Universal Soil Loss Equation (USLE)- following the methodology used by Wischmeier & Smith (1978) in Morgan & Kirby. (1984). These specific cartographies were superimposed to establish the synthetic cartography of potential erosive risk (Graña et al., 2003).

In a second phase, we obtained a cartography of the plant cover, or C factor, from the current synthesized map of vegetation, and performed a field campaign to characterise each patch of vegetation selected and determine more precisely the parameters affecting the C factor (height of tree canopy, percentage of organic matter, percent area of tree cover, shrub cover, etc) owing to its importance since it significantly reduces the risk of soil erosion. The use of remote sensing techniques (PCI v8.1) allowed us to delimit the highly eroded sectors, with gullies and rills, by use of multitemporal scenes from Landsat-5 satellite images, Thematic Mapper ™ sensor. "Fig. 1".

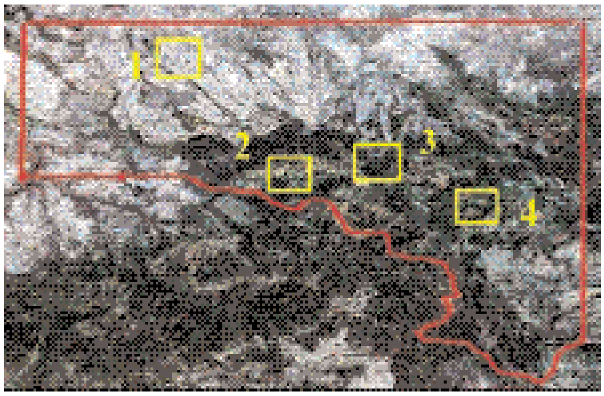

Fig. 1. Satellite image showing some degraded sectors with erosion in the form of gullies and rills.

The values of the plant cover are a function of the emitivity of each surface cover in different zones of the electromagnetic spectrum, using a series of indices, such as the vegetation index (VI) or the normalized vegetation index (NVI) (Van Der Knijff et al., 2000).

The classification and later grouping of the different digital levels of the image allowed new values of the plant cover to be added to the database of the GIS, together with observation of the erosive forms present throughout the natural environment (gullies, rills…). Unsupervised classification categorizes the pixels of the image according to spontaneous classes, grouping them as a function of similar spectral values. This classification helps to understand the potential classes of the image and affords a preliminary interpretation of the sectors with erosive processes and forms (gullies) and plant covers (Toutin, 2004).

The conservation practices factor (Factor P) is taken as null (owing to its scant importance) so that, depending on the estimation of soil losses, the optimum conservation measures for each degraded sector can be determined.

Finally, in a third phase we performed a cross of the potential erosion map and the plant cover map, obtaining a map of current erosion "Fig. 2".

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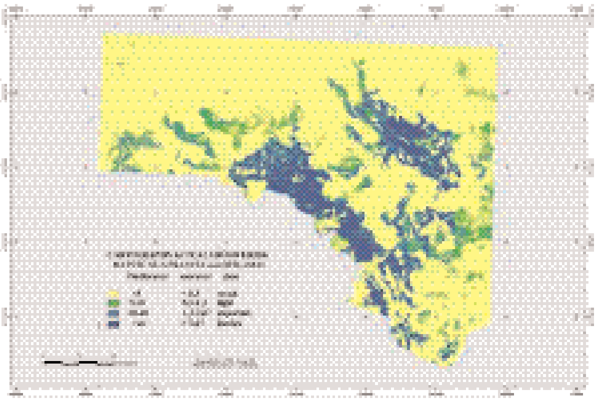

Fig. 2. Cartography of actual erosive risk.

We also carried out a detailed analysis of the zones where the erosive risk was high, delimited in the previous phase with remote sensing based on the spectral contrast of reflectivity values on the eroded and gullied surfaces “Fig. 3”.

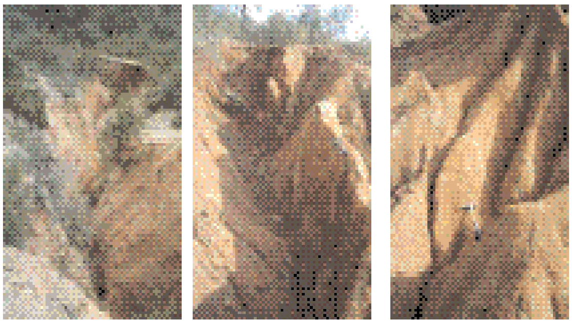

Fig. 3. Gullies with a depth of about 3 m in the Monsagro (left) and Aldehuela de Yeltes (middle and right) sectors.

These areas affected by accelerated erosion (badlands, rills, ravines…) were located in aerial photographs from different years (1956, 1978, 1990 and 1999) and were interpreted and plotted on the orthophoto and map at 1/10,000 scale of the studied area. Digitization of these areas allowed us to assess the retraction of the different scarps and predict, with GIS, the temporal morphological changes and the current and future evolution by estimation of the relative erosion rates and the effect on the extent and magnitude of the degraded zones and their effect on landscape quality.

In these tasks, erosion spikes were emplaced and pins in the zones of gully retraction with a view to quantifying erosion rates at individual sites or by sectors in the future.

3. Results and conclusions

Calculation of potential and current erosion in the Protected Natural Environments of “Batuecas-Sierra de Francia” and Quilamas has allowed us to estimate the degree of soil loss; this qualitative evaluation, based on parametric models, was then related to individual quantitative assessments (erosion spikes and pins….).

Joint use of GIS techniques and remote sensing helped to establish the potential zones of water erosion, delimiting the most problematic areas and using them as training areas to determine and characterise erosive forms (layer erosion, gullies, rills….) developed in each sector, bearing in mind the influence of the parametric factors (lithology, slopes, rainfall and vegetation).El riesgo de erosion actual, es altoen las zones elevadas de las sierras,

Multitemporal analysis of images (orthophotos, aerial photos and Landsat images) helps in the assessment of the rate of erosive processes and in estimating the degree of degradation that may be present in each zone analysed, distinguishing the zone with the greatest natural environmental impact as regards such processes, and hence making it easier for the management of the natural environment to establish the most appropriate conservation practices for each sector (P factor).

The field analysis in the training areas has allowed us to know the effect of the erosive processes as a function of the different lithologies with mean depth data for the different substrates: detritic Tertiary (3-4 m), granite (1-2 m) and slates (< 1 m).

This GIS and remote sensing analysis favours the elaboration of cartographies of the present and future risks of soil loss, which may facilitate the tasks of prevention and detection in the location of different activities and influence in the cartography of landscape naturalness and quality.

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References

Graña, A.M.; Goy, J.L.; Forteza, J; Zazo, C; Barrera, I; González, F.M., 2003. Riesgo de pérdida de suelo en los espacios naturales de Batuecas - S. Francia y Quilamas (Salamanca, España). Aplicación cartográfica mediante SIG. R Bienes & MJ Marqués (eds): .593-596

Morgan, R.P.C. Kirkby, M.J.,1984. *Erosión de Suelos*. Ed. Limusa. Madrid: 368.

Toutin, Th 2004. Geometric Processing of Remote Sensing Images: Models, Algorithms and Methods. *International Journal of Remote Sensing*, 25 (10): 1893-1924.

Van Der Knijff, J.M.; Jones, JR,J,A.; Montanarella, L.,2000. Estimation du risque d’erosion en Italie. Centre European Comisssion: 45.

PHOTOGRAMMETRICAL AND FIELD MEASUREMENT OF GULLIES WITH CONTRASTING MORPHOLOGY

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1. Introduction

Hitherto, most of the studies on gully erosion aim to estimate the spatial and/or temporal evolution of either single gullies or gully networks under different situations. With regard to the accuracy of experimental datasets, a field survey makes possible to obtain accurate measurements on gully geometry, even in three-dimensional coordinates, with (relative) ease (Oostwoud Wijdenes and Bryan, 1994). In addition, the accuracy of this *direct* measurement mainly depends on the researcher's judgment (e.g., to choose the experimental setup and the density of measurements), rather than in the precision of the measuring equipment used.

On the other hand, remote-sensing techniques of gully measuring, in two and three-dimensional coordinates, have been increasingly used (e.g., quantification of volumen loss, Marzolff and Poesen, in prep). Unlike field measurements, these indirect measuring techniques allow covering of large study areas with a minimum of time and effort (e.g., Martínez-Casasnovas et al., 2004). However, the accuracy of the dataset obtained in this way does much depend on the precision of the applied technique (e.g. on image resolution, quality of ground control). Moreover, an accurate gully measurement on three-dimensional coordinates may also (much) depend in the gully morphology (e.g., on the gully width/depth relationship). A gully cross-sectional area is more difficult to assess in a narrow, deeply eroded feature where measuring may be somewhat hindered by shadows cast on gully walls and bottom.

Despite a wealth of studies on monitoring different types of gullies by using remote-sensing technique such as photogrammetry, relatively few efforts have been made to test their accuracy. Therefore the question arises as to what extent the accuracy of gully monitoring using photogrammetric technique depends on gully morphology. The objective of this work is to investigate this issue. To do that, we confront field measurements of cross-sectional areas of gullies with contrasting morphology with a similar dataset obtained using photogrammetry. Below, we present the first findings of this investigation.

2. Material and Methods

Within the region of Bardenas Reales (Navarre, Spain) a plot of around 1000 m2 presenting a large collection of gullies of different sizes and morphologies, was selected to carry out the experiments (Fig. 1).

Fig. 1. Aerial picture of the experimental plot showing different types of gullies. A person in the lower, right-hand margin for scale (see arrow). Bardenas Reales, Navarre, Spain.

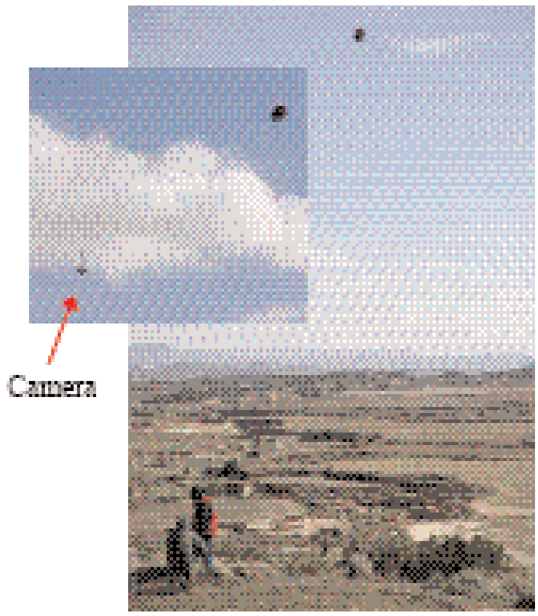

Fig. 2. Kite used as an aerial camera platform.

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Five different gullies were selected according to contrasting differences in their width/depth ratio. Several ground control points were marked in the study area prior to the surveys and their coordinates measured with a total station. With a specially designed kite (Marzolff et al., 2003) as a sensor platform, large-scale aerial photographs were obtained from the study area (Fig. 2). These high-resolution stereoscopic pictures allowed for further digital image processing and the constructions of large-scale digital elevations models (DEM) and GIS analysis. In addition, several cross-section elevation profiles along each of the different types of gullies were obtained from the stereo image models.

On the other hand, cross-section profiles in the same location as before were obtained by field survey. These were determined by using a laser profilometer (Fig. 3). Where the extremely large width and depth of the largest gully prevented the use of the profilometer, cross-section profiles were obtained instead by means of a total station.

Fig. 3. Determination of a gully cross-section profile using a laser profilometer.

3. Results

Hitherto, 12 cross-section elevation profiles have been obtained from 6 transects located along the largest gully headcut (Fig. 4): from each transect we determined a pair of elevation profiles, one by photogrammetry and the other one by using the total station (Fig. 5). At this point, it is important to mention that this large gully underwent local collapses of its walls and headcut. This occurred after the image capture and before mapping the entire surface height with the total station. However, only two of the aforementioned elevation profiles were affected by some change at the southern gully wall, all other areas remaining largely unchanged. Each pair of elevation profiles was plotted apart for a better comparison (Fig. 5). It can be seen that there is a remarkable match between equivalent profiles. Nevertheless, a lesser concordance between both set of result was observed in some spots densely cover by shrubs. Here, relative surface height is somewhat overestimated by photogrammetry since soil surface is (partially) hidden by the vegetation canopy.

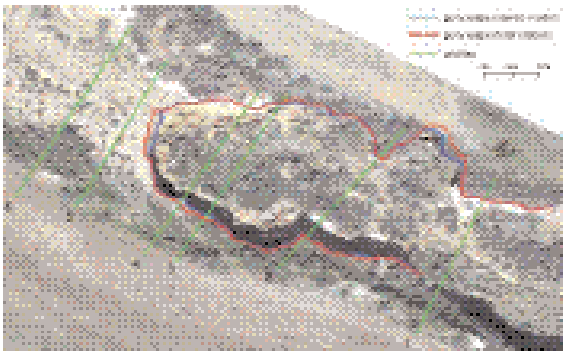

Fig. 4. Aerial view of the largest studied gully. Transverse lines indicate the exact position of each of the six gully cross-section profiles.

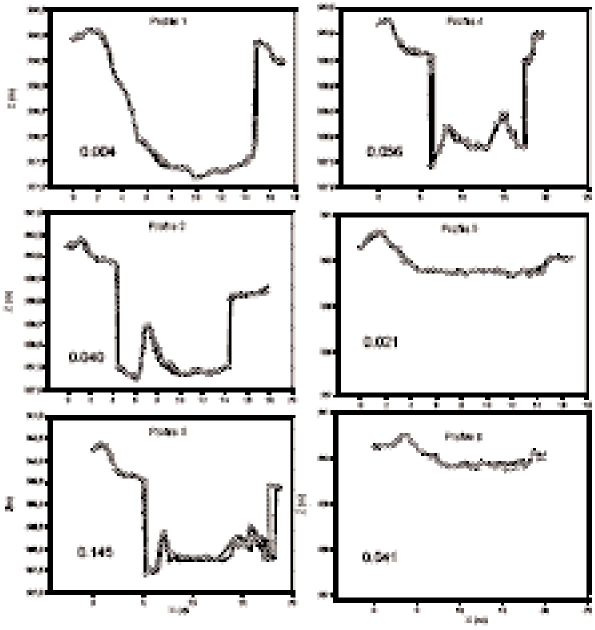

Fig. 5. Cross-section elevation profiles of the largest gully, facing upstream. (For location, see Fig. 4). Full circle: from total station; Empty circle: from stereo model. Inner number is the mean of height differences in meter.

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References

Martínez-Casasnovas, J.A., Ramos, M.C. and Poesen, J., 2004. Assessment of sidewall erosion in large gullies using multi-temporal DEMs and logistic regression analysis. Geomorphology, 58(1-4): 305-321.

Marzolff, I. and Poesen, J. (in prep). 3D monitoring of erosion gullies with GIS using high-resolution aerial photography and a digital photogrammetry system. Submitted to Geomorphology.

Marzolff, I., Ries, J.B. and Albert, K.-D., 2003. Kite aerial photography for gully monitoring in sahelian landscapes. Proceedings of the Second Workshop of the EARSeL Special Interest Group on Remote Sensing for Developing Countries, 18-20 September 2002, Bonn, Germany. (CD-ROM publication)

Oostwoud Wijdenes, D.J. and Bryan, R.B., 1994. Gully headcuts as sediment sources on the Njemps flats and initial low-cost gully control measures. Catena Suppl., 27: 205-229.

REGIONAL ASSESSMENT OF GULLY SYSTEMS IN A HILLY OLIVE-ORCHARD DOMINATED LANDSCAPE

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1. Introduction

Olive orchards dominate the land use at the hills of Afrin area, and olive oil represents the most important cash income source for rural communities in this area. However, olive yields in many orchards have been decreasing steadily over the last 20 years (Hoorelbeke, 2006).

The major reason for the yield decline is the severe land degradation taking place in this region. Deforestation, expansion of olive production into steeper areas, and inappropriate land management practices, accelerated the rate of soil erosion. Especially the replacement of mule contour tillage by the cheaper up-and-down tractor tillage during the 1970's was very detrimental. Tractor tillage not only moves down sizable amounts of soil during every tillage run, but also the consequent (mostly) vertical furrows stimulate water-induced soil erosion.

The widespread presence of rills and gullies during the rainy season is a clear indicator of the severity of this problem. It is not exceptional to see that the parent material is surfacing, which indicates that a complete loss of the surface soil layer. However, gully systems are mere symptoms of ongoing degradation rather than the cause of degradation itself (Stocking et al., 2001). In order to facilitate the development of an effective soil conservation strategy for olive-dominated hill landscapes, the main focus of this study was to assess the severity of gully systems and to increase the understanding of the causes of gully system development.

2. Methodology

The first survey took place during the peak of the rainy season (February-March 2005) before the spring tillage. The gully survey was based on four sequential steps: (1) locating active gullies in the landscape and indicating them at a topographical map of the area (scale 1:25,000); (2) sketching the gully system; (3) measurement and visual assessment of the gully system and the affected areas; and (4) identification in the field of the most likely main causes of the gully system.

During the peak of the next rainy season (February-March 2006), selected gully systems were described in more detail in order to develop a gully typology. The surveyors attempted to cover representative areas of Afrin District in terms of topography, soil type and land use (use was made of an Agro-ecological zoning map). The framework for analysing gully systems in the field was based on identifying the causes for runoff generation, runoff concentration and sedimentation. In addition, landform, land use (including land cover and land management) and gully morphology (size, branching) were assessed by GPS, field measurements and visual assessments. At the end of each description, the group surveyors brainstormed on the preliminary gully type and potential soil conservation measures. When the gully system database was completed in Excel, a final typology was built and parameters for each type were identified.

The team surveyors consisted out of a land management expert of ICARDA and 14 trained staff from the Agricultural Extension Services of Afrin District.

3. Results and discussion

3.1. Major causes of gully systems in an olive orchards-dominated landscape

For the whole target area (120,000 ha) the surveyors identified 583 main gully systems. This revealed that at least 3,989 ha (or 9%) of the total area of sloping olive orchards (or 45,000 ha) were affected by gully systems.

Three main causes are (in declining order): concave terrain, up-and- down tillage, and shallow soil (see Figure 1). Terrain concavity is an inherent landscape factor, but by itself it is not enough to cause gully systems. It is only when concavity is combined with other factors, that gully systems are formed. We found that specific combinations of causes occur very frequently. The most common combination is: concave terrain with up-and-down tillage and shallow soils (21% of the total surveyed gully systems).

The survey revealed differences in gully frequencies related to the soil type. More gullies were formed in sloping areas with white soils (formed on clayey limestone or marls, which are more fragile and prone to water erosion- Regosols or Cambisols), compared to similar slopes with red soils (soils formed on pure limestone- Luvisols on deeper soils, and Cambisols on more shallow soils). This indicates that the red soil type is probably more resistant to gully erosion than the white soil type.

Furthermore, use of GIS and remote sensing will help to specify factors relevant to identifying areas at risk of soil erosion and will result in a provisional methodology for identifying hot spots of current and potential rill and gully erosion.

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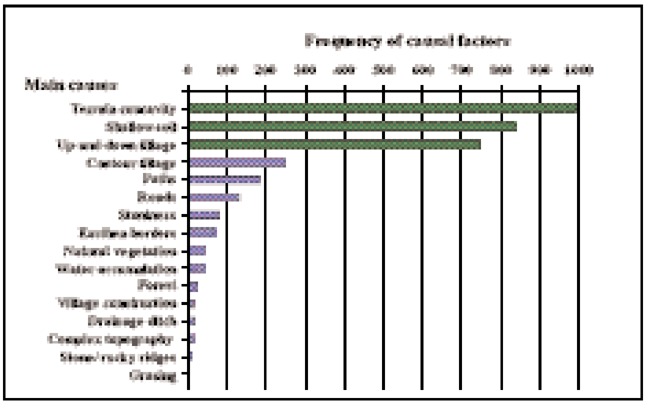

Fig. 1. The frequencies of causal factors for formation of gully systems in the hills of Afrin District, NW Syria (based 2006 winter survey).

3.2. A gullies typology for an olive orchard dominated landscape

Based on the dominant causes, eight types of gullies were identified: road gullies, barrier gullies, shallow soil gullies, forest gullies, long-slope gullies, tillage-furrows gullies, tractor gullies, and plan-concavity gully systems.

Road, barriers, tillage-furrows, shallow soil, and long slope gullies occur very frequently. Plan concavity, forest gullies, are less common, while the tractor gullies are the least frequent. However, road and barrier gullies associated with shallow soils and tillage furrows gullies are the most common types of gullies system.

3.3. Implications of gully typology survey for soil and water conservation (SWC)

Categorization of gully typology and their causes may help to identify proper remedies to decrease the risk of gully system formation. In this context, main feasible actions for controlling the different gully system types are suggested (see Table 1).

4. Conclusions

- Field surveying of gully systems is a valid approach to quickly assess the occurrence, severity and causes of gully erosion systems in an area of 1200 km^2.
- The formation and development of the gully system on Afrin's olive orchards were not caused by single factors, but it are specific combinations of landscape factors, soil type, and land management practices which make them happen.
- Most frequent types of gullies are road, barrier, shallow soil, and long slope gully systems.
- Expansion and mechanization in olive production over the hill slopes are the likely drivers of accelerated water erosion over the recent decades.
- Identification of cause-effect for gully system formation will help to identify effective SWC strategies that will decrease the risk of gully formation.

Table 1. Main feasible actions for controlling gully system formation

Gully types	Main causes	Remediation action
Barrier	Concentrated flows	- Effective barriers (thick barriers + close gaps, e.g. by using olive prunes).
Road	Runoff generating & concentration	- Diversion channels to safe drainage paths
Shallow	Saturated overland flow	- Diversion channels - No or late tillage - Roughen soil surface??
Tillage furrows	- Up-down tillage furrows	- Sturdy contour furrows - Contour buffer strips
Forest	- Concentration flows - Tillage step at top of orchard	- Sturdy contour furrows - Safe drainage path
Long slope	- Accelerated flows - Shallow soil	- Diversion channels - Late tillage - Roughen soil surface - Contour buffer strips
Plan concavity	- Concentrated flow due to topography-	- Diversion channels - Retard flows
Tractor path	- Tracks path generating flows	- Mule tillage - Roughen soil surface - Avoid tractor paths perpendicular along the contour

References

Geyik, M. P. 1986. FAO Watershed management field manual, Gully control. *FAO conservation manual guide 13/2*. FAO, Rome, Italy.

Hoorelbeke, S., Turkelboom. F., Deckers. J., Poesen. P., Masri. Z., De Pauw. E. 2006. Long-term impact of cultivation on soil properties in the hilly olive orchards of NW-Syria. Paper presented in ISCO, 15- 19 May, 2006, Marrakech, Morocco.

Lal, R. (editor), 1994. *Soil Erosion Research Methods*. 2nd Ed. Soil and Water Conservation Society, Ankeny, Iowa.

Morgan, R.P.C. 1995. *Soil Erosion & Conservation*, 2nd Edition, Longman Group Limited, London.

Stocking, M., Murnaghan, N. 2001. Land degradation guidelines for field assessment. *Handbook for the field Assessment of Land degradation*. Earthscan publications Ltd, London, Stering VA. 169p.

EROSION PROCESSES AT THE GULLY SCALE: OBSERVATIONS, QUANTIFICATION AND INTERPRETATION OF FIELD DATA FROM THE DRAIX LABORATORY

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1. Introduction

In the Southern French Alps, the black marls formation covers a large area and is highly susceptible to weathering and erosion. It has a badlands topography and is subject to high solid transport, bringing high sediment yield downstream and silting up reservoirs. Many studies have been carried out in southern Europe and North Africa evaluating sediment yield from this type of basin. However, most of these studies provide information on the average annual rate and only a few studies focus on the sediment response to a specific rainfall event (Canton et al., 2001). Scale is important in the study of erosion processes and quantification of sediment production (de Vente and Poesen, 2005). This paper focuses on erosion at the slope and gully spatial scale and at the event temporal scale.

2. Material and Methods

Since 1983, the Cemagref has been monitoring a group of four small basins, with a surface area ranging from 1330 m? to 1.08 km?, in order to study the processes and factors that influence the production, storage and transfer of water and sediments in marly basins and their network. The smallest, called Roubine (1330 m?), is well adapted to the study of erosion processes at the slope and gully scale (Fig. 1). The vegetation cover is limited and gathered at the top of the basin, the hydrographic network is simple and allows for no or very little intermediate sediment storage.

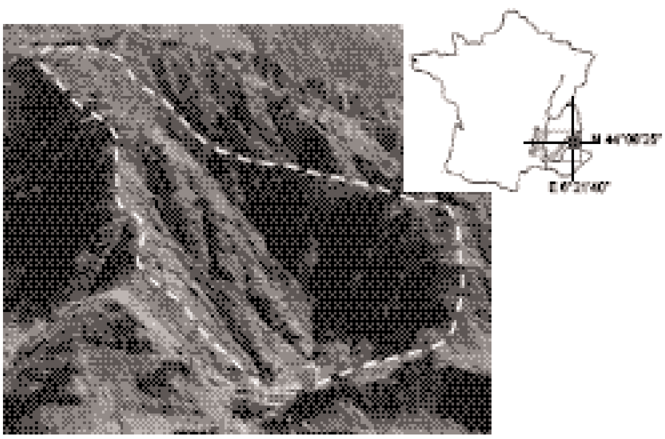

Fig. 1. View and location of the study site.

The basin faces west, the altitude ranges from 848 to 885 m, with very steep slopes (40–45°). The substratum is Callovo-Oxfordian marls with dips facing north at 40°. As a consequence, most of the marl surfaces are perpendicular to the bedding and steep, which is the most favourable situation for infiltration, weathering and erosion (Mathys et al., 2005).

A rainfall recorder measures the precipitation close to the gully with 0.2-mm accuracy. The gauging control section is a V-shaped weir equipped with two level-recorders (one floating device and one numerical ruler). A sediment trap upstream of the gauging station retains the coarse material. The measurement of the deposited material, with a bucket for low volumes and a topographic method for larger deposits, gives the global amount of transported bed-load material. Downstream of the sediment trap grid, an automatic sampler takes samples during floods with a program recording both the water level and the time lag between two samples.

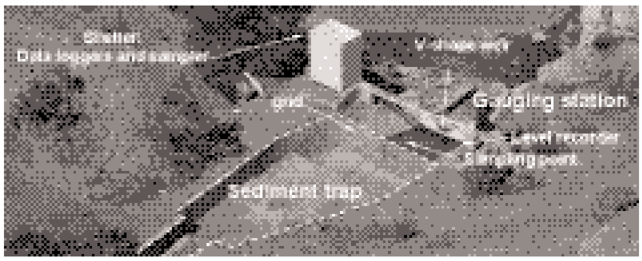

Fig. 2. Measurement device at the outlet of the basin.

Other measurements were conducted occasionally or for shorter monitoring periods:

– soil temperature for different soil depths and aspects,
– properties of the weathered layer such as vertical profile and grain size distribution, and
– water content, bulk density, and grain size distribution of the deposits in the sediment trap.

For the 1985–2003 period, 1016 rainfall events (over 5 mm of total rainfall or over 30 mm h^{-1} in 1 min) were registered, 472 produced runoff at the outlet and 373 yielded measurable erosion. A total of 288 sediment trap measurements are available: 196 for a single event and 92 corresponding to two to nine successive rainfall events. Two hundred and five floods were sampled for suspended sediment.

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3. Results and discussion

Table 1 summarizes various features of the rainfall-runoff-sediment yield data (N is the size of the data set). The large difference between the medians and the maxima highlight the role of the major events in the sediment yield. For the 19 years of the study period, the 19 highest values represent 33% of the total production of the period.

Table 1. Range of values for the main features of the events studied.

	median	Two max values	Dates	N
Rainfall (mm)	18.1	145.4 138.5	14/11/2002 02/11/1994	373
Hourly max intensity (mm h^{-1})	7.8	43.6 43.6	07/08/1996 21/08/1997	373
5-min max intensity (mm h^{-1})	22.8	156 149	25/07/2001 12/09/1995	373
Peak discharge (l s^{-1})	0.9	80 28	08/09/1994 12/09/1995	373
Maximum concentration (g l^{-1})	7.6	293 244	22/10/2002 05/06/2003	204
Average concentration (g l^{-1})	0.6	253 222	22/10/2002 25/08/2003	204
Suspended sediment yield (kg)	37.8	1865 1780	31/03/1992 28/09/1986	204
Coarse deposit in the trap for one event (kg)	330	7500 6035	08/09/1994 01/07/1986	196
Total sediment yield (kg)	541	6622 5744	01/07/1986 05/06/2003	117

3.1. Suspended sediment yield

For the data of all the events, there was no relation between sediment concentration and flow discharge, but for one event, as commonly described, hysteresis curves were observed (Alexandrov et al., 2003; Soler et al., 2006). Three types of curve were found: clockwise (type 1), anti-clockwise (type 2) and figure-eight shaped or complex (type 3). These three types were found for all the levels of sediment production, but the high concentrated floods were mainly type 2. The seasonal pattern shows that spring floods were mainly type 1 and June–October (except September) floods were mainly type 2. The rainfall intensity and the peak discharge were the main factors explaining sediment concentration, whereas the depth of the intense fraction rainfall and the runoff volume of the 5 min of maximum discharge explain the total yield.

3.2. Coarse sediment yield

The average amount of sediment deposited in the trap per year is 9 m^3 or 10 kg y^{-1} m^{-2} (bulk density 1.5 Mg m^{-3}). Many events with high rainfall depth produced low or no deposit, whereas a moderate rainfall amount could yield a huge amount of coarse sediment. For the trap volumes corresponding to a single event, the deposited volume was correlated with the peak discharge (R = 0.7), but several low discharges yielded high amounts of deposit and most of the corresponding events were in spring.

3.3. Total sediment yield

The total sediment yield was related to both the peak discharge of the event and the amount of intense rain (threshold, 15 mm h^{-1}), but in some cases these variables considerably underpredicted the erosion (Fig. 3). This occurred mainly in spring when the weathered mantle was very thick because of freez–thaw processes in winter and debris accumulation in the gully bottom. The ratio of suspended sediment in the total yield was 15% on average and 20% in cumulated amount, but reached 50% for a few events. The most productive months were July–September due to the number and high yield of storms, followed by May and March with rarer productive events.

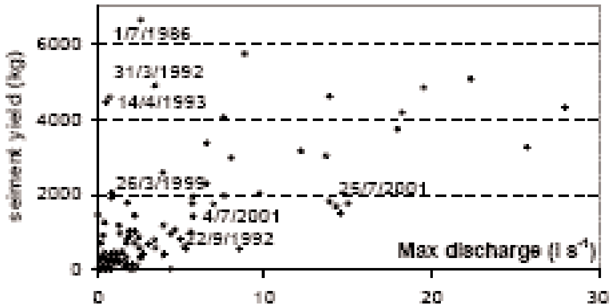

Fig. 3. Sediment yield–discharge relationship.

The analysis conducted on 19 years of rainfall-runoff-erosion data and field observations allows us to propose an erosion production model at the gully scale in marly badlands catchments. A seasonal pattern was observed with the renewal of the weathered mantle in winter, substantial displacement of material with spring events, high production of numerous and intense summer storms, and a decrease in sediment availability in autumn. The detailed succession of the different successive processes within a storm needs to be investigated further.

References

Alexandrov, Y., Laronne, J.B. and Reid, I., 2003. Suspended sediment concentration and its variation with water discharge in a dryland ephemeral channel, northern Negev, Israel. Journal of Arid Environments, 53(1): 73-84.

Canton, Y., Domingo, F., Sole-Benet, A. and Puigdefabregas, J., 2001. Hydrological and erosion response of a badlands system in semiarid SE Spain. Journal of Hydrology, 252(1-4): 65-84.

De Vente, J. and Poesen, J., 2005. Predicting soil erosion and sediment yield at the basin scale: Scale issues and semi-quantitative models. Earth-Science Reviews, 71(1-2): 95-125.

Mathys, N., Klotz, S., Esteves, M., Descroix, L. and Lapetite, J.M., 2005. Runoff and erosion in the Black Marls of the French Alps: Observations and measurements at the plot scale. Catena, 63(2-3): 261-281.

Soler, M., Regues, D., Latron, J. and Gallart, F., in press, Frequency–magnitude relationships for precipitation, stream flow and sediment load events in a small Mediterranean basin (Vallcebre basin, Eastern Pyrenees). Catena.

GULLY DEVELOPMENT AND TOPOGRAPHIC THERSHOLDS, CASE STUDY: KERMAN PROVINCE, SOUTHEAST OF I. R. IRAN

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1. Introduction

Gully development in Kerman province, southeast of I. R. Iran has caused many problems for stakeholders, especially for croplands and their landusers. Gullies are defined as erosional channels with a cross-sectional area larger than 929 cm^2 (Poesen, 1993). Gully erosion is a threshold phenomenon. As such, identification of topographic threshold for gully development in different environments is essential (Poesen et al., 2003). This threshold concept was first applied by Patton and Schumm (1975). Based on this theory, there is a critical slope and drainage area above a gully head to produce sufficient runoff to cause gully development. This phenomenon is examined in an arid environment with dominantly cropland in Kerman province (Fig. 1). Desmet et al.(1999) found that a negative power relationship exists between slope and drainage area above the headcuts for gullies formed by surface runoff.

2. Materials and Methods

In order to test the impact of different control measures on gully development, a research project began in 2002. At first, the gullies were classified based on their location in the landscape, their general and headcut view plans, shape of their cross-sections, land use above headcuts, and soil material. Six representative gullies of one class were selected and benchmarks were installed inside and outside the gullies. The view plan of each gully and headcut and its long profile were surveyed. The soil samples were collected from different layers of gully headcuts. Drainage area and slopes above the headcuts were determined by surveying. After rainstorms with significant runoff (rain which caused changes in gullies) gully development was measured., correlation between gully development as the dependent parameter and drainage area, slope, and the product of drainage area and slopes above headcuts was analyzed using regression method. Correlation coefficients (R^2) were used to determine the most important factors influencing on gully development.

Fig. 1. Map of study area, Kerman Province, I. R. Iran.

3. Results

The research site located in a longitude between 56º, 13', 31.6"E and 56º, 14', 52.4"E and a latitude between 28º, 49' N and 28º, 49', 20"N in Kerman province. The average rainfall in the nearest rain station, Khabr, was 287.8 mm. Study area is mainly croplands and gullies are formed and distributed around them.

Selected gullies had U shape cross section with the average depth of 1.2 m and average length of 17.7 m. Soil texture in the surface and depth was silt-loam and sand content decreases from surface to under layers in the bank of gullies. Fig. 2. shows a sample of studied gullies.

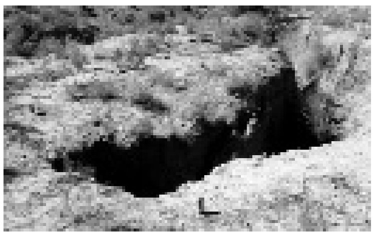

Fig. 2. Sample of studied gullies.

Gully development was measured by two benchmarks inside and outside of headcut in a direction that surface runoff enters into the headcuts (Fig. 3). The distance between two points and headcut was measured after each effective rainfall with surface runoff.

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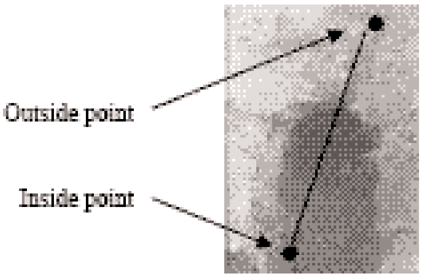

Fig. 3. Inside and outside points to determine gully development.

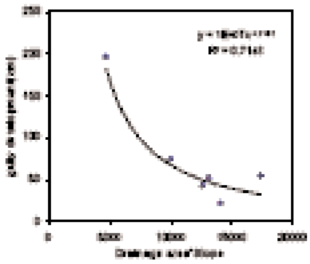

Fig. 4. Relationship between length progress and drainage area*slope.

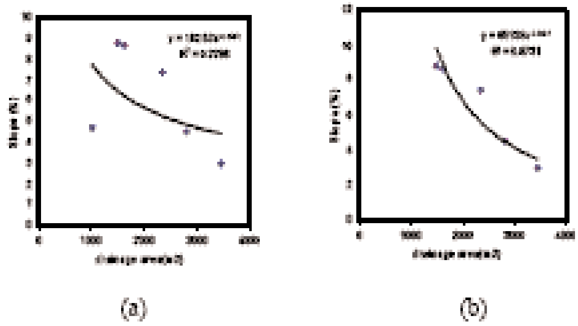

Fig. 5. Relationship between Slope and drainage area.

Headcuts extension was between 22.7 and 196.5 cm in 3 years (Table 1). A power relationship was established between gully development as dependent variable and drainage area, slope and the product of drainage area and slope above headcut in Kerman Province.

Table 1. Values of gully development, slope above headcuts, and headcut drainage area.

Gully	Slope (%)	Headcut drainage area (m^2)	Gully development (cm)
1	4.7	1004.5981	196.5
2	2.9	3452.0294	74.7
3	8.7	1615.8495	22.7
4	4.5	2808.1219	43.2
5	8.8	1493.9235	52
6	7.4	2351.1286	54.5

Comparisons were made between correlation coefficients derived for gully development with (1) only drainage area above headcuts, (2) only slope above headcuts, and (3) product of drainage area and slope above headcuts. These data indicated correlation coefficient of the relationship between gully development and the product of drainage area and slope was the highest(R^2 = 0.71) as compared to using just drainage area or just slope (Fig. 4).

Examining the relationships between gully development with drainage area above headcut and gully development with slope revealed that drainage area is more important than slope on gully development in this arid and agricultural environment.

A negative power relationship indicated in Figure 5 to show the proposed relationship between slope and drainage area above headcuts by Desmet et al.(1999), Our results are agree with Desmet et al.(1999) results(Fig.5-a). It implies that Kerman gullies were formed by surface runoff. Between gullies, one dariange area was covered by croplands and with deletion of this data the correlation coefficient of the relationship between slope and drainage area was improved(Fig 5-b). In our research area, the optimal relative area exponent(b) ranged from 0.46 to 1.2 in gullies.

4. Conclusion and Discussion

This research indicated that gully erosion can severely damage croplands in this area of Iran. Significant gully development occurred in the 3 years of study and the product of drainage headcut area and slope was more strongly correlated to gully development than using just slope or drainage headcut area.

Slope and drainage area indicated an inverse relationship for initiation and development of gullies The relative area exponent (b) ranged from 0.46 to 1.2 in this research. Our results are agree with Desmet et-al's findings. Results imply that with these drainage area above headcuts , slopes less than 2 percent is required for gully development. Therefore, changing slopes above gullies in this region would be recommended to mitigate gully erosion.

References

Desmet, P.J.J., Poesen, J., Govers, G., Vandaele, K. 1999. Importance of slope gradient and contributing area for optimal prediction of initiation and trajectory of ephemeral gullies. *Catena* 37(3-4): 377-392.

Patton, P.C. and Schumm, S.A., 1975. Gully erosion, Northwestern Colorado: a threshold phenomenon. *Geology* 3: 88-90.

Poesen, J., 1993. Gully typology and gully control headcuts: Drainage area and slope above their headcut measures in the European Loess Belt. In Wicherek, S. (Ed.), *Farm Land Erosion in Temperate Plains Environment and Hills*. Elsevier, Amsterdam, pp. 221-239.

Poesen, J., Nachtergaele, J., Verstraeten, G., and Valentin, C. 2003. Gully erosion and environmental change: importance and research needs. *Catena* 50: 91-133.

HYDROLOGICAL AND SEDIMENT DYNAMICS WITHIN A SMALL CATCHMENT WITH BADLAND AREAS

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1. Introduction

Badlands are the main sediment source areas affecting the headwaters of the Gállego and Aragón rivers in the Central Spanish Pyrenees. These morphologies characterise the landscape of the Inner Depression, occupying about 15 km^2, which represent more than 2.5 % of the Inner Depression, and their occurrence is mainly associated to marly outcrops. Beguería (2005) suggested that Eocene Marls are the main sediment source in the Central Spanish Pyrenees, since this lithology is very sensitive to weathering and erosion processes.

Previous studies showed that the hydrological response and sediment yield in mountain humid badland areas are highly seasonal and are mainly controlled by regolith development (Regüés and Gallart, 2004). Moreover, rainfall intensity and rainfall depth are considered to be the most important factors in determining the hydrological and sediment response in badland areas (Mathys et al., 2005).

The aim of this work is to study the hydrological and sediment dynamics in a small catchment with badland areas by exploring the temporal variability of the hydrological and sedimentological response, and the relationships between hydrological and sedimentological variables.

2. Study area

The Araguás catchment has an area of 45 ha and it is located in the Inner Depression (Central Spanish Pyrenees), 8 km northwest of Jaca (Fig. 1). The highest divide reaches 1100 m a.s.l. and the outlet is at 780 m a.s.l.

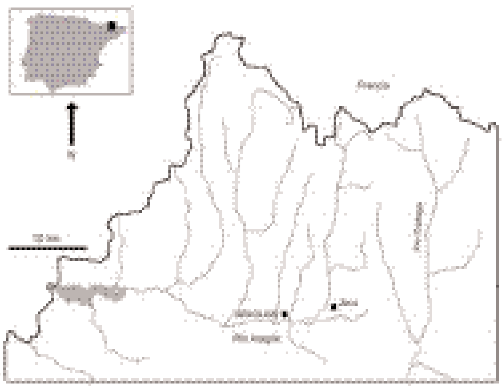

Fig. 1. Map of the localization of the Araguás catchment.

The rock substratum is composed of Eocene Marls in the lower part (massive marls and interbedded decimetre-scale sandy layers). In the upper part of the catchment the bedrock is Eocene Flysch (thin alternating layers of sandstones and marls).

The climate is defined as sub-Mediterranean mountain type with a mean annual temperature of about 10 ºC and mean annual precipitation of about 800 mm, mostly concentrated in autumn and spring.

Three different land cover types can be differentiated: badland areas, associated with the outcrops of Eocene Marls are located in the lower part; grasslands and meadows dominated the central part whereas the upper catchment is covered by dense forest plantation.

3. Equipment and methods

Instrumentation of the Araguás catchment started in 2004 in order to study weathering, erosion and transport processes. In October 2005, a gauging station was installed at the outlet of the catchment; the water level is measured using an ultrasound water-level sensor (Pepperl+Fuchs) and pressure-based water level probe (Keller DCK-22AA); the suspended sediment is measured using a turbidity meter (Endress+Hauser); furthermore, an automatic water-sampler (ISCO 3700) collect samples during flood events to evaluate sediment concentration and analyse for dissolved salts. All instruments are connected to a datalogger (Data Taker DT50) that scans the information every 10 seconds, recording the average value every 5 minutes.

Three tipping-bucket rain gauges (David Instruments) were installed from the lowest to the highest parts of the badland area (780 m, 800 m and 1000 m a.s.l.).

Finally, air temperature and two profiles of regolith temperature in north- and south-facing slopes were recorded and stored every 30 minutes.

Relationships between hydrological and sedimentological variables were analysed at the event scale through a linear correlation matrix.

4. Results

A total of 64 floods were recorded and identified within the study period (October 2005-January 2007). The Araguás catchment reacts to almost any rainstorm event. Most of the rainstorms were small in magnitude, with more than 80 % lower than 15 mm. The highest rainfall amount was 49.8 mm and the highest peak flow was 2046 ls^{-1} (rainfall amount in this event was 28.4 mm). Suspended sediment was always transported during floods and the highest

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suspended sediment concentration (SSC) was 1230 gl^{-1}. More than 50 % of the events exported less than 10 Mg but 3 extraordinary events exported more than 1000 Mg.

Fig. 2 shows two examples of flood hydrographs with their sedigraphs. The response was characterized by a rapid hydrological and sedimentological response, a relatively narrow flood peak and a steep recession limb. The peaks of suspended sediment concentration almost coincide or slightly precede the peak flow. Moreover, there is a good adjustment between the shape of the hyetograph and the hydrograph, suggesting a large contribution to overland flow processes (Fig. 2).

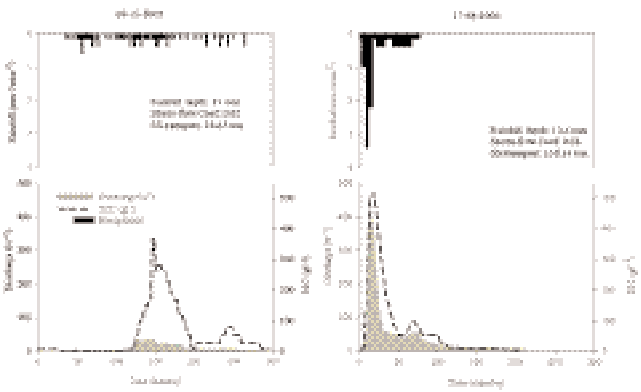

Fig. 2. Hydrographs, sedigraphs and hyetographs for two selected events of different magnitude in the Araguás catchment.

Table 1. Linear correlation coefficients between hydrological and sedimentological variables for the observed rainfall-runoff events. n=64 ** correlations are significant with p<0.01 and *correlations are significant with p<0.05.

	Storm-flow coefficient	Peak flow (ls^{-1})	Peak of SSC (gl^{-1})	SS transport (gl^{-1})
Rainfall depth (mm)	**0.598****	**0.686****	**0.429****	**0.638****
Maximum rainfall intensity (mm h^{-1})	0.192	**0.657****	**0.313***	**0.261****
Baseflow (ls^{-1})	**0.339****	**0.398****	0.124	0.239
Peak flow (ls^{-1})	**0.575****	1	**0.377****	**0.695****
Storm-flow (mm)	**0.797****	**0.673****	**0.391****	**0.793****
Rainfall depth 1 day before the event (mm)	-0.058	-0.021	0.125	-0.026

Table 1 summarises the linear correlation coefficients between some hydrological and sedimentological variables. Storm-flow coefficient show good relationships with rainfall depth, peak flow and storm-flow. No significant correlations were found between the storm-flow coefficient and rainfall intensity and rainfall recorded one day before the event. Peak flow was significantly correlated with all variables except with the rainfall recorded one day before. Finally, significant correlations were observed between maximum suspended sediment concentration and suspended sediment transport and rainfall depth, maximum rainfall intensity, peak flow and storm-flow.

5. Discussion and conclusions

This study shows the high variability of the hydrological and sedimentological response in a small catchment characterized by extensive badlands areas, as described in other previous studies (Mathys et al., 2003). One of the most relevant features of this Mediterranean catchment was its responsiveness, with very high suspended sediment concentrations and yield, closely related to badland development and dynamics (Regüés and Gallart, 2004). Correlation analysis indicated that no single variable was able to explain the hydrological and sedimentological response of the Araguás catchment.

The similarity between the hydrograph, the sedigraph and the hyetograph, as well as the rapid response of most of the floods, suggests a large contribution of the overland flow, mainly resulted from the generation of infiltration excess runoff on badland areas.

Badlands are one of the most erosive morphologies due to their superficial dynamics, mainly affected by the climatic seasonality. Marls are subject to strong weathering, as shown by the mean erosion rate estimated in the catchment, close to 2.9 cm $year^{-1}$. The dynamics and effectiveness of weathering processes related to erosion processes produce high suspended sediment values. In this way, each event in a badland area can be compared to many responses in vegetated areas.

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References

Beguería, S. 2005. Identificación y Características de las Fuentes de Sedimento en Áreas de Montaña: Erosión y Transferencia de Sedimento en la Cuenca Alta del Río Aragón. Instituto Pirenaico de Ecología: Zaragoza.

Mathys, N., Brochot, S., Meunier, M., Richard, D., 2003. Erosion quantification in the small marly experimental catchments of Draix (Alpes de Haute Provence, France). *Catena,* 50 (2-4): 527-548.

Mathys, N., Klotz, S., Esteves, M., Descroix, L., Lapetite, J.M. 2005. Runoff and erosion in the Black Marls of the French Alps: Observations and measurements at the plot scale. *Catena*, 63: 261-281.

Regüés, D. and Gallart, F. 2004. Seasonal patterns of runoff and erosion responses to simulated rainfall in a badland area in Mediterranean mountain conditions (Vallcebre, Southeastern Pyrenees). *Earth Surface Processes and Landforms,* 29: 755-767.

**ASSESSMENT OF GULLY EROSION USING PHOTOGRAMMETRIC TECNIQUES.
A CASE STUDY OF THE UPPER MBULUZI RIVER, SWAZILAND**

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1. Introduction

Swaziland is severely affected by gully erosion contributing to a sediment budget up to 250,000 m^3 y^{-1} (WMS Associates, 1988). This type is more important than inter-rill and rill erosion. Severe gully erosion is mainly in the Middleveld especially on communal land highly populated (43.65 inhabitants km^{-2}) and with high livestock concentrations. Here, the calculated carrying capacities are 0.27 LSU ha^{-1} (Livestock Units) vs. stocking rates 0.87 LSU ha^{-1}.

In general, to assess gully erosion, numerous investigators have made use of aerial photos and GIS to predict the morphometric conditions that favoured gulling (Nachtergaele and Poesen, 1999).

In Swaziland, from 1947 to 1987, the WMS Associates (1988) established gully erosion rates from aerial stereo photos. Subsequently, Mushala et al., 1994 analyzed the gullies distribution and their relationship to lithology and land tenure.

In the present research long terms rates of gully erosion have been measured by aerial photos taken from 1947 to 1996. Particular attention was focused on two dendritic gully systems. One of them is dynamically evolving, whereas the other one is in a static phase (Sidorchuk, 1999). The objectives of this research were to calculate the historical development of the morphology of gully as input data to the *gully erosion model* (Sidorchuk et al., 2001) and to predict hillslope area susceptible to gulling. A High Digital Terrain Models (HDTMs) with 1-m resolution were devised for this purpose.

2. Materials and methods

2.1. Study area

The study site “Fig. 1” is located in Mbothoma, 15 km north of Manzini (26°20’S; 31°23’E). This area is in the Mhalambanyoni river basin (42 km^2) a tributary of the Upper Mbuluzi river, Swaziland. Mbothoma district is a densely populated area with widespread overgrazing. The altitude ranges from 610 to 760 m a.s.l. and the mean slope is about 12%. The lithology consists of a thick granodioritic saprolite layer and a system of amphibolite and serpentite dykes (Hunter et al., 1984; Mushala et al., 1994). The mean annual rainfall ranges from 700 to 1,200 mm. Kiggundu (1986) has calculated a rainfall erosivity (EI_{30}; Wischmeier and Smith, 1978) of 450 KJ mm m^{-2} h^{-1}.

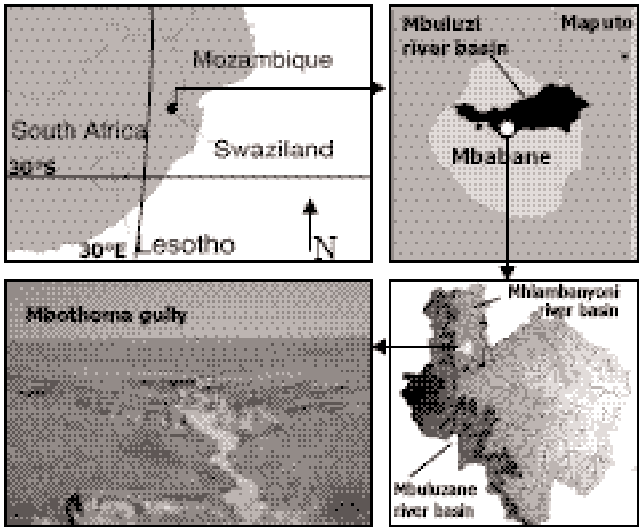

Fig. 1. Location of the study area, Mbothoma, Swaziland.

2.2. DTM analyses

To determine the historical development of gullies, aerial stereo photos were analyzed using a photogrammetric stereoanalyser (Planicomp P33, Carl Zeiss, Jena). To obtain HDTMs “Fig.2”, gully breaklines, borderlines and surface points were digitized from 1940s, 1960s, 1970s, 1980s and 1990s aerial photo series. The georeferencing was done with 1:5,000 scale orthophoto maps.

The stereo photo analysis was repeated using an automatic digital procedure to cover a bigger surface. This approach was taken because gully erosion is often caused by the hydraulic saturation overland flow. These HDTMs were utilized to calculate the flow lines (MDD8-combined flow; Schäuble, 2003) and to predict hillslope areas susceptible to gulling by Topographic Wetness Index (TWI; Moore et al., 1988). For the areas affected by footpaths and tracks the headcut was predicted using a ratio of flow length to flow accumulation (MDD8-combined flow; Schäuble, 2003).

3. Results

A quantitative assessment of gully dynamics was conducted by comparing the elevation of gully mouth for different time steps of aerial photos. The results show that the mean lowering rate of the gully bed was of 0.25 m y^{-1} during the 1960 decade and of 0.93 m y^{-1} for the two

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following decades. Selective erosion affected the river bed from 1960 to 1990. The erosion of granodioritic saprolite was more intensive, with 0.77 m y^{-1}, than the amphibolite dykes with 0.59 m y^{-1}, so new steps of a longitudinal profile were formed. Furthemore, a field observation in the 1999 showed a collapse of an amphibolite dyke, crossing the river downstream the gully study site. It is hypothesized that the Tropical Cyclone named Domoina in January 1984 (242 mm d^{-1} in Mbothoma area) caused the removal of the blocking dikes and consequently the erosional base was lowered instantaneously.

In the 1947 photos the dynamic gully investigated was absent, but the surface was cut by a cattle trail. In 1960 it was about 180 m long and 5 m deep, presently the cutting has continued above the gully head. In the 1998 it was 490 m long and 14 m deep. Hence, in the first 11 years the average growth rate was 2 m y^{-1} along the axial part. It deepened of 0.64 m y^{-1} while it widened of 0.36 m y^{-1}. From 1971 to 1998 the gully

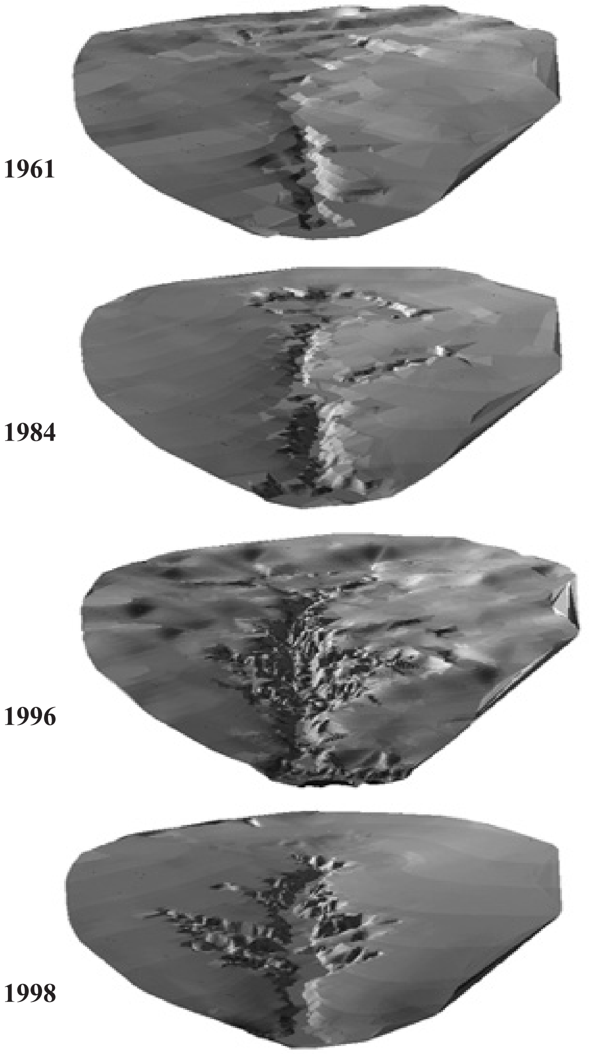

Fig. 2. Time series of the Mbothoma gully (Manzini, Swaziland). High resolution DTMs (1mx1m) derived from photogrammetric stereoanalyser and survey (1998).

length increased of 10 to 11 m y^{-1}; its depth increased at the rate of 0.14 m y^{-1} while the width rate was 0.4 m y^{-1}.

Hillslope areas susceptible to gulling were predicted based on TWI and by using a ratio of flow length to flow accumulation. This analysis will be used in a subsequent step to assess the regional potential for gulling.

4. Conclusions

The results show that gully erosion are associated with footpaths and tracks. The mean lowering rate of the gully bed increased from 0.25 m y^{-1} during the 60s to 0.93 m y^{-1} during the next two decades. The bedrock plays a role in affecting the temporary base level. A catastrophic event due to a Tropical Cyclone caused the removal of the dikes with consequent lowering of the stream base level.

This study shows that the use of remote sensing is particularly suitable in area lacking of monitoring structures; it can provide important information on erosion. In this specific research the use of aerial photos and GIS techniques was able to predict the development of the gully pattern and the areas susceptible to gully formation. In addition it was possible to quantify the gully erosion from the time aerial photos were available.

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References

Hunter , D.R., Baker, F., and Millard, H.T., 1984. Geochemical investigation of archean bimodal and dwalidle metamorphic suites, Ancient Gneiss Complex, Swaziland. *Precambrian Res., 24*:131-155.

Kiggundu, L., 1986. Distribution of rainfall erosivity in Swaziland. *Research paper 22*. Kwaluzeni Campus, University of Swaziland.

Moore, I.D., Burch, G.I., and MacKenzie, D.H. 1988. Topographic effects on the distribution of surface soil water and the location of ephemeral gullies. *Transactions of the American Society of Agricultural Engineers*, *31*:1098-1107.

Mushala, H.M., Scholten, T., Felix-Henningsen, P., Morgan, R.C.P., and Rickson, R.J. 1994. Soil erosion and river sedimentation in Swaziland. *Final report to the EU*, Contract number TS2-CT90-0324.

Nachtergaele, J., and Poesen, J., 1999. Assessment of soil loss by ephemeral gully erosion using high-altitude (stereo) aerial photographs. *Earth Surface Processes and Landforms, 24*:693-706.

Shäuble, P., 2003. HydroTool 1.0 for ArcView 3.x. Hydrological analyses with single-flow and multiple-flow algorithms. *http//www.terracs.de*.

Sidorchuk, A. 1999. Dynamic and static models of gully erosion. *Catena*, *37*:401-414.

Sidorchuk, A., Märker, M., Moretti, S., and Rodolfi, G., 2001. Soil erosion in the Mbuluzi river catchment (Swaziland, South Africa). Modelling the dynamic evolution of gullies. *Geografia Fisica e Dinamica Quaternaria, 24:*177-187.

Wishmeier, W.H., and Smith, D.D., 1978. Predicting rainfall erosion losses – a guide to conservation planning. *Agricultural handbook,537*. USDA, Washington DC.

WMS Associates 1988. Gully erosion in Swaziland. *Final report*. Fredericton, N.B., Canada.

ACTIVITY OF GULLIES DURING THE HOLOCENE IN THE EBRO VALLEY

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1. Introduction

The flat-bottomed valleys in the central sector of the Ebro Depression keep sediment records that enable the paleoenvironmental reconstruction from the Upper Holocene, differentiating alluviation phases alternated with incision phases and explaining the presence of active gullies since the Roman era.

2. Study Area

The central sector of the Ebro Depression is characterized by the presence of lake Miocene sedimentary series, composed of lutites, sands and evaporitic formations with limestones at their top levels. During the Pliocene, the discharge of the lake basin to the Mediterranean Sea started (García-Castellanos et al, 2003) through the Ebro fluvial network formation, which has shaped land configurations of the "muela" type (flat-topped tabular mountain of ~700 m) and has opened broad valleys with important Quaternary accumulations. Among them, the flat-bottomed valleys, locally called "*vales*," constitute one of the most representative landscape formations. These are valleys filled with sediments coming from the erosion of the surrounding hillsides that could not be drained through the fluvial network. In some cases, these bottoms are incised by still active gullies (Peña et al., 2004), linked to other processes such as piping or landslides, which are also observed in other sites (in the low Huerva valley, Barrón et al., 1995; in Southeast Spain in dispersive marls, Harvey, 1982; López Bermúdez and Romero, 1989; Faulkner et al., 2003 or Desir and Marín, 2006, in Bardenas, in the Ebro Basin).

Some of the factors that help understand the piping dynamics include the presence of easily dispersible silty soil, scarce plant cover, flat topography accelerating water infiltration and favoured by surface cracks, and a water gradient facilitating the mechanical erosion of water (Gutiérrez et al., 1988).

3. Holocene evolution and gulling activity

The Holocene evolution of the *vales* in the central sector of the Ebro Depression is represented by the existence of three accumulative levels, the oldest of which (N3) takes up a large extension, while the more recent ones (N2 and N1), only appear in sectors of fluvial incision. The dating of these deposits has been carried out by means of geoarchaeological prospection techniques, such as geomorphologic mapping and the analysis of organic remains, through ^{14}C, or archaeological remains.

N3 level, or general level, reaches a great continuity in all the *vales* analyzed, being this one, in many cases, the single level. The basal sediments show ages ranging between 6015±75 yr BP for the *val de la Morera*, 5910±270 yr BP in *Las Lenas* (in the Huerva valley) and 4270±55 yr BP in the *Barranco de Alfocea* (Fig. 1) or *Barranco de Los Lecheros*, a tributary on the left bank of the River Ebro (Constante et al, 2006), coinciding with the dryer and warmer climate of the Atlantic Climate Optimum, although it is true that some marginal sediments in *Las Lenas* present pre-Holocene ages (Andres et al., 2002). The *barranco de Miranda* is a tributary on the left bank of the River Ebro and contains important archaeological remains (Fatás, 1972 a, b) that range from the Iron Age to the Iberian-Roman Period (V BC-I AD), which has enabled us to establish the relative chronology of the various cumulative levels, as well as to relate it with the environmental characteristics and the human occupation of the territory (Peña, 1996). The top of the accumulation, constituted by silts of the late Post-Roman Period (1.500 yr BP), forms a totally flat surface linked to alluvial fans at their exits towards the main valleys. The time coincidence of these fillings with periods of intense human occupation of the environment, since the Bronze Age to the Roman Period, allows us to imagine that deforestation has been decisive in the increase of the erosion rates, since the hillslopes are no longer protected.

Once this filling stage ends, an incision period starts that lasts up to nowadays and remains active in the most important *vales*, or with an increased longitudinal gradient. The sediments are transported from the *vales* to the main streams (e.g., Huerva River and Ebro River), which carries them towards the Mediterranean Sea, widening the Ebro River Delta since the 4th century.

Gully developments over the last 1500 years triggered by a combination of human-induced land cover changes and extreme rainfalls have been documented (Faulkner, 1995, in southern Spain; Peña et al., 2000, in the Ebro Basin; Poesen et al., 2000, in Belgium).

Fig. 1. Gully in the *Barranco de Alfocea*.

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Inside these gullies there were sedimentation episodes that originated N2 levels, from the Medieval or Post-Medieval Ages associated with the Medieval Climate Optimum (Peña, 1996) and N1 levels, 380±60 yr BP, that can be related to extreme events of the Little Ice Age. The subsequent incision has left this terrace inactive, remaining a current bed subjected to short alternating filling and incision cycles. The good longitudinal connection between levels N1 and N2 and the corresponding alluvial terraces of the Huerva River support the climatic nature of these deposits from the Post-Roman Period, with a less important anthropic action in an environment that has not recovered its biostasic state since the main disturbance of the Iron Age-late Roman Period.

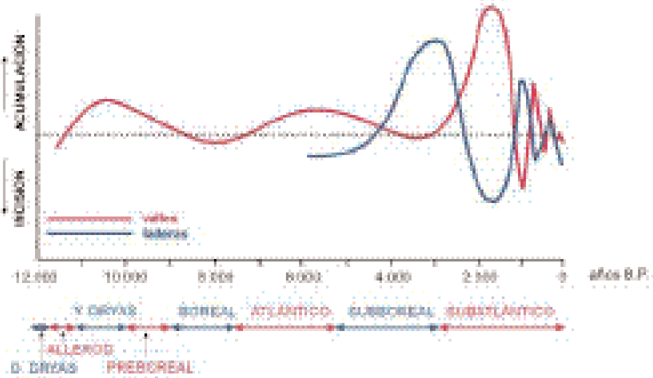

Fig. 2. Accumulation and incision phases in hillslopes and Holocene valley fillings, chronologic connection with the Holocene division and large phases based on archaeological data of the NE of Spain (Peña et al., 2005).

4. Conclusions

The use of detailed geomorphology for the study of the Upper Holocene and the application of geoarchaeology and radiometric datings make it possible to get important results on the recent stages of valley bottom shaping. The timing of the aggradation and degradation phases shows the activity of the processes over the last 8000 years and the decisive influence of the Holocene evolution on present landscapes (Fig. 2).

The reasons for this phase alternation are anthropo-climatic, as Jordá and Vaudour (1980), Bintliff (1981, 1982), Gutiérrez and Peña (1998) and Peña (1996), Peña et al. (2000, 2004) recognize in different sectors of the Mediterranean basin.

The gullies formation and activity from the late Roman Period has progressed by means of a regressive activity of the headwaters, although the excavation process has been temporarily interrupted by new fillings.

References

Andres, W., Ries, J., Seeger, M. (2002) Pre-Holocene sediments in the Barranco de las Lenas, Central Ebro Basin, Spain, as indicators for climate-induced fluvial activities. *Quaternary International*,pp. 93-94 and 65-72.

Barrón, G., Echeverría, MªT, Ibarra, P., Marco, P., Pérez, F. and Sesé, P. (1995) Algunos datos sobre la evolución de los pipes en el bajo Valle del Huerva (Zaragoza, España). *Actas del VII Coloquio Ibérico de Geografía*. Cáceres.

Bintliff, J.L. (1981) Archaeology and the Holocene evolution of coastal plains in the Aegean and circum-Mediteranean. In, D. Brothwell & G. Dimbleby (Eds.). Environmental aspects of coast and island, *BAR Int. Series, 94*: p. 11-31.

Bintliff, J.L. (1982) Paleoclimatic modelling of environmental changes in the East Mediterranean region sincethe last Glaciation. In. J.L. Bintliff and W. Van Zeist (Eds.). Paleoclimates, Paleoenvironments and Human Communities in the Eastern Mediterranean Region in Later Prehistory. *BAR, IntSer.:* p. 485-527.

Constante, A., Dossche, R., Peña, J.L., Sancho, C. and de Dapper, M. (2006) Dinámica morfosedimentaria holocena en laderas y valles del escarpe de Alfocea-Juslibol (sector central de la Depresión del Ebro). *Actas de la IX Reunión Nacional de Geomorfología*. *Geomorfología y Territorio*. Santiago de Compostela, p. 979-992.

De Ploey, J. (1990) Threshold conditions for talweg gullying with special reference to loess areas. In Bryan, R.B. (Ed.) Soil Erosion. Experiments and Models. *Catena* Suppl.,*17*:p. 147-151.

Desir, G. and Marín, C. (2006) Evolución y procesos de erosión en gullies. Bardenas Reales (Navarra, España). In Pérez Alberti, A. y López Bedoya, J. (Eds..) *Geomorfología y Territorio*. Actas de la IX Reunión Nacional de Geomorfología, Santiago de Compostela, p. 189-199.

Fatás, G. (1972a): Un poblado zaragozano que perdura hasta el Imperio. Estudios I, Zaragoza: p. 155-163.

Fatás, G. (1972b) Excavaciones en el castillo de Miranda. Noticiario Arqueológico Hispánico*,* 1, Zaragoza: p. 277-169.

Faulkner, H. (1995) Gully erosion associated with the expansion of unterraced almond cultivation in the coastal Sierra de Lújar, S. Spain. *Land Degradation and Rehabilitation, 9*: p. 179-200.

García-Castellanos, D., Vergés, J., Gaspar-Escribano, J. and Cloething, S. (2003) Interplay between tectonic, climate and fluvial transport during the Cenozoic evolution of the Ebro basin (NE Iberia). *Journal of Geophysical Research*, 108 (B7), p. 2347.

Gutiérrez, M. and Peña, J.L. (1998) Geomorphology and Upper Holocene climatic change in Northeastern Spain. *Geomorphology, 23*: p. 205-217.

Harvey, A. (1982) The role of piping in the development of badlands and Gully systems in south-east Spain.,. In Bryan, R. & Yair, A. (Eds). *Badland. Geomorphology and Piping*. Geobooks: p. 317-336.

Jordá, M. and Vaudour, J. (1980). Sols, morphogènese et actions anthropiques à l'époque historique s.l. sur les rives nord de la Mediterranée, *Naturalia Monspeliensia*, nº hors série, Montpellier, p. 173-184.

López Bermúdez, F. and Romero, M.A. (1989) Piping erosion and badlands devellpment in Southeast Spain. In Yair, A. & Berkowitz, B. (Eds.) Arid and semiarid environments-Geomorphological and Pedological Aspects. *Catena Suppl., 14*: p. 59-73.

Peña, J.L. (1996) Los valles Holocenos del escarpe de yesos de Juslibol (sector central de la Depresión del Ebro). Aspectos geomorfológicos y geoarqueológicos, *Arqueología espacial*, 15, p. 83-102, Revista del Seminario de Arqueología y Etnología Turolense, Teruel.

Peña, J.L. , Echeverría, M.T. , Julián, A. and Chueca, J. (2000) Processus d'accumulation et d'incision pendant l'Antiquité Classique dans la vallée de la Huerva (Bassin de l'Ebre, Espagne). In, F. Vermeulen and De Dapper, M. (Eds.): *Geoarchaeology of the Landscapes of Classical Antiquity*, p. 151-159.

Peña, J.L., Julián, A., Chueca, J., Echeverría, M.T. and G.R. Ángeles. (2004) Etapas de evolución holocena en el valle del río Huerva: geomorfología y geoarqueología. In, J.L. Peña, L.A. Longares and M. Sánchez (Eds.). *Geografía Física de Aragón. Aspectos generales y temáticos*. Universidad de Zaragoza e Institución Fernando el Católico. P. 289-302

Peña, J.L., Sancho, C. and Rubio, V. (2005) Aportaciones desde la geomorfología y la geoarqueología al conocimiento de los paleoambientes holocenos del NE de España. Actas X Coloquio Ibérico de Geografía. Évora (en prensa).

Poesen, J., Nachtergaele, J., Verstraeten, G., Valentin, C. (2003) Gully erosion and environmental change: importance and research needs. *Catena*, *50, (2-4):* p. 91-133.

RECENT DEVELOPMENTS IN GULLY EROSION RESEARCH AND THEIR IMPLICATIONS FOR CONTROLLING SOIL LOSS AND SEDIMENT YIELD

(Keynote)

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Soil erosion by water causes significant soil degradation worldwide. Most erosion process research and erosion control has focussed on sheet and rill erosion. Relatively little research has dealt with (ephemeral) gully erosion which is illustrated, for instance, by a recent review of soil erosion studies in Europe (Boardman and Poesen 2006). Gullies typically occupy less than 5 % of the upland area, but gully erosion may be held responsible for relatively large soil losses (up to 80 %) by water erosion and related sediment production with significant on and off site consequences. Hence, controlling soil erosion in concentrated flow zones pays of. However, innovation in research on gully erosion control is rather limited compared to progress in research on gully (or more generally concentrated flow) erosion processes (Poesen et al. 2003). The objectives of this study are therefore to review recent developments in gully erosion research that have implications for improving the effectiveness of (ephemeral) gully erosion control measures and to formulate some important challenges.

Various techniques can be applied to control ephemeral gully erosion rates by increasing topsoil resistance to erosion by concentrated flow : e.g. conservation tillage, avoiding sub soiling, soil compaction, increasing crop density (double drilling), stimulating microbiotic crust development and establishing grassed waterways. Other techniques include the planting of selected species in concentrated flow zones (vegetation barriers) so as to interrupt sediment connectivity in the landscape. For this, a methodological framework is needed to select plant species based on suitable aboveground (e.g. stiffness, sediment trapping capacity) and belowground (e.g. fine root density and root tensile strength) biomass characteristics. Structural measures to control gully head cut retreat or gully channel deepening include the establishment of geomembranes, drop pipe structures and check dams. However, each of these techniques has a different effectiveness, advantages and disadvantages, depending on the environmental conditions as will be illustrated with examples from various countries.

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Despite these recent developments, important challenges in gully erosion control research remain. Among these we list the following ones:

– the prevention and control of soil piping and tunnelling, as these erosion processes often precede gully initiation or are associated with rapid gully expansion;
– the prevention and control of large gullies in tropical and subtropical environments;
– the conditions for natural infilling of gully channels;
– the selection of suitable native plant species for controlling gully development in different environments taking both above- and belowground biomass characteristics into account;
– the long-term environmental impacts and sustainability of gully erosion control measures; and
– soil loss tolerance for gully erosion.

References

Boardman, J. and Poesen, J. 2006. Soil Erosion in Europe. Wiley, Chichester, UK, ISBN 0-470-85910-5, 855 p.

Poesen, J., Nachtergaele, J., Verstraeten, G. and Valentin, C. 2003. Gully erosion and environmental change: importance and research needs. Catena 50(2-4):91-133.

GULLY EROSION IN SEMI-ARID LANDSCAPES - MONITORING OF PROCESSES AND DEVELOPMENT

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1. Introduction

The research project MoGul (Large-scale Monitoring of Gully Erosion in Semi-Arid Landscapes) at Trier and Frankfurt University investigates the various types, development and dependencies of gullies as well as geomorphological processes involved in gullying. The investigations are carried out at different sites following a transect from the semi-arid Ebro Basin in Northeast Spain, via the sub-humid Baza and Guadalentín Basins in Southeast Spain and the arid Drâa Valley in South Morocco to the semi-arid Oudalan in Sahelian Burkina Faso.

Investigations on short-term gully change are mostly realised using field methods for quantification of linear headcut retreat rates. The lack of image resolutions corresponding to the magnitude and dynamics of gully erosion usually prevents the use of remote sensing data, which in contrast to field measurements allow for the rapid and spatially continuous coverage of a site (Marzolff, 1999; Ries and Marzolff, 2003). The objective of this paper is to present an overview of the first results of the MoGul project on gully monitoring which employs large-scale aerial photography taken from remote-controlled platforms (hot air blimp and kites).

2. Methods

The research methods include large-scale aerial photographic surveys, mapping of the regional surroundings and experimental measurements of surface runoff and infiltration capacity, with strong emphasis on monitoring and modelling of gully development with photogrammetry and GIS.

The large-scale aerial photographies were taken with a frequency of between 6 months and 2 years. The resulting high-resolution images (pixel sizes <10 cm) are employed for photogrammetric and GIS analysis in order to quantify gully development with linear, areal and volumetric measures.

The mapping of the surroundings focused on the catchments of the gully-headcuts and described amongst others soil surface characteristics and geomorphodynamic units.

Runoff and erosion data were collected by different experiments within the gully catchments. Infiltration rates were measured by a single ring infiltrometer. Runoff coefficient and erosion rate were determined by plot scale rainfall simulations (Seeger, 2007).

GIS-analysis of the spatial data combined with the experimental point data was performed to characterise the catchments runoff and erosion behaviour.

3. Results

Maximum linear headcut retreat rates for 12 gullies were analysed in order to investigate their relation to patterns of runoff and infiltration behaviour in the gully headcut surroundings.

Table 1. Experimental data on erosion rates (from rainfall simulations, summarised after 30 min experiment) and monitored headcut retreat rates.

Study region	erosion rate [g m^{-2}] min	erosion rate [g m^{-2}] max	headcut retreat Rmax [m a^{-1}]
Northeast Spain	0.1	94.3	0.07 – 0.50
Southeast Spain	4.5	93.6	0.13 – 0.51
South Morocco	2.7	29.2	0 – 0.31
Burkina Faso	0.0	312.0	3.16 – 9.85

Retreat rates for South Moroccan sites (0-0.31 m a^{-1}) were found to be lower than those obtained for Spanish gullies (0.07-0.51 m a^{-1}); however, by far the highest maximum retreat was observed in the West-African Sahel (3.16-9.85 m a^{-1}) (see Table 1). Infiltration measurements, runoff coefficients and erosion rates show differing ranges but always high variability within the gully catchments (Table 2).

Table 2. Summarised experimental data on infiltration (by single ring infiltrometer) and on runoff behaviour from rainfall experiments.

Study region	I/RS n	inf. rate [mm h^{-1}] min	inf. rate [mm h^{-1}] max	runoff start [min] min	runoff start [min] max	runoff coefficient min	runoff coefficient max
Northeast Spain	25/48	24	159	00:38	29:30	0.01	0.76
Southeast Spain	10/7	14	60	01:25	06:33	0.44	0.80
South Morocco	8/5	33	67	02:21	06:02	0.16	0.52
Burkina Faso	13/13	16	120	01:00	24:00	0.01	1.00

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Ranges of minimum and maximum values for the soil erosion parameters result in the same ranking of study regions as ranges for maximum linear headcut retreat. This indicates a clear association between runoff behaviour and gully headcut retreat with respect to their spatio-temporal variability.

2D change quantification with detailed maps derived from the large-scale aerial photography provide additional information about the differences in headcut retreat behaviour which cannot be described by linear measures, illustrating the benefits of high-resolution aerial photography for monitoring and understanding gully erosion processes. An example for this quantification technique, the change analysis from Gully Gorom-Gorom, Burkina Faso, is given in Fig. 1.

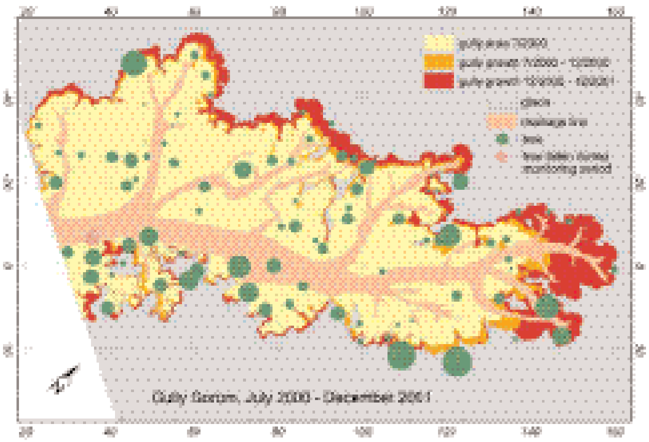

Fig. 1. 2D change analysis of Gully Gorom-Gorom, Burkina Faso, quantifying gully growth during the rainy seasons 2000 and 2001.

4. Conclusions

Like other measurement methods sampling the appearance of a changing object, the technique of large-scale aerial photographic survey also provides snap-shots of an ongoing process, and the development being monitored is described only incompletely depending on the temporal resolution. However, more than other measurement methods, photographic capture of a transient situation allows for retrospective interpretation of the spatial process leading to the actual gully form, and new parameters of interest may be derived years after the survey owing to the spatial continuity and sample density of the camera's "measurements".

Furthermore, the spatially continuous survey of the entire form offers the possibility of distinguishing different zones of activity both at the gully rim and within the gully interior, identifying patterns of erosion and deposition which prove the limited use of linear headcut retreat rates for the assessment of sediment production on a short-term basis.

The combination of this monitoring method with mapping of surface characteristics and the experimental quantification of runoff and erosion processes reveals that the spatial and temporal distribution of runoff generation and sediment production is important for gully development.

References

Marzolff, I., 1999. Großmaßstäbige Fernerkundung mit einem unbemannten Heißluftzeppelin für GIS-gestütztes Monitoring von Vegetationsentwicklung und Geomorphodynamik in Aragón (Spanien). Freiburger Geographische Hefte 57. Freiburg University, Freiburg, pp. 227.

Ries, J. B., Marzolff, I., 2003. Monitoring of gully erosion in the Central Ebro Basin by large-scale aerial photography taken from a remotely controlled blimp. Catena 50(2-4), 309-328.

Seeger, M., 2007: Uncertainty of factors determining runoff and erosion processes as quantified by rainfall simulations. Catena, in press.

INFLUENCE OF SNOWMELT AND HEAVY RAINFALLS ON WATER AND SEDIMENT YIELD FROM LOESS GULLY CATCHMENT (LUBLIN UPLAND – POLAND)

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1. Introduction

Gully erosion is a troublesome process in the loess areas of the SE Poland. In places, where relative heights are 50-100 m, density of gullies reaches 2.5 km·km^{-2}, and locally it is over 10 km·km^{-2}. In the humid temperate climate, gullies have been fixed by forest vegetation, but the water runoff from fields during heavy rainfalls and snowmelt induces erosion processes even on the slopes of wooded gullies (Rodzik, Zglobicki 2000). This causes splitting of arable land as well as silting and sliming of meadows, roads, and settlements in the valleys. The intensity of present-day erosion is difficult to determine because of its episodic occurrence. The effects of disastrous heavy rainfalls and snowmelts can be assessed by means of geomorphological mapping (Buraczyński, Wojtanowicz 1974; Rodzik 1984; Gardziel, Rodzik 2005). However, to seize the brief, particularly night-time rainfall runoff, requires the installation of recording devices.

2. Investigation area

Detailed research was conducted in the gully catchment in Kolonia Celejów, in the NW part of the Lublin Upland, at the edge of the region with the gully net of the highest density in Poland. The gully catchment with the area of 1.23 km^2 and relative heights reaching 50 m (213-165 m a.s.l.) is cut by gullies 5-15 m deep whose total length is 7.5 km. The surface of the catchment is covered by loess 10-20 m thick, on which Luvisols have developed, presently in various degree of erosion. The system of gullies takes up 18% of the gully catchment, the rest being under cultivation. Cereal growing prevails, but recently orchards and berry-shrubs have covered 1/3 of the farmland. The field pattern usually follows the slopes, and that stimulates the development of gullies (Rodzik, Zglobicki 2000) in which secondary succession of dry-ground forest Tilio-Carpinetum has occurred.

3. Research method

The water discharge from the gully catchment was recorded at the mouth of the main gully. A concrete baffle was built, with a water-level indicator, Thomson's V-notch weir, and a digital limnigraph THALIMEDES by OTT, with HYDRAS data recording software. During surface runoffs, every 1-2 hours, water was sampled for turbidity. To determine the sediment load, raising functions were used, derived from the relation between the flow and the turbidity. The results were presented in the hydrological year system (November-October).

Measured were also snow-cover thickness and precipitation level – with Hellmann's ombrometer and by means of a TPG-023 digital pluviograph by A-STER, accurate to 0.1 mm. After each major runoff, the active erosion forms in the gully and within the catchment were mapped and the accumulation volume (area and thickness of depositional forms) on the gully bottom was measured.

4. Results

4.1. Climate and weather conditions

Average multi-annual temperature in this region is 7.7° C, July: 18.1° C, January: –3.4° C. Average multi-annual total precipitation is 600 mm; the highest monthly mean (83 mm) is that of July. Snow cover is present for 75-80 days and usually disappears in March. Average annual discharge is 110 mm, including the surface runoff of 30 mm.

Compared to the above, the period 2003-2006 was dry, with average annual precipitation of 517 mm (Table 1). It was solely in the years 2005-2006 that heavy rainfalls occurred (five times) with the totals of 15-65 mm and the intensity reaching 0.5-2.5 mm·min.$^{-1}$. The winters were quite snowy, with the maximum snow-cover thickness of 30-40 cm. During the winter of 2002/2003 the ground was ice-covered and frozen to 30 cm, during the next one (2003/2004) it did not freeze. In the winter of 2004/2005 the frost penetration was 5-10 cm deep and in the winter of 2005/2006 15-20 cm.

Table 1. Water and sediment yield from the Kolonia Celejów gully catchment in the hydrological years 2003-2006.

Hydrological year	2003	2004	2005	2006	Mean
Precipitation (mm)	419	538	530	580	517
Discharge (10^3 m^3)	37.9	6.6	10.3	17.9	18.2
Discharge index (mm)	30.8	5.4	8.4	14.6	14.8
Sediment load (t)	94.8	0.3	29.2	30.2	38.6
Denudation (t·km^{-2})	77.1	0.2	23.7	24.6	31.4

4.2. Surface runoff and sediment load

During the time of research, ten runoffs occurred, with the intensity of >50 dm^3·s^{-1} (five snow-melt runoffs and five

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rainfall runoffs) and with considerably diversified geomorphological effects (Fig. 1). The highest flow, 382 $dm^3 \cdot s^{-1}$ (308 $dm^3 \cdot s^{-1} \cdot km^{-2}$), was recorded during the thaws on March, 28th, 2006. In four years, from the gully catchment $72.8 \cdot 10^3$ m^3 of water and 155 t of sediment was discharged. 31% of the water discharge and 58% of the sediment transport took place during the several days of the runoff in March, 2003. It was the second big snowmelt runoff in this region in the last twenty-five years (Gardziel, Rodzik 2005). Its volume (18.2 mm) was affected by deep freezing and ice-covering of the ground during January snowmelt. In the first (2003) year of the research, when as many as three snow-melt runoffs occurred, the water discharge was 52% and the sediment load was 61% of four-year totals.

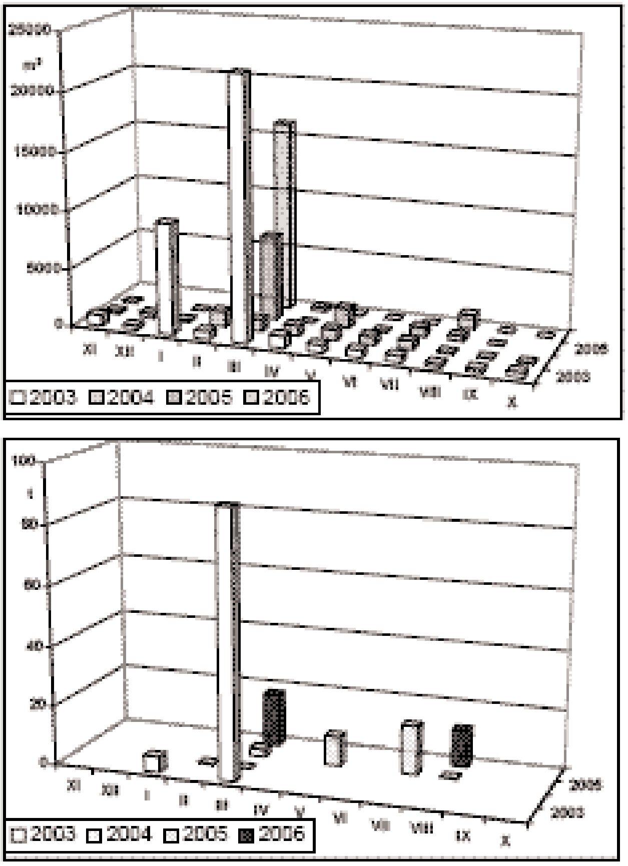

Fig. 1. Monthly totals of discharge (top) and sediment load (bottom) from the Kolonia Celejów gully catchment in the years 2003-2006

In the years 2003-2006 average annual discharge was $18.2 \cdot 10^3$ m^3, and the discharge index was 14.8 mm, which is by half less than average annual discharge index of several decades. Snowmelt discharge was 81% of the figure, whereas heavy rainfall discharge was 6%. The share of snowmelt in sediment load was 75%, and that of heavy rainfalls 25%. However, only 1/4 of the material, set in motion mainly by piping, was discharged from the catchment, the effects of surface wash in the gully and within the catchment was very limited. Most of material (>400 t) was accumulated as colluvial fans and covers in the bottom of the gully. In the accumulation process the prevalence of snowmelt is clearly marked (90%), whereas the role of heavy rainfalls (25%) is mostly visible in sediment load.

Table 2. Snowmelt and heavy rains share in water and sediment yield from the Kolonia Celejów gully catchment in hydrological years 2003-2006.

Index	Snowmelt	Heavy rainfall	Other
Discharge	81%	6%	13%
Sediment transport	75%	25%	0%
Accumulation	90%	10%	0%
Total erosion	84%	16%	0%

Caused by rainfall runoff, the highest flow was 284 $dm^3 \cdot s^{-1}$, and the highest discharge index was 1.3 mm. During the research, however, the precipitation was not as big as in the years 1997-1999 (Zglobicki 2002). Gully bottoms are eroded particularly by disastrous heavy rains occurring every 50-100 years, with the total rainfall of about 100 mm and the intensity of 1-2 $mm \cdot min.^{-1}$; at such time mechanical denudation can reach $4\text{-}10 \cdot 10^3$ $t \cdot km^{-2}$ (Buraczyński, Wojtanowicz 1974, Rodzik 1984).

5. Conclusions

The surface discharge from the gully catchments of the Lublin Upland (Poland) usually is not very high and amounts to about 15 $mm \cdot yr^{-1}$. It is mainly an episodic discharge of snow/rainfall regime. Surface runoff and rill erosion are caused by rains of the total >10 mm and intensity >1 $mm \cdot min.^{-1}$, the main factor of gully erosion is however snowmelt runoff. Most of the material set in motion at that time remains at the bottom of the gully, and can be carried away during heavy rainfalls.

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References

Buraczyński, J., Wojtanowicz, J. 1974: Rozwój wawozów lessowych w okolicy Dzierzkowic na Wyżynie Lubelskiej pod wplywem gwaltownej ulewy w czerwcu 1969 roku. *Annales UMCS, B, 26*: 135-168.

Gardziel, Z. and Rodzik, J. 2005. Rozwój wawozów lessowych podczas wiosennych roztopów na tle ukladu pól (na przykladzie Kazimierza Dolnego). In *Współczesna ewolucja rzeźby Polski*, VII Zjazd Geomorfologów Polskich, Kraków, 19-22.09. 2005: 125-132.

Rodzik, J. 1984. Nateżenie współczesnej denudacji w silnie urzeźbionym terenie lessowym w okolicy Kazimierza Dolnego. In *Przewodnik Ogólnopolskiego Zjazdu PTG*, Lublin 13-15 IX 1984, 2: 125-130.

Rodzik, J. and Zglobicki, W. 2000. Wplyw ukladu pól na rozwój wawozu lessowego. In Radwan, S. and Lorkiewicz, Z. (eds.) *Problemy ochrony i użytkowania obszarów wiejskich o dużych walorach przyrodniczych*, Wyd. UMCS, Lublin, 257-261.

Zglobicki, W. 2002. *Dynamika współczesnych procesów denudacyjnych w pólnocno-zachodniej cześci Wyżyny Lubelskiej*. Wyd. UMCS, Lublin.

SURFACES OF GULLIES GENERATED BY PIPING PROCESS IN ABANDONED FIELDS (SOUTH-EAST OF SPAIN)

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1. Introduction

In the Region of Murcia, the areas where the development of gullies is very important are numerous, in particular in the Neogene-Quaternary sedimentary basins that are filled with marl. In these basins, historically valley bottoms were terraced and turned into culture fields. More recently, from the decade of sixties and seventies to the present time, these terraced culture fields were abandoned and them processes of erosion by "piping" have affected very remarkably. As it is known, this is a process of subsuperficial erosion, that originates underground tubular conduits (pipes), with later loosenings, that usually evolve to gullies, sometimes quite deep, with vertical walls. In this way, a new surface of gullies has settled on these areas, due to human origin.

Different areas of badland related to piping have been studied in the Region of Murcia: Harvey (1982) in Sucina; Romero Diaz and Lopez Bermúdez (1985), López Bermudez and Romero Díaz, 1989), and Romero Diaz et al. (2007), in the River basin of Mula; Vandekerckhove the al. (2000) and Poesen et al. (2002), in the Guadalentín river basin, etc.

It is important to mention how the areas with piping, in the Region of Murcia, are associated to areas of badland and, very specially, to lands that were cultivated and that currently have been abandoned (Sanchez Soriano et al., 2003). The reduced productivity of most of these lands and the process of water erosion affecting these soils, which implies a high cost of maintenance of the culture parcels, are the fundamental reasons for its abandonment. After them, the appearance and/or evolution of piping processes, in susceptible lands, take place immediately.

2. Study area

The studied area is located in the basin of the Mula river, in the municipal term of Campos del Rio, right margin of the Mula river (Figure 1). In the present time it is an area intensely affected by water erosion processes, which explains why it presents an important development of gullies and ravines. Great part of the bottoms of lowest part of valleys were terraced and used as cereal culture first, and as almonds tree culture later in some of them, until approximately the seventies of the last century. Since these days a progressive abandonment has been taking place, and the irreversible deterioration of these culture fields, where the piping process is very developed.

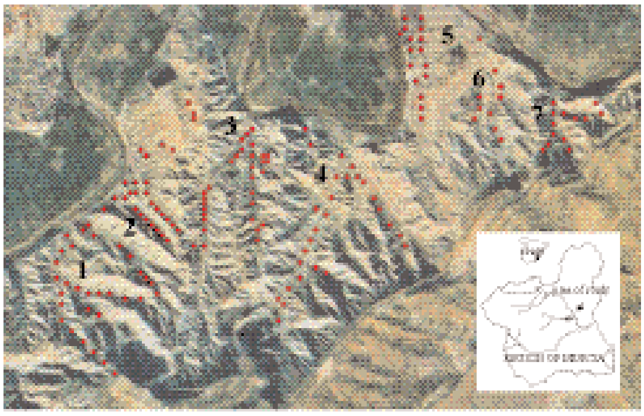

Fig. 1. Study area in the Mula basin (Region of Murcia). The points are plots affected by piping and gullies.

The Mula basin constitutes a Neogene-Quaternary basin that presents an advanced state of excavation. The present hierarchized drainage and canalized by the Mula river towards the Segura river has drained, and continues doing it, the depression composed of marls-clayey. The climatic characteristics are semi-arid, with an average temperature of 17 ºC and annual average precipitations around 300 mm, but with a high irregularity and frequent extreme episodes.

The soils are Calcaric Regosols, developed on marls. The present few existing vegetation does not have the sufficient protective character that these soils need.

The development of the important existing bad-lands in the Mula basin is due fundamentally to the lithology and to the topographic configuration. In the area studied the marly filling is culminated by sandstones levels, that dip slightly towards the Southeastern, delimiting the area of bad-lands and forming a scarp. The remarkable existing topographic gradient between the level of sandstone units and the nearby channel of the Mula river (15% of slope) has favoured the erosion development in gullies and ravines in all this area, becoming thus very important.

3. Methods

The study of piping has been realized from detailed cartographic recognitions, aerial photo interpretation and meticulous field works, next to the determination of some soils analytical parameters. For the recognition of the different areas, at different times, available aerial photograms

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have been used (years: 1956-1978-1984-1999). For the field works the cartography on 1:5.000 scale in line map and orthophotomaps has been used (Figure 1).

By means of the field work the pipe areas have been located and studied their forms and dimensions. Slopes, surfaces, pipe depths, different terraces from culture, altitudes, etc., have been measured with the purpose of relating these data to the different processes that characterize the appearance and the development of piping. On the other hand, these data provide us with important information about the new generated areas of gullies as a result of the pipe evolution.

The study zone has been divided in seven areas that are those displayed in figure 1.

4. Results and discussion

The measurements made show the existing relation between the depth of pipes and the height between agriculture terraces. The development of pipes is so that the pipes may connect two consecutive agriculture terraces, with a length over 8 metres (Figure 2). It should be mentioned how the importance of the hydraulic gradient like one of the generating causes of pipes, since it has already been done by many other authors.

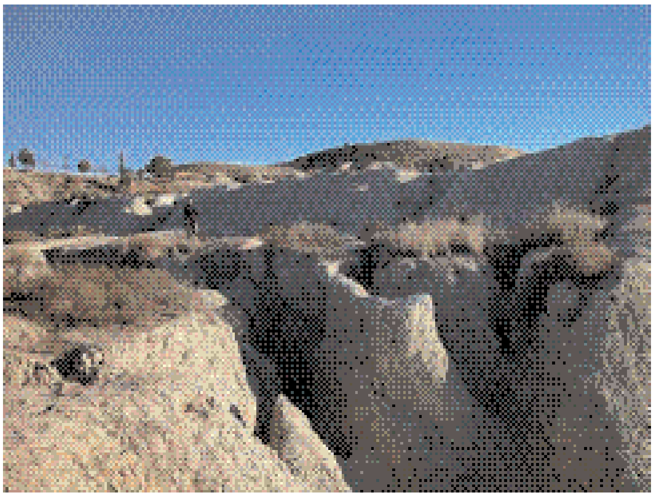

Fig. 2. Gully generated by piping in an abandoned terraced plot.

In most cases, the pipes appear aligned and interconnected, both between the existing ones in the same field and/or between terrace plots having itself generated a new network of drainage, like the one that existed before the terraced plots.

The 7 studied areas occupy altogether a surface of 26.7 hectares, of which 17.6% are affected by processes of piping. 70.7% of the historical layers terraces are affected by piping and 5 hectares are seriously affected (Table 1). It is in these last plots where are hardly recognised, giving way to deep gullies formation.

Table 1. Surfaces affected by piping in the study area.

Area	Surface affected by piping %	Plots affected by piping			Seriously affected hectares
		N°	%	Hectares	
1	11.9	18	72.0	1.4	0.32
2	20.0	2	66.6	0.7	0.23
3	8.9	19	50.0	1.8	0.53
4	6.8	26	88.5	4.9	0.94
5	9.3	8	40.0	1.9	1.12
6	25.7	13	86.6	2.0	0.79
7	40.5	11	90.9	0.5	0.43
Total o mean	17.6	Σ=97	70.7	Σ=13.2	Σ=4.36

5. Conclusions

The piping process have an important development in old agricultural terraced fields. The abandonment of these fields, together with the lithologies, hydraulic and climatic characteristics favour the quick development of pipes. Its subsequent evolution is the development of a landscape with gullies, with a deteriorated and non-recoverable space for agricultural use, in addition to constituting an important sediment source with elevated rates of erosion.

References

Harvey, A., 1982. The role of piping in the development of badlands and gully systems in south-east Spain. En R. Bryan, R. & A. Yair, A. (Eds.) *Badland. Geomorphology and Piping*. Geobooks. Cambridge, 317-335.

López Bermúdez, F. & Romero Díaz, A., 1989. Piping erosion and badland development in South-East Spain. *Catena Supplement*, 14: 59-73.

Poesen, J., Vanderkerckhole, L., Nachtergaele, J., Oostwoud Wijdenes, D., Verstraeten, G. & Van Wesemael, B., 2002. Gully erosion in Dryland Environments. L.J.Bull & M.J. Kirkby (Eds.), *Dryland Rivers. Hydrology and Geomorphology of Semi-Arid Channels*. Wiley, 229-262.

Romero Díaz, A., López Bermúdez, F., 1985. Procesos de erosión en Cuencas Neógenas-Cuaternarias: La Cuenca de Mula. Guía de Itinerarios Geográficos de la Región de Murcia. Departamento de Geografía, Universidad de Murcia., 83-97.

Romero Díaz, A., Marín Sanleandro, P., Sánchez Soriano, A., Belmonte Serrato, F., Faulkner, H. (2007): The causes of piping in a set of abandoned agricultural terraces in southeast Spain. *Catena* 69: 282-293.

Sánchez Soriano, A., Romero Díaz, A. & Marín Sanleandro, P., 2003. Procesos de piping en campos de cultivo abandonados (Campos del Río, Murcia). En R. Bienes y M.J. Marques (eds.), *Control de la erosión y degradación del suelo*. IMIA, Madrid, 625-629.

Vandekerckhove, L., Poesen, J., Oostwoud Wijdenes, D., Gyssels, G., Beuselinck, L. De Luna, E., 2000. Characteristics and controlling factors of bank gullies in two semi-arid Mediterranean environments. Geomorphology. 33, 37-58.

THE IMPORTANCE OF THE PRESENCE OF GULLIES IN THE PRODUCTION OF SEDIMENTS IN SEMIARID AREAS (MURCIA, SOUTH-EAST OF SPAIN)

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1. Introduction

Numerous authors have already put in evidence how areas with marly lithologies produce greater amount of sediments than other lithologies (Cerda, 2001; Romero Díaz, 2002). If, in addition, in them gullies, which can evolve quickly in semi-arid areas, are influenced by local climatic conditions, the erosion rates can remarkably increase.

In a study made on 425 dikes for hydrological correction, we have been able to verify and quantify, in a direct way, (i) the erosion rates and sedimentation that toke place in the different flowing areas from each one of the dikes, (ii) the variation appearing between the different lithologies, and (iii) in areas with and without gully development.

2. Study area

The study has been carried out in the river basin of the Quípar river, affluent of the Segura river by its right margin (Fig. 1), where the Hydrographic Confederation of Segura (HCS) carried out two Projects for Hydrological Correction (1962 and 1996) to solve the serious filling problems that underwent the Alfonso XIII dam constructed in its mouth. Put in operation in 1916 with an initial capacity of 42 Hm^3 it was decreased to 14.2 Hm^3 in 1976 (Romero Diaz et to. 1992).

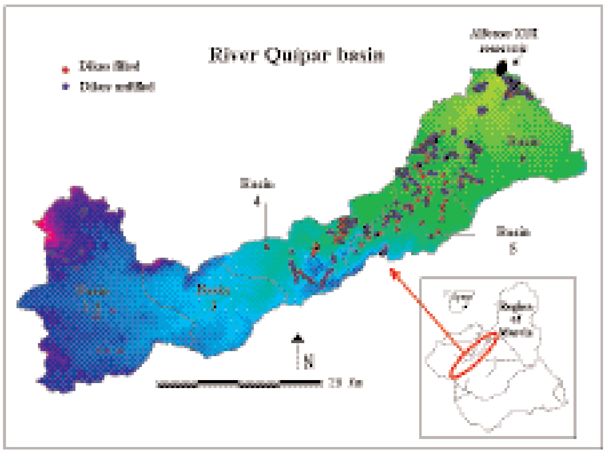

Fig. 1. Location of study area, main sub-basins and built dikes.

The works were developed in 33 ravines and gullies, where 425 dikes of gabions were constructed (stones within 1 m wide cages of metal mesh) and of masonry (cement and concrete), as well as a great quantity of dry-stone walls (HCS 1992). Using the dikes as a sediment trap, it is possible to calculate the tons of sediments retained in the sedimentation wedges, and later do an approach on the erosion rate in tons, hectare and year (Romero Diaz et al. 2006).

The most problematic zone of the river basin is subbasin 6 (according to denomination of the HCS). This is the zone nearest the dam, where the predominant lithologies are marls, marls-sandstone and clays, with a vegetal cover little developed, precipitations that oscillate between 250 - 350 mm per year and in which until mid 20th century an intensive culture of "*Stipa tenacissima*" was developed, with land preparation for such activity. The end of the commerce of "*Stipa tenacissima*" brought with it the abandonment of these lands and the acceleration of the erosive processes. The development of gullies is important to a great extent of the surface.

3. Methods

In the studied sub-basin there are 13 ravines, where 213 dikes have been constructed and which supposes 50.2% of the dikes constructed in the whole basin of the Quipar river. The amount of dikes selected for this investigation has been 165 (distributed by all the sub-basin), of which it has been possible to calculate the retained tons of sediments to date. In the non-filled dikes the rate of erosion has been calculated.

The basins have been analyzed separately in those which were predominating over the gullies and the ones that did not, comparing their results.

4. Results and discussion

The Ravines P.Nevado, Gilico, Salar, Romanos, H.Pilica and Coto are located in zones where gullies are very developed (Fig . 2).

Fig. 2. Example of a increase dike for filled up of sediments in an area of marls with gullies.

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According to the analyzed data (Table 1) it is observed that the ravines located in zones related with gullies have percentages of filled dikes very high, with data of up to 60% in the H. Pilica basin and of 70.5% in the Romanos basin. It is to also remarkable how 42,4% of the studied dikes total, which are constructed in these zones, are filled.

The total volume of retained sediments, in the set of the dikes constructed in this sub-basin, is of 284,027 tons, of which 245,633 tons (86.4% of sediments) have been generated in areas with presence of gullies.

Table 1. Sub - basin 6. Dikes and characteristics.

Basin	Nº of dikes	Dikes filled %	Sediment retained (T)	T/ha/year
P. Nevado*	17	59	49.841	14.14
Bayo	5	0	7.980	1.29
Salinas	8	25	10.251	1.23
Gilico*	51	45	75.003	3.01
Casa Aire	2	50	5.507	5.33
Los Pinos	4	0	4.852	3.27
Salar*	19	63	33.235	15.9
Salero	6	33,3	3.330	10.88
Romanos*	17	70,5	63.866	1.93
H.Pilica*	5	60	12.454	4.5
Coto*	16	25	11.234	3.69
Marines	9	11,1	5.379	3.25
Losares	6	0	1.095	0.4
Total	165	42,4	284.027	5.29

* Basin with gullies

Regarding the calculated erosion rates for this sub-basin, 60% of the dikes have a lower erosion rate than 2 t/ha/year; 23% of dikes have a rate of erosion that oscillates between 2 and 5 t/ha/year; 17% remaining compose the dikes that have a rate of greater erosion than 5 t/ha/year, emphasizing the dikes constructed in ravines next to the zones of gullies with rates superior to 60 t/ha/year.

The average erosion rate in functional dikes (not filled) in this sub-basin is of 5.29 t/ha/year, being the highest erosion rate of all the river basin of the Quípar River. In sub-basin 1-2-3 (located in head-board and with predominance of quaternary materials, conglomerated and limestone), the obtained rate has been of 0.71 t/ha/year, in sub-basin 4 (with predominance of conglomerates and limestones) a value of 3,39 t/ha/year was obtained, and in sub-basin 5 (also with predominance of the same type of materials) a rate of 2.64 t/ha/year was obtained.

If figure 3 is observed, where the rates of erosion and their frequency of the existing dikes in basins with and without gullies have been represented, it is verified how the dikes located in settled areas of gullies they retain a greater quantity of sediments eroded upstream, which means that its rates of erosion are considerably superior to the registered ones in the dikes located in areas without predominance of gullies.

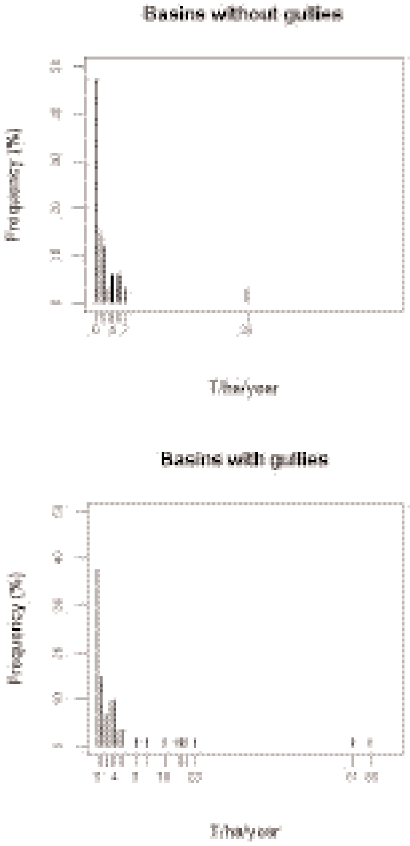

Fig. 3. Frequency of dikes and erosion rates in basins with gullies and without them.

5. Conclusions

The study has shown how the existence of gullies remarkably increases the rates of erosion and, therefore, the volume of sediments that arrives at the dikes of hydrological correction. A consequence of this is the need to carry out works of this type in basins with reservoirs to avoid its filling, in spite of the little life utility of the constructed dikes.

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References

Cerda, A. 2001. *Erosión hídrica del suelo en el territorio valenciano*. Geoforma Ediciones. Logroño, 79 pp.

Romero Díaz, A., Cabezas, F., López Bermúdez, F. 1992. Erosion and fluvial sedimentation in the River Segura Basin (Spain). *Catena* 19:379-392.

Romero Díaz, A. 2002. *La erosión en la Región de Murcia*. Servicio de Publicaciones de la Universidad de Murcia. Murcia, 337 pp.

Romero Díaz, A., Alonso Sarría, F., Martínez Lloris, M. 2006. Erosion rates obtained from check-dam sedimentation (SE Spain). A multi-method comparison. *Catena* (doi:10.1016/j.catena.2006.05.011).

SEEPAGE FLOW IN AQUIFERS WITH OPEN AND CLOSED BOUNDARIES

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1. Introduction

At previous gully erosion conferences, the effect of surface seal development on gully formation and growth was analyzed (Prasad and Römkens, 2003) and the effect of hydrological conditions on gully growth was discussed (Römkens and Prasad, 2005). In the latter study, it was suggested that seepage forces, i.e., exit gradients, may appreciable affect gully growth and that solutions of Laplace's equations for a quasi-steady state flow field might be helpful in assessing the effect of seepage on gully growth. In this presentation, seepage flow is discussed, based on selected studies that used conformal mapping procedures. These studies may be helpful in making assessments of the impact of seepage on gully erosion.

2. Theory

The stream flow area is described in terms of the complex spatial variable z, with x and y being the Cartesian coordinates, and the flow regime described by the complex potential ω where φ, is the potential function and ψ is the stream function. Thus:

$$z = x + iy \qquad \text{and} \qquad \omega = \varphi + i\psi \tag{1}$$

Solutions for the stream flow area are sought of the type $w = f(z)$ or $z = g(\omega)$, which either are obtained directly or indirectly through a complex variable $\zeta = \zeta + i\eta$, so that $\omega = f_1(\zeta)$ and $z = g_1(\zeta)$ facilitates calculations of the relationships $\omega = f(z)$ or $z = f(\omega)$. Also, in cases of free or open boundaries, the hodograph method is used, that describes the complex velocity field, given by

$$w(z) = u(x,y) + iv(x,y) = -\frac{d\omega}{dz} \tag{2}$$

where

$$\frac{\delta\varphi}{\delta x} = -u(x,y) \;\; and \;\; \frac{\delta\psi}{\delta x} = -v(x,y) \tag{3}$$

3. Discussion

The studies indicated are by:

1. van Deemter (1950), who discusses a number of 2-dimensional flow problems under steady state conditions in a homogeneous, isotropic aquifer with free as well as closed boundaries. Specifically, he analyzed, among others, the case of (i) drainage to a water free rectangular ditch with vertical, impervious, straight walls and (ii) the case of drainage to a partially filled ditch with vertical, pervious, walls. The solution obtained for case (ii) is:

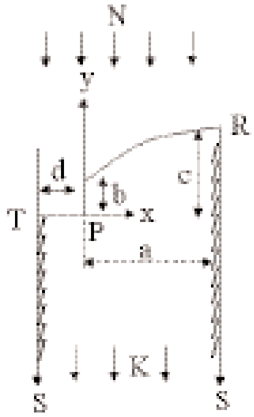

Fig. 1a. Flow field to be rectangular ditch without water and a permeable vertical wall with seepage (After v. Deemter).

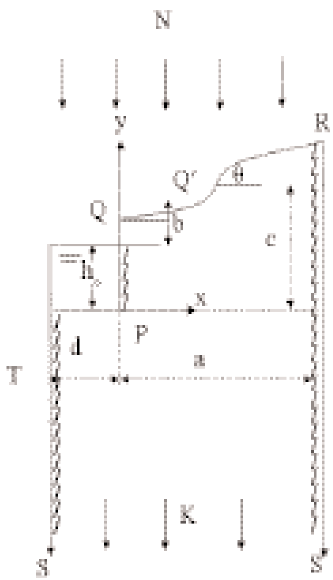

Fig. 1b. Flow field to be rectangular ditch water height h_o and impervious vertical wall (After v. Deemter).

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$$\left[\cosh\left[\pi\frac{\omega + i\left(kz + kd\right)}{k\left(a + d\right)}\right] - \lambda\right] \bullet$$

$$\left[\cosh \pi \frac{k + N}{\frac{d\omega}{dz} + ik} - \cos\frac{N\pi}{k}\right] = \qquad (4)$$

$$\left(1 + \lambda\right)\left(1 - \cos \pi \frac{N}{k}\right)$$

where

$$\lambda = \cos \pi \frac{\left(kd - Na\right)}{k\left(a + d\right)} \qquad (5)$$

This solution shows an implicit relationship between z and ω.

2. Römkens (unpublished, 1964) analyzed seepage to a partially filled ditch with circular bottom, an impervious wall above the ditch water level, and a constant horizontal ground water table (infiltration problem in a ponded field) (Fig. 2). Solution obtained for the seepage flow rate, Q, is for an infinitely long aquifer with buffer zone of width c:

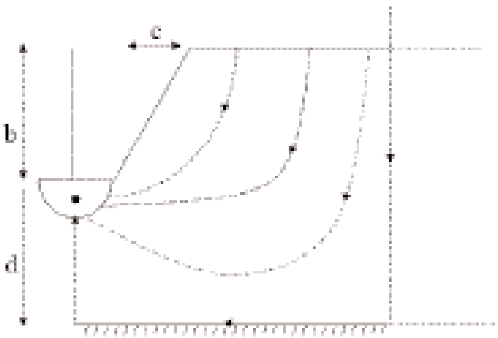

Fig. 2. Flow field to a partially filled ditch and an impervious side wall and a buffer zone with widcth c. Q is seepage per unit ditch length.

$$\omega = -\frac{Q}{\pi}\ln\left[\frac{-\sqrt{\cosh\frac{c\pi}{d} - \cosh z\frac{\pi}{d}} - \sqrt{\cosh\frac{c\pi}{d} - \cos\frac{b\pi}{d}}}{-\sqrt{\cosh\frac{c\pi}{d} - \cosh z\frac{\pi}{d}} + \sqrt{\cosh\frac{c\pi}{d} - \cos\frac{b\pi}{d}}}\right] \qquad (6)$$

For c=0, this formula reduces to the case of a tile drainage problem.

3. Bakker (1997) discusses new solution procedures in analyzing groundwater flow problems, including flow with free boundaries using the hodograph method and flow problems over a horizontal impervious layer to a straight

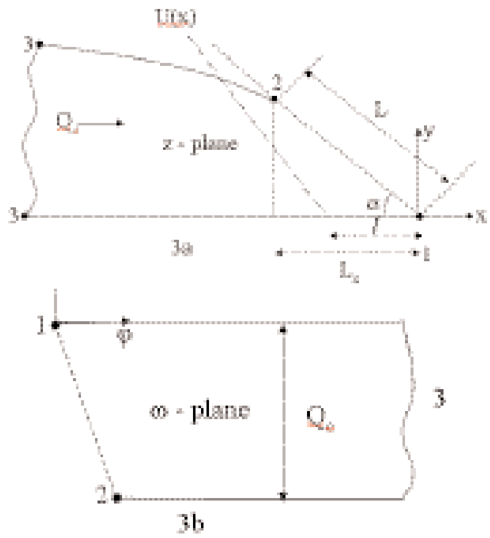

Fig. 3. Flow to a straight seepage surface. (a) The complex z-plane configuration, and (b) the complex potential-stream function representation.

seepage surface of angle ∇ with the horizontal using the Dupuis-Forchheimer model (Fig. 3). That relationship is:

$$\frac{dQx}{dx} = \frac{d^2U}{dx^2} = -N(x), \quad \text{where} \qquad (7)$$

$$U = \int_0^h kydy - \frac{1}{2}Kh^2 = 0 \qquad (8)$$

The various solutions obtained can now, in principle, be used to determine the potential and stream functions, and subsequently the exit gradients at the seepage surfaces. However, the calculations can be very complex and generally only be handled for simplified cases.

References

Bakker, Mark. 1997. Groundwater flow with free boundaries using the hodograph method. Advances in Water Resources 20(4): 207-216.

Deemter, J.J. van. 1950. Theoretical and numerical treatment of flow problems connected with drainage and irrigation. Verslag. Landbouwk, Onder. No. 56. 7; 's Gravenhagen. The Netherlands (In Dutch).

Prasad, S.N., and Römkens, M.J.M. 2003. Energy formations of head cut dynamics. Catena. 50: 469-487.

Römkens, M.J.M. and Prasad, S.N. 2005. Hydrologically driven mechanisms of head cut development. Inter. J. of Sed. Res. 20(3): 176-184.

Römkens, M.J.M. 1964. Wegzijgingsverliezen naar een sloot in een homogeen doorlatend watervoerend grondpakket. Ir thesis, Wageningen University, The Netherlands. Pg. 53 (In Dutch).

ESTIMATING SEDIMENT YIELD FROM GULLY EROSION USING EASILY MEASURABLE MORPHOMETRIC CHARACTERISTICS IN DAREHSHAHR REGION, SOUTH OF I.R. IRAN

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1. Introduction

Assessing the impacts of climatic and, in particular, land use changes on rates of soil erosion by water is the objective of many national and international research projects. However, over the last decades, most research dealing with soil erosion by water has concentrated on sheet (interrill) and rill erosion processes operating at the (runoff) plot scale. However, gully erosion contributes to soil loss between 10 and 94 percent (Poesen et al., 2003; Nagasaka et al., 2005) in different climates. Relatively few studies have been conducted on gully erosion operating at larger spatial scales (Poesen et al., 2003) while describing types of ephemeral gullies and determining their origin, evolution and importance as sediment sources is very important (Valca´rcela et al., 2003). Up to now, no distinct procedure has been introduced in the field of sediment yield prediction for gully erosion (Nachtergaele et al., 2001; Sidorchuk et al., 2003). The sediment yield assessment is presently conducted through field measurement which is too much demanding for time, energy and money. The development of applicable models are therefore necessary for predicting magnitude of sediment yield from gullies and evaluating effects of any changes in watershed systems on sediment yield variation. The models can be then used for selecting appropriate soil and water conservation approaches. In the present study, an attempt was therefore made to develop an applicable model for estimation of sediment yield in gullies under development stage. This is the stage of a slow gully deepening at the upper part and aggradations at the lower part, with increasing of the whole gully width and volume (Sidorchuk, 2005).

2. Material and Methods

The study was conducted in a part of Ilam Province where the gully erosion is seriously extending and causing major problems. The general view of the study area is depicted in Fig. 1. It comprises some 15000 ha with maximum and minimum elevation of 2790 and 500 m absl. The study area receives an average annual precipitation of 428.7 mm and is governed by semi arid climate. The study was formulated through selecting 18 gullies in different frontal (5 gully), digitated (7 gully) and axial (6 gully) types. They were then accurately staked and surveyed after rain storms (rainy seasons) between 2005 and 2006. The exact volumes of sediment were measured with the help of two times surveying at the beginning and end of study period during which 5 storm events occurred. Three cross sections were designated at down and upper ends, and middle for each study gully and their areas were calculated at first. The volume of gully at two study stages were then calculated based on intermediate volumes between each two cross sections and ultimately the differences between initial and final volume were measured and considered as the sediment yield from the gully. The different gully morphometric characteristics such as length, head distance, depth, head height, top and bottom width, cross section area and perimeter, length, hydraulic radius, mean depth, maximum depth, longitudal slope, side slope and form factors were repeatedly surveyed after five rain storms during the study period and then regressed with calculated volume of sediment yield. The appropriate model was ultimately selected based on statistical criteria of determination coefficient and relative error. The models with less relative error and the higher determination coefficient were selected as better performed models.

3. Results and Discussion

Different regression analyses of were applied to the data set of sediment yield and morphometric specifications of study gullies. The results of better performed models led to the following final simple equation applicable for estimation of sediment volume in the study area.

$$V = -256122.5\ HH+248107.9 \qquad (1)$$

where V is volume of sediment in cm^3 and HH is head cut height in cm. The performance of the model (1) was satisfactorily assessed using goodness of fit of correlation coefficient, error of estimation and verification of 61.82, 25.49 and 64.69%, respectively. It showed that the head cut height was a good predictor variable for sediment yield from the study gullies which disagrees Nachtergaele et al. (2001) who advocated the superiority of gully length over head cut height. It is consistent with Sidorchuk et al. (2003) who mentioned that the static models can be used for estimation of sediment yield from gully erosion in Switzerland. The negative sign of the regression coefficient also verified that the sediment generation would be taken place in the study gullies and storm under consideration until the head cut height was beyond 96.87cm.

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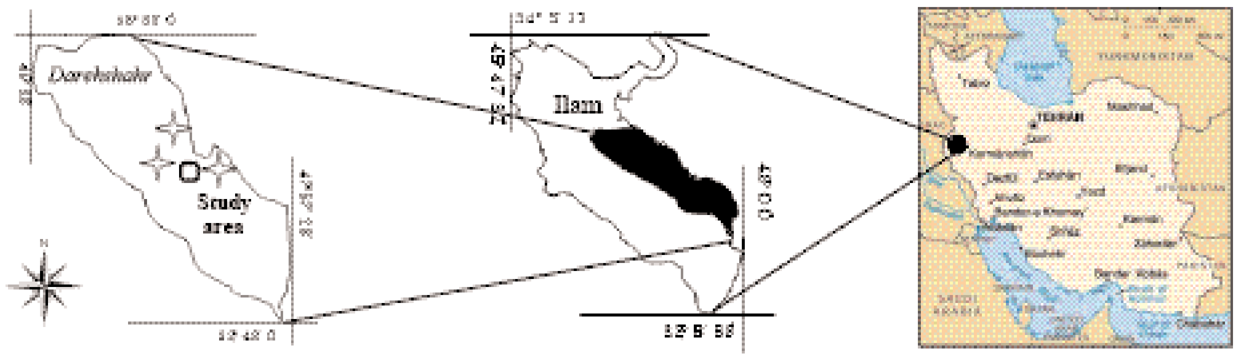

Fig. 1. Schematic presentation of the study area in Ilam Province, Iran.

Another attempt was also made for substituting the HH factor by other easily accessible factors using applying many factors and modelling processes. The following equation was the result of well establishment of relationship between head cut height and the maximum depth of upstream end of gully (DX in cm) with correlation coefficient, relative error of estimation and verification of 78.42, 5.79 and 26.35%, respectively.

$$HH=0.629DX+10.51 \qquad (2)$$

From the results of the study, it can be simply understood that the developed equations can be reliably applied for estimation of sediment yield and prediction sediment yield. It is seen from the results that the sediment yield from gully erosion in the study area can be simply estimated using a easily measurable variable of head cut height with reasonable level of accuracy.

4. Conclusions

A case study was conducted in a part of Ilam Province, I.R. Iran, to establish a reliable model for estimating sediment yield from gully erosion. The attempt was satisfactory and led to an applicable model whose input could be obtained through a simple field measurement or applying remote sensing. The finalized factors can be found out through interpreting high resolution aerial photos or images and with the help of necessary soft wares or techniques. Although the model was statistically sound especially for the study area but the more numbers of gullies in different types distributed in miscellaneous climates and land uses may help to draw final conclusions.

References

Nachtergaele, J., Poesen, J., Steegen, A., Takken, Z., Beuselinck, L., Govers, G. 2001. The value of physically based model versus an empirical approach in the prediction of ephemeral gully erosion for loess-derived soil, *Journal of Geomorphology*, 40:237-252.

Nagasaka, A., Yanai, S., Sato, H., Hasegawa, S. 2005. Soil erosion and gully growth associated with cultivation in south western Hokaido Japan, *Journal of Ecology Engineering,* 24: 203-508.

Poesen, J., Nachtergaele, J., Verstraeten, G., Valentin, C. 2003. Gully erosion and environmental change: importance and research needs, *Catena*, 50:91– 133.

Sidorchuk, A., Maker, M., Mor Hi, Sandro, Rodolfi, G. 2003. Gully erosion modelling and land scape response in the Mbuluzi River Catchment of Swaziland, *Catena*, 50:507-525.

Sidorchuk, A. 2005. Stochastic components in the gully erosion modeling, Catena 63: 299–317.

Valcárcela, M., Taboadab, M.T., Paz, A., Dafonte, J. 2003. Ephemeral gully erosion in northwestern Spain, *Catena*, 50:199– 216.

WATERFALL EROSION AS A MAIN FACTOR IN EPHEMERAL GULLY INITIATION IN A PART OF NORTHEASTERN IRAN

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1. Introduction

Gully erosion is defined as the erosion process whereby runoff water accumulates and is concentrated in narrow channels and, over short periods of time, removes the soil from this narrow area to considerable depths. In some areas, gully erosion is also a main source of sediment yield (Poesen et al., 2003; Nagasaka et al., 2005). Classical gullies can be described for agricultural land as permanent channels too deep to easily ameliorate with ordinary farm tillage equipment, typically ranging from 0.5 to as much as 25-30 m depth (Soil Science Society of America, 2001). Ephemeral gullies result from concentrated flow erosion larger than rill erosion but smaller than classical gully erosion (Poesen et al., 2003). Gully erosion consists of four stages: formation, development, healing and stabilization. As reported by Sidorchuk (2005), the gully initiation stage comprises only about 5% of the entire gully lifetime, but in that stage more than 90% of gully length, 60% of its area and 35% of the gully volume may be formed. In the remaining gully lifetime the morphologic conditions are relatively stable. Thus is important to understand the controlling factors in the formation stage. Sidorchuk (2005) also mentioned that in humid conditions the linear water erosion at the gully bed and rapid shallow mass movement at the gully sides of major importance during the first stage of gully evolution. The present study assesses the factors controlling gully formation in a study area located in northeastern Iran. Gully erosion in northeastern Iran is very high because of the high rate of human encroachment and the resulting impacts on soil erosion.

2. Materials and Methods

The study took place in the rolling hills region of the Sanganeh Plateau at almost 600 m absl in the vicinity of the Turkmenistan border (Fig. 1). This area is covered by highly erosion susceptible brown soils (Iranian Planning and Budget Organization, 1994). The area receives some 200-300 mm of precipitation per annum (Jafari, 1997) and is primarily covered by annual grasses. These grasses grow during the time of the main precipitation, i.e. during December to March, and then diminish with the onset of rising temperatures. The main land use of the area is natural rangelands that are intensively and untimely grazed by sheep. The rate of soil erosion is very high and vegetation pedestals have been well developed in the area.

The study was based on long-term field investigations and detailed monitoring of gully stages. The intermediate stages of soil erosion (i.e. sheet and rill erosion) were also considered to determine the dominant processes in gully formation and development. The study cases were then depicted pictorially.

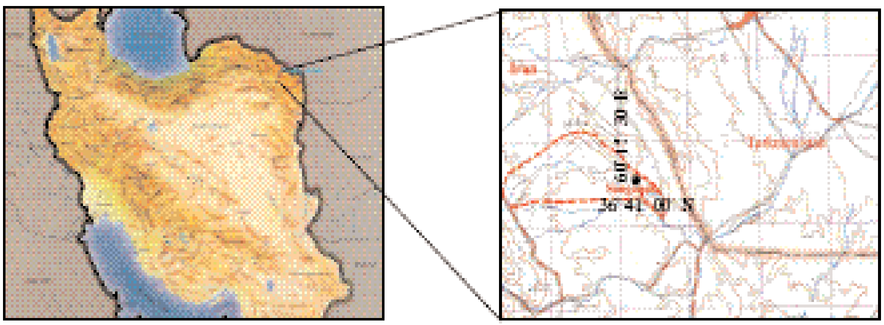

Fig. 1. General view and location of the Sanganeh study watershed, Iran.

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3. Results and Discussions

The study was concentrated in Sanganeh Watershed which drains to Turkmenistan. The burrowing activities of animals and insects such as mice, ants and rabbits and untimely overgrazing were recognized as initiating factors for gully formation. It was interesting that no intermediate stages of intensive sheet and rill erosion were observed that contributed to the more intensive gully erosion. The successive processes of gully formation and subsequent development in the study region are illustrated in Fig. 2.

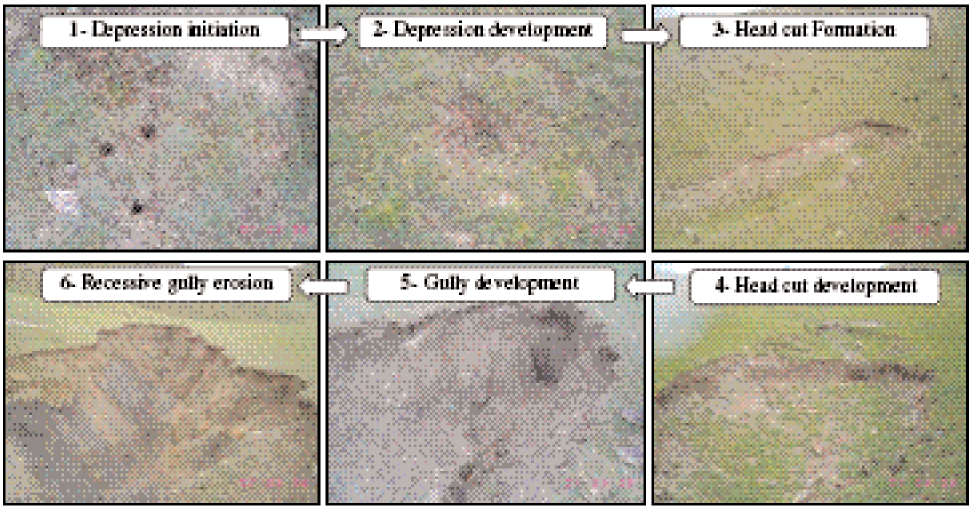

Fig. 2. Processes of gully formation and development in Sanganeh Watershed, Northeastern Iran.

The initial stage of depression formation and subsequent gully initiation were recognized in the area. Once the water accumulated in depressions made by rodents, uprooted plants and animal hooves, the gully head cut was then shaped as the result of waterfall erosion. The erosion processes then proceeded to develop an upward progressing gully channel. No downward extending channel/rill erosion could be distinctly identified as a gully forming process. Dominant mechanisms other than waterfall erosion were not observed contrary to Sidorchuk (2005) regarding the role of channel erosion in gully formation and development in humid conditions. The gullies developed until they were subjected to stoppage of waterfall erosion and surface runoff. It was also observed the linear water erosion at the gully bed, rapid shallow mass movement at the gully sides as well as tunnel roof collapse were of major importance for gully evolution after initial first stage gully development. During the second stage of gully evolution slower processes such as ground water seepage, earth flow and soil creep became more important in gully extension as partially mentioned by Sidorchuk (2005).

4. Conclusion

The mechanisms of gully formation were scrutinized in a part of northeastern Iran through field observations. Waterfall erosion was recognized as an important factor in gully initiation originating from depressions made by rodents, uprooted plants and animal hooves leading to waterfall erosion and developing gully erosion. The authors believe that gully erosion can be controlled by implementing managerial measures that focus on timely prescribed grazing and prevent overgrazing of the area. Continued monitoring and field data collection are advised.

References

Jafari, A. 1997. *Iranian streams and rivers Atlas*, Hamoon Publ., 544 pp.

Iranian Planning and Budget Organization, 1994. *Iran National Atlas*, National Surveying Organization.

Nagasaka, A., Yanai, S., Sato, H., Hasegawa, S. 2005. Soil erosion and gullygrowth associated with cultivation in south western Hokaido Japan, *Journal of Ecology Engineering,* 24: 203-508.

Poesen, J., Nachtergaele, J., Verstraeten, G., Valentin, C. 2003. Gully erosion and environmental change: importance and research needs, *Catena,* 50:91– 133.

Sidorchuk, A. 2005. Stochastic components in the gully erosion modeling, *Catena,* 63: 299–317.

Soil Science Society of America, 2001. *Glossary of Soil Science Terms.* Soil Science Society of America, Madison, WI, http://www.soils.org/sssagloss/.

DISCHARGE AND GULLY EROSION IN A SMALL RANGELAND CATCHMENT

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1. Introduction

Valley bottom gullies are a common feature in rangelands. Although these gullies are found in the bottom of drainage lines, information about the relationship between discharge and gullying is scarce (Crouch, 1990; Thomas et al., 2004). This may in part be due to the large temporal variation of this phenomenon making necessary monitoring of runoff and erosion for a large number of years. Since 1990 research is carried out on the development of valley bottom gullies in small wooded rangeland catchments in southwest Spain. Erosion varies strongly along the gully section with high losses related to headcut retreat (Schnabel et al., 1999). The importance of extreme events producing exceptional sediment losses has also been demonstrated (Schnabel, 1997). In the year 2000 investigation started in the Parapuños experimental basin. The present paper aims at understanding the relationship between gully erosion and catchment hydrology.

2. Study Area

The Parapuños catchment (100 ha) is located northeast of the city of Cáceres, in a peneplain developed in Precambrian schist. Openly spaced evergreen Holm oaks cover grasslands which are grazed by sheep and pigs. The gullies are commonly developed in the valley bottom of the undulated landscape, where they are incised into an alluvial fill of 1 to 2 meters thickness. These sediments are roughly composed of 23% rock fragments, 45% sand and 32% clay and silt. The bulk density is 1.6 g cm^{-3}. Soils at the hillslopes are shallow sandy and silty loams with low organic matter content. Climate is Mediterranean with a pronounced dry season in summer and high rainfall variability (Schnabel, 1997). The gully is located in the lower part of the catchment. It is a second order channel with a short tributary gully joining the main branch at a distance of 174 m from the basin outlet. Table 1 shows the dimensions of the three gully sections. The tributary is a typical discontinuous gully with 2 active headcuts close to the junction. The main gully has a headcut in the upper part.

3. Methods

Gully monitoring is carried out by repeated measurements of 28 topographic cross sections using a laser total station, with a frequency of 6 months, and further measurements if there are exceptional rainfall events. Subsequent profiles are superposed and the area of erosion or deposition calculated. These two-dimensional values of erosion or deposition are used to estimate the volume of sediment gain or loss between two neighbouring cross sections (mean of two profiles multiplied by the distance between them). The total amount of net erosion or accumulation is determined by summing the volumes of the channel sections. Discharge is determined at the outlet of the basin (compound weir) and rainfall is registered with 6 tipping bucket devices. Data are registered with a resolution of 5 minutes. Table 2 shows the dates of measurement, the corresponding periods covered, together with their total amount of rainfall. The analysis is carried out on the basis of periods, i.e. the time between each field survey. The total net erosion or deposition is related with the discharge characteristics of the corresponding period.

Table 1. Dimensions of the gully sections and the total of erosion (negative values) and deposition.

	Length (m)	Catchment (ha)	Erosion, deposition (m^3)
Main branch, lower section	174	4.2	2.81
Main branch, upper section	630	49.9	-9.99
Tributary	133	45.4	-7.26

Table 2. Dates and periods of monitoring and corresponding amounts of rainfall and net erosion (negative values) or deposition of the complete gully system.

Measurement	Period	Rainfall season	Rainfall (mm)	Erosion, deposition (m^3)
December 2001				
July 2002	P1	Spring 02	247.5	-1.49
January 2003	P2	Autumn 02	410.5	-18.18
June 2003	P3	Spring 03	168.3	9.42
January 2004	P4	Autumn 04	296.2	-15.16
July 2004	P5	Spring 04	212.3	-5.02
January 2005	P6	Autumn 05	259.1	1.46
July 2005	P7	Spring 05	81.4	11.07
December 2005	P8	Autumn 05	212.3	0.74
June 2006	P9	Spring 06	208.8	2.72

4. Results and conclusions

Total net erosion of the complete gully during the 9 periods was 14.44 m^3. However, gullying varied between 18.18 m^3 of sediment loss (P2) and 11.07 m^3 of deposition (P7) (table 2). Besides the maximum erosion observed in P2, losses were also high during P4. Both were produced by discharge events registered during autumn and early winter (2003 and 2004). Considering the total amount, the lower

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branch showed net deposition and the upper branch and the tributary registered net erosion (table 1). More insight can be gained observing the losses and gains of the different channel sections, illustrated in figure 1. In the upper section of the main branch sediment losses took mainly place during the autumn periods (note that Autumn refers to the period which includes the autumn and early winter rains, and Spring includes late winter and spring). Deposition in this section was only observed during the spring periods. No seasonal tendency can be observed in the lower section of the main channel and the tributary. Table 3 presents the main characteristics of the discharge events for each period, including the total amount of runoff, the maximum peak discharge, the number of times total event discharge exceeded 1000 m^3 and the number of times maximum peak discharge exceeded 100 l s^{-1}. No relationship could be found between discharge and erosion for the tributary whereas for the upper branch the data indicate a relation between water flow and erosion (fig. 2).

Table 3. Discharge characteristics during the study periods (Qmax - maximum peak discharge, Q>1000 – number of times the total event discharge exceeded 1000 m^3, Qmax>100 – number of times the peak discharge exceeded 100 l s^{-1}).

Period	Discharge (m^3)	Qmax (l s^{-1})	Q>1000 m^3 (n)	Qmax>100 l s^{-1} (n)
P1 Spring	3436.6	457.8	1	2
P2 Autumn	58164.8	454.3	11	8
P3 Spring	15355.0	302.7	4	4
P4 Autumn	22556.6	1157.9	6	5
P5 Spring	16035.6	325.1	4	4
P6 Autumn	26437.8	1115.0	6	5
P7 Spring	12.8	2.9	0	0
P8 Autumn	16875.1	1586.7	2	2
P9 Spring	8073.1	273.4	1	2

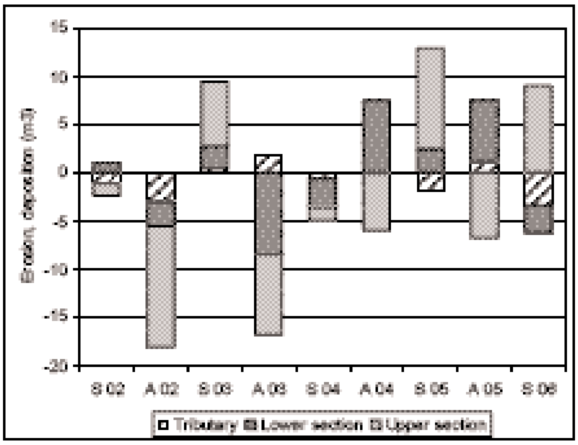

Fig. 1. Total erosion and deposition of the different gully sections for each study period (S – spring, A – autumn).

Although data suggest a positive relation between discharge and gullying, no simple relationship exists. The main upper reach of the channel showed a clear seasonality, with higher losses during the autumn and early winter, presumably related with the higher erosive capacity of the runoff events registered during these periods. In addition, sediment availability is presumably also higher in autumn. The erratic evolution of the tributary, however, indicates that the erosion processes are more complex. The higher losses during the spring periods indicate the importance of soil moisture content, reducing the cohesion of the sediments. As a consequence, bank failures are observed at the wall of headcuts and also in other places along the gully banks.

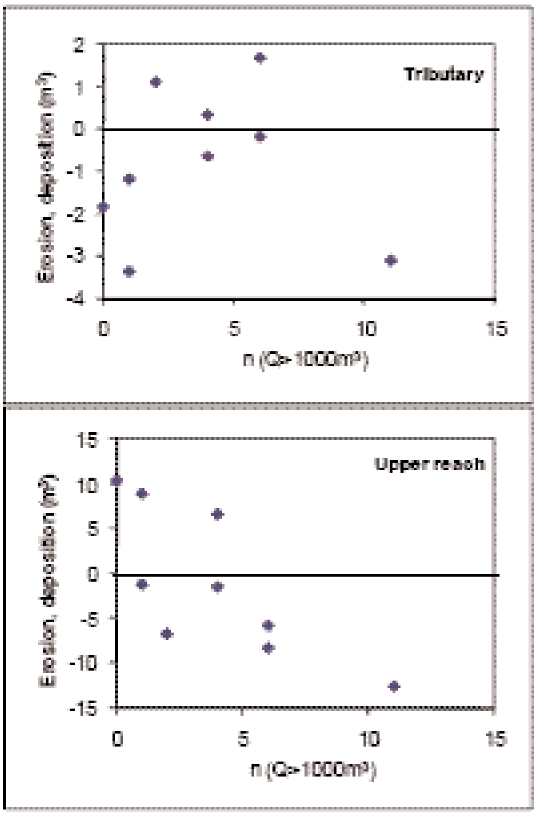

Fig. 2. Relationship between discharge and gully erosion for the upper reach of the main channel and the tributary (explanation see text).

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References

Ceballos, A. & Schnabel, S. 1998. Hydrological behaviour of a small catchment in the dehesa land use system (Extremadura, SW Spain). *Journal of Hydrology*, 210, 146-160.

Crouch, R.J. 1990. Rates and mechanisms of discontinuous gully erosion in a red-brown earth catchment, New South Wales, Australia. *Earth Surface Processes and Landforms*, 15: 277-282.

Schnabel, S. 1997. *Soil erosion and runoff production in a small watershed under silvo-pastoral land use (dehesas) in Extremadura, Spain*. Geoforma Ediciones, Logroño.

Schnabel, S., Gómez Amelia, D. y Ceballos Barbancho, A. 1999. Extreme events and gully erosion. *Proceedings of the International Seminar on Land Degradation and Desertification, International Geographical Union*, Lisbon 1988, 17-26.

Thomas, J.T., Iverson, N.R., Burkart, M.R. and Kramer, L.A. 2004. Long term growth of a valley-bottom gully, western Iowa. *Earth Surface Processes and Landforms*, 29, 995-1009.

EFFECTIVENESS OF PALM AND BAMBOO GEOTEXTILES IN REDUCING CONCENTRATED FLOW EROSION

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1. Introduction

Rills and gullies, caused by concentrated flow erosion, represent an important sediment source in many environments (Poesen et al., 2003). Studies indicate that vegetation can be very effective in controlling gully development. However, the establishment of a vegetation cover can be delayed or obstructed by the development of rills and gullies due to concentrated flow erosion. Before the vegetation has reached a critical cover and root density to significantly reduce concentrated flow erosion, a period of high erosion risk occurs. Hann and Morgan (2006) indicate that applying geotextiles on the soil surface is the most efficient method to control erosion until a critical vegetation cover has been established. Preliminary investigations suggest palm-mat geotextiles could be an effective and cheap soil conservation method, with enormous global potential. However, very little is known about the effectiveness of (palm) geotextiles in reducing concentrated flow erosion. Almost no data are available on the impacts of palm geotextiles on the hydraulic, hydrologic and erosion characteristics of concentrated flow for a range of environmental conditions. Therefore, the objectives of this study are (i) to assess the effectiveness of two palm-mat and one bamboo geotextile in increasing the hydraulic roughness of the soil surface under concentrated overland flow and in reducing soil erosion rates by concentrated flow on an erodible soil type and for a range of flow shear stresses; and (ii) to investigate which is the most appropriate hydraulic variable (e.g. shear stress, unit length shear force or stream power) to predict the net soil detachment by concentrated flow.

2. Materials and methods

2.1. Experimental conditions

All experiments are conducted in the laboratory using a concentrated flow erosion flume (length: 2.0 m, width: 0.35 m, depth: 0.05 m, Fig. 1). Water can be stored in a small reservoir at the top of the flume and can be evenly applied to the top of the flume. Flow discharge can be regulated using the tap and pressure regulator connected to the reservoir. At the bottom of the flume runoff and sediment samples can be collected using a gutter. The slope of the erosion flume can be adjusted from 0-45%.

The soil used in this study is a Tertiary sandy loam (i.e. an erodible subsoil), quarried in central Belgium (Bierbeek). The sandy loam is often found in road cuttings and on construction sites; it has 13% clay (<0.002 mm), 24% silt (0.002-0.063 mm) and 63% sand (0.063-2 mm) and 0.2% organic matter.

Three natural geotextiles are used in this study: Borassus geotextile, constructed from the leafs of Borassus Aethiopum Palm in The Gambia (Davies et al., 2006); Buriti geotextile, constructed from the leafs of Brazilian Buriti Palm in Brazil; and Bamboo geotextile, constructed from Bamboo stems in Thailand. These three types of geotextile have dimensions of 0.50 x 0.50 m, a surface cover of 43, 42 and 40% and a mean thickness of 0.03, 0.02 and 0.01 m, respectively.

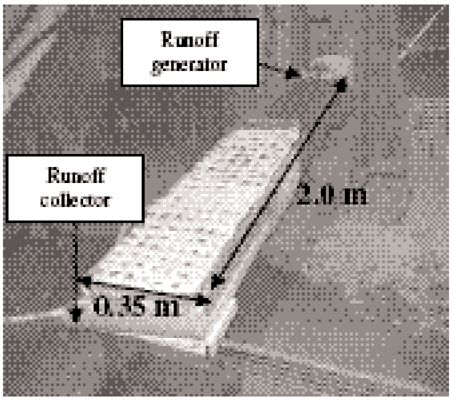

Fig. 1. Concentrated flow erosion flume.

2.2. Experimental treatments and measurements

Soil was air dried during 4 days and passed through a 2.7 cm sieve in order to minimize differences in soil structure among treatments. The upstream part of the flume (1.0m long) was covered with a wooden shelf over which the water was led to the entrance of the 1.0 m long test section without causing any erosion. The 5.0 cm deep test section was filled with sieved soil in two 2.5 cm layers to achieve a constant dry bulk density (1.2 g cm^{-3}). Before each experiment gravimetric moisture content and bulk density of the soil were determined using Kopecki cylinders (diameter=5cm; n=3). The treatments included: one soil type (sandy loam); three geotextiles (Borassus, Buriti and bamboo) and one bare soil surface (control); three slope gradients (15, 30 and 45%); and three flow discharges. All treatments had two replicates, so in total 72 experiments were conducted.

During each experiment flow discharge, mean flow velocity, flow width and slope gradient were measured. Sediment loaded runoff samples were taken during 5 s every

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30 s in order to determine sediment concentration and net soil detachment rate. Flow depth, Manning's n, Darcy-Weisbach f, shear stress, unit length shear force, stream power and runoff rate were calculated. Experiments were continued until steady state flow and detachment conditions were reached, i.e. flow velocities and detachment rates no longer changed significantly over time. Therefore, experiments lasted between 5 and 15 min. Flow discharge was measured before and after each experiment at the top of the flume. Surface flow velocity was measured using the dye tracing technique (Giménez and Govers, 2002). A small amount of the dye (Brilliant Blue) was injected 0.3-0.4m upslope of the test section in the flume. Flow velocities were then measured by recording the travel time of the leading edge of the dye over a distance of 0.7m in the test section.

2.3. Data processing

2.3.1. Hydraulics

Flow depth (d, m) was calculated by dividing flow discharge (Q, $m^3\ s^{-1}$) by the product of mean flow velocity (V, $m\ s^{-1}$) and flow width (a). Using the calculated data of flow width and mean flow velocity, the following hydraulic parameters were calculated:

Darcy Weisbach f: $$f = \frac{8gRS}{V^2} \quad (1)$$

Hydraulic shear stress (τ, Pa): $$\tau = \rho gRS \quad (2)$$

Stream power (ω, kg s^{-3}): $$\omega = \tau V \quad (3)$$

Where, g is the acceleration due to gravity ($m\ s^{-2}$), S is the sinus of the soil surface slope angle in degrees, ρ is the water density ($kg\ m^{-3}$), and R is the hydraulic radius (m).

2.3.2. Soil detachment

The sediment loaded runoff samples were weighed and oven dried (105 °C) during 24 h. The oven-dried sediment was weighed and runoff discharge ($m^3\ s^{-1}$) was calculated by subtracting the mass of the oven-dried sediment from the mass of the loaded runoff samples. Sediment concentration (SC, $kg\ m^{-3}$) was determined as the ratio of dry sediment mass to runoff volume. Net soil detachment rate (net DR, $kg\ m^{-2}\ s^{-1}$) was calculated as the ratio of the product of sediment concentration and flow discharge to the area of the test section. Relative soil detachment rate ($DRrel$) was calculated as the ratio between net DR for a geotextile covered soil surface and net DR for a bare soil surface under the same experimental conditions.

3. Results

Preliminary results indicate that Borassus, Buriti and Bamboo geotextiles significantly reduce mean flow velocities compared to bare soil surfaces (Fig. 2); mean flow velocities were reduced relatively by 35-44% compared to a bare soil.

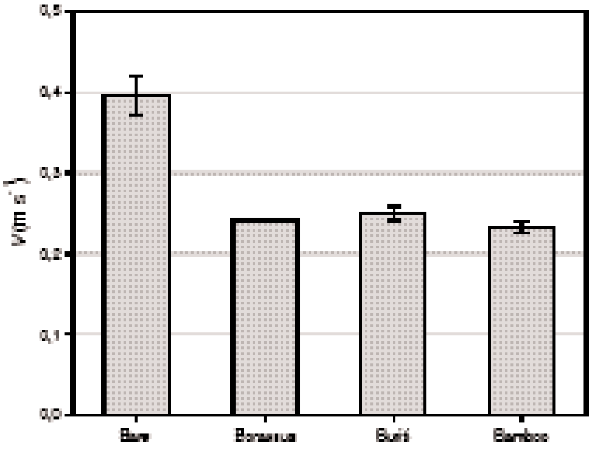

Fig. 2. Mean flow velocity (V, $m\ s^{-1}$) on a bare soil surface and soil surfaces covered with Palm and Bamboo geotextiles; slope: 15%, runoff discharge: 0.002 $m^3\ s^{-1}$, Reynolds number: 370.

Darcy-Weisbach friction coefficients, ranging from 0.06-1.75, significantly increased for all geotextile treatments compared to a bare soil treatment. Net DR ranges from 0.003-0.02 $kgm^{-2}s^{-1}$ and decreases significantly on geotextile covered soil surfaces. Final results on the effectiveness of Borassus, Buriti and Bamboo geotextile in increasing the hydraulic roughness of the soil surface and in reducing soil erosion by concentrated flow will be presented during the International Symposium on Gully Erosion.

Acknowledgements: This research is part of the BORASSUS Project: 'The environmental and socio-economic contribution of palm-leaf geotextiles to sustainable development and soil conservation' (contract number: INCO-CT-2005-510745), funded by the European Commission (EC), Specific Targeted Research Projects (FP6-STREPs) for Developing Countries (INCO-DEV) Programme. This Project is dedicated to the memory of Dr Kathy Davies, who was the initiator and inspiration for palm-leaf geotextile research.

References

Davies, K., Fullen, M.A. and Booth, C.A., 2006. A pilot project on the potential contribution of palm-mat geotextiles to soil conservation. *Earth Surface Processes and Landforms 31*, 561-569.

Giménez, R. and Govers, G., 2002. Flow Detachment by Concentrated Flow on Smooth and Irregular Beds. Soil Sci. Soc. Am. J. 66, 1475-1483.

Hann, M.J. and Morgan, R.P.C., 2006. Evaluating erosion control measures for biorestoration between the time of soil reinstatement and vegetation establishment. *Earth Surface Processes and Landforms 31*, 589-597.

Poesen, J., Nachtergaele, J., Verstraeten, G., Valentin, C., 2003. Gully erosion and environmental change: importance and research needs. *Catena 50*, 91-133.

MORPHOLOGY AND CONTROLLING FACTORS OF LANDSLIDE CIRQUE GULLIES: A CASE STUDY FROM THE SPROGU GRAVAS NATURE MONUMENT (SE LATVIA)

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1. Introduction

Human-induced changes of landscape and the vegetation cover have been recognized in the majority of studies focusing on gully formation as one of the most important factors triggering the development of gullies throughout the world. However, detailed studies of singular erosion landforms in south-eastern Latvia, particularly those that are located on steep slopes of river banks modified by mass movement processes and presently found under forest, indicate that these gullies are not a geomorphic features resulting entirely from human agricultural activities. Such short, bottleneck-shaped gullies (Crosta, di Prisco, 1998), described in Latvia as landslide cirque or spring cirque gullies (Venska, 1982), can be found in deep river valleys and subglacial tunnel valleys in Latvia, but few studies have reported on their morphological characteristics and their origin.

This study investigates these landslide cirque gullies initiated via mass movement processes in the local case-study area of the river Daugava Valley in south-eastern Latvia. The objectives are (1) to determine the spatial distribution of these gullies, (2) to measure their morphological and topographical characteristics and (3) to interpret the factors that led to their development.

2. Study area

The investigation of landslide cirque gullies is performed in nature monument “Sprogu gravas” (the Nature Park “Daugavas loki”, Fig. 1.), located in the river Daugava Valley, SE Latvia.

Fig. 1. Location of the study site.

The average difference in local topography is about 25 to 35 m. The territory is characterised by a temperate semi-humid climate influenced by the westerlies. The mean annual precipitation varies mostly within 600 to 700 mm yr^{-1}; number of days with precipitation 100 to 120 d yr^{-1}; mean temperature in January from –7°C to –5°C; the mean temperature in July from +16°C to +17°C; recurrence interval of extreme rainfall events (more than 20 mm d^{-1}) is 10 years or more.

The study site is located within the most ancient part of the Daugava ancient valley, which is also the only such valley in Latvia with regard to its configuration, and has very unique scenery with 10 river bends. The present flow of the Daugava has begun to form as a proglacial spillway valley at the final stage of the last Weichselian (Vistulian) glacial event 15 to 13 thousand years ago. Later in the Holocene, it was modified by fluvial processes. The processes have created an open-air museum of geological objects with 1700 springs, large boulders, bedrock and interglacial peat exposures, hanging gullies, high Quaternary bluffs and glaciokarst sinkholes that other rivers do not have. “Sprogu gravas” is one of nature monuments, also listed in World Database on Protected Areas, Site Code: 172696 (http://www.unep-wcmc.org/wdpa/sitedetails.cfm?siteid=172696&level=nat). “Sprogu gravas” is featured by intricate topography, where landslide–gully complexes are formed by combination of gullying, landsliding and seepage erosion processes.

3. Materials and methods

During field studies, the depth, width, length, channel gradient and sidewall slope gradient of landslide–gully complexes were measured by standard geomorphological methods. Width and depth were measured several times along each gully in order to determine maximum values. Sidewall slope gradients were determined with a clinometer (type Suunto, error 0.005 m m^{-1}). At the same time morphology of gully channels, forms of cross-profiles and longitudinal profiles, as well as the type and intensity of geological processes in gullies were assessed. Position of landslide-cirque gullies was mapped with GPS (Trimble GeoXT). Because of a dense canopy of broad-leaved forests common in gullies, errors remained (a maximum error up to several metres) even after the differential correction. The spatial analysis and calculating of gully density was made by GIS ArcMap 9.0. Finally, principal geomorphological, geological, and hydrological factors which have affected formation of these landslide–gully complexes were studied.

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4. Results and discussion

In total, 20 short landslide cirque gullies and 3 large permanent gullies were mapped and surveyed. Landslide cirque gullies typically have bottleneck shape with cirque-like or amphitheatre-shaped sub-circular depression at the gully head and v-shaped cross-profile at the gully outlet. A large number of small springs (discharge less 0.05 l s^{-1}) and sapping signs, which can be observed at the bottom of landslides scarp, usually form small streams. This indicates that these landslide–gully complexes were initiated by seepage erosion.

Landslide cirque gullies are short (15 to 90 m), the depths of the incisions vary from 0.8 to 2 m and gully catchments are relatively small, from 0.29 ha to 1.22 ha. Taking into account volume of eroded sediment, they can be compared with ephemeral gullies. However, from ephemeral gullies they differ by step-like thalweg and steep longitudinal profile (inclination up to 20º - 25º) (Fig. 2.).

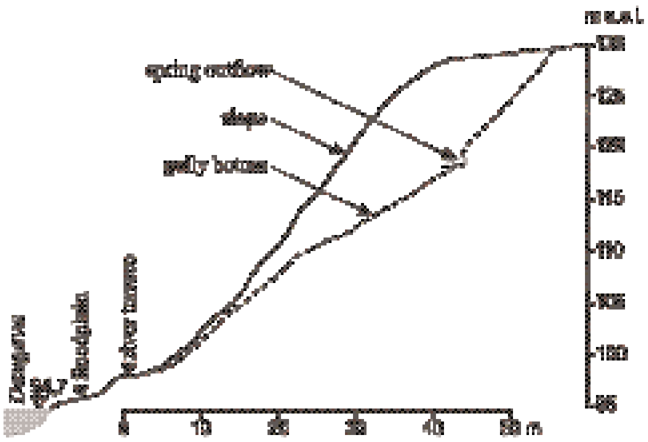

Fig. 5. Typical longitudinal profiles of landslide cirque gully.

In order to interpret the factors that led to their development, the Leopold and Maddock (1953) width–discharge relationship, extended on rills and gullies (1) (Nachtergaele et al., 2002; Torri et al., 2006) was applied:

$$W = 2.51\ Q^{\,0.412} \qquad (1)$$

from which one gets:

$$Q = 0.1072\ W^{\,2.427} \qquad (2)$$

Hence, it (2) let us to calculate discharge of spring outlets, which possibly forms these gullies. Calculation shows, that discharge have to be from 0.0058 $m^3\ s^{-1}$ (W = 0.3 m) to 0.0831 $m^3\ s^{-1}$ (W = 0.9 m). Comparison of data shows that calculated values is almost 2 orders as large as for the ones obtained by measurement of real spring discharges in-situ.

This fact can be explained by assumption, that gullies are not formed entirely by focussed groundwater seepage and spring outflow, but also by surface runoff concentrated in landslide cirques. On the other hand, channel gradient (>25 m m^{-1}), the effect of which in equations extended to rills and gullies (Nachtergaele et al., 2002; Torri et al., 2006) is considered negligible, obviously plays additional role in accelerated erosion in channels of landslide cirque gullies, despite the fact that these are similar to ephemeral gullies. Steep longitudinal profiles create favourable conditions for formation of micro-waterfalls due to collapse of colluvium in gully channel, which in turn invokes a variety of small scarp failures that intensify backward erosion.

5. Conclusions

The formation of bottleneck-shaped spring cirque gullies and landslide–gully complexes alongside the valley of river Daugava is determined mainly by the topographic indicators and geological structure. The latter is characterised by alternation of Pleistocene fine to medium glaciofluvial deposits covered by stony sandy clayey till. This type of lithostratigraphic sequence leads to an increase of erodibility and to the development of short gullies as the result of combination of the mass movement, surface run-off (incision process) and sub-surface run-off (seepage process).

Initiation of gully erosion in this case was determined by seepage and sapping, formation of landslides and up-slope development of spring cirques, which in their turn concentrate sub-surface run-off and lead to slumping.

In the river Daugava Valley, the most frequent cause of landslides is a change in groundwater conditions. This is caused by interference with natural drainage conditions after annual spring floods or by an increase in groundwater due to excessive rainfall. The presence of groundwater affects slope stability by increasing the effective weight of the saturated materials, creating appreciable pore pressure and tending to weaken soft Quaternary deposits and unconsolidated materials.

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References

Crosta, G., di Prisco, C., 1998. On slope instability induced by seepage erosion. *Canadian Geotechnical Journal 36*:1056– 1073.

Leopold, L.B., Maddock, T., 1953. The hydraulic geometry of stream channels and some physiographic implications. *U. S. Geological Survey Professional Paper 252*: 1–57.

Nature monument "Sprogu gravas" [Online, 12 February 2007], URL: http://www.unep-wcmc.org/wdpa/sitedetails.cfm?siteid=172696 &level=nat

Nachtergaele, J., Poesen, J., Sidorchuk, A., Torri, D., 2002. Prediction of concentrated flow width in ephemeral gully channels. *Hydrological Processes 16*:1935–1953.

Torri, D., Poesen, J., Borselli, L., Knapen A., 2006. Channel width–flow discharge relationships for rills and gullies. *Geomorphology 76*: 273-279.

Venska, V. 1982. Contemporary geological processes in the National Park "Gauja". In: *Contemporary exogenic geological processes and research methods*. LGU, Riga:139-159 (in russian).

CAUSES OF GULLY EROSION IN ARID ECOSYSTEM: CASE STUDY SOUTHERN PART OF I.R.IRAN

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1. Introduction

In spite of many research efforts on gully erosion, there is an argument about causes of gully erosion among researchers. Causes of gully erosion can be classified into three categories: human impact (Bork et al., 2001, Starr, 1989), climate change (Gregory and Moore, 1931) and intrinsic changes (Schumm and Hadley, 1957). Examples and causes of gully erosion include: land use change and changing vegetation cover in ninth and tenth century by human in England (Harvey, 1996); intensive land use in combination with rain storms in Germany (Bork and et al., 1998); increasing the area of corn in Central Belgium (Nachtergaele, 2001); almond planting without terracing after clearing the Mediterranean native vegetation in southern Spania; road construction on sloping area in different ecosystems (Moyersons, 2000; Wemple and et al., 1996; Crok and Mockler, 2001).

Gully erosion is known as a main problem in the southern watersheds of I.R. Iran. One of the famous watershed is Lamerd and Ala-marvdasht watersheds which is located 40 km north of Persian Gulf. Gullies are developed in the flat alluvial area and caused many damages to roads, crop and rangelands, bridges. The linear extension of gullies threatens villages. It is a long watershed with northwest- southeast aspect. The area of the watershed is about 8549.1 sq.km. Average annual rainfall is equal 268 mm (20 years period). Rains are usually as storms with short duration. In some years total annual rainfall occurs in a few days and sometimes twice of annual rainfall happens in two or three days. This watershed is one of the selected sites for research on gully erosion and many researches have been conducted in the past 10 years.

2. Material and Methods

Anecdotal evidence, historical evidence and intensive field observation and measurements are used to determine causes of gully erosion. Our data collection include talking with old residents and rural people, and analyzing aerial photos from different times, Topographic maps are produced by photogrammetric method. Area of gully erosion, cropland and residential and length of roads were measured from the topographic maps. Rainfall and flood data were used and analyzed between 1951 and 2002. Soil samples were taken in location with gully erosion. Soil chemical properties such as pH, EC, OM, Na, Ca, K, Mg, ESP and SAR were either measured or estimated.

3. Results and Discussion

Results of this research show that after four decades, 1955-1994, the area of gully erosion, residential area and cropland are increased respectively 4, 10 and 3 folds in the Lamerd and Ala-marvdasht watersheds. Gullies are located in lowlands with slopes less than 1%. Seventy five percent of gully erosion was developed on saline/non-saline soils while the remaining located on sodic soils. Historical evidence show that gully erosion was limited to the sodic soil in early time but after urban development and road construction, a vast area of rangeland was changed to dryland farming (wheat). After a few drought periods, these farmlands changed to barelands. Gully erosion on the sodic soil was mainly caused by high ESP and low OM. Table 1 shows sites of gully erosion larger than 10 sq.km in the Lamerd and Ala-marvdasht watershed.

Table 1. Main gully sites with area larger than 10 sq.km.

No	Site name	Area of gully erosion (sq.km)	Total length of gullies (km)	Gully density (km/sq.km)
1	Sigar	24.63	309.615	12.57
2	Mohr	10.99	115.21	10.48
3	Kashkoo	30.70	278.485	9.07
4	Chahvarz	12	101.35	8.44
5	Chaheini	25.6	150.27	5.87
6	Kahnooye	9.29	59.45	6.4
7	Kamali	91.74	480.82	5.24
8	Keirgoo	35.65	455.5	12.78
9	Chahkoor	15.48	141.323	9.13
10	Labshekan	37.24	213.45	5.73

In order to identify causes of gully initiation and development, factors such soil, rain and floods, vegetation cover, were surveyed in detail. Our results show that for sites with similar rainfall and soil properties, gullies tend to be found at sites with more barelands or roads around them. In other words this evidence reveals that gully development is associated with human impact (Table 1). In these watersheds rainfall occurs as rainstorms and in some years total annual rain falls in two or three days. Using area of gully erosion (Y_1) and total length of gully (Y_2) as dependent variables and area of mountain (X_1), area of plain (X_2), length of roads (X_3), area of bareland (X_4), area of cropland (X_5), area of residential sites (X_6) as independent variables, a multivariable regression was conducted with the SPSS statistical software. The results show that two factors, area

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of bareland (X_4) and length of roads (X_3) are dominant factors for gully development in different sites. These two factors interpreted 78 percent of variations in the area of gully erosion in the Lamerd and Ala-marvdasht watersheds. The impact of bareland area and length of roads was not equal in all sites. In some sites such as Kamali (table1) the impact of bareland is more important than length of roads but in other sites such as Kashkoo (Table 1) the impact of road length is more than bareland area. The overall impact of bareland area is 58 percent and length of roads has 20% percent impact on gully development.

4. Conclusions

This research demonstrated that the I.R. region is prone to gully erosion. The study area had limited gully erosion four decades ago. With accelerating urban development during the past, two to three decades, areas of gully erosion increased. Comparison of gully advancement showed that the area of gully erosion increased 4 times in four decades before. Gullies are located around urban areas with more deteriorated cropland and roads. Statistical analysis revealed that area of gully erosion could be attributed to the area of bareland and road length. The overall the impact of bareland area is more significant than road length in study watersheds, although their contribution in individual site is completely different.

References

Bork, H.R., Li, Y., Zhao, Y., Zhang, J. and Shiquan, Y. 2001. Land use changes and gully development in the Upper Yangtze River Basin. *SW China, J. of Mountain Science*. 19(2):97-103.

Croke, J. and Mockler, S. 2001. Gully initiation and road-to-stream linkage in a forested catchment, Southeastern Australia. *Earth Surface Processes and Land forms*. 26. 205-217.

Gregory, H. E. and Moore, R.C. 1931. The Kaiparowits Region. U.S. *Geological Survey Prof.* Paper, 164.

Harvey, A.M. 1996. Holocene hillslope gully systems in the Howgill Fells, Cumbria. In: *M.G. Anderson, Brooks, S.M.(Eds.), Advances in hillslope processes*. 2: 731-752.

Moyersons, J. 2000. Desertification and man in Africa. *Bulletin of the Royal Academy of Overseas Science*. Brussels. 49:151-170.

Nachtergaele,J. 2001. A spatial and temporal analysis of the characteristics, importance and prediction of ephemeral gully erosion. *Ph.D thesis*. Dept. of Geography-Geology. K.U.Leuven. 255pp.

Schumm, S.A. and Hadley, R.F. 1957. Arroyos and the Semiarid cycle of erosion. *Am. J. Sci*. 225. 161-74.

Starr, B. 1989. Anecdotal and relic evidence of the history of gully erosion and sediment movement in the Michelago Creek catchment areas NSW. *Australian J. of Soil and Water Conservation*. 2(3):26-32.

Wemple, B.C., Jones, J.A. and Grant, G.E. 1996. Channel network extension by logging roads in two basins, Western Cascades. *Water Resources Bulletin*. 32(6):1195-1207.

COMPARISON OF HISTORICAL EVOLUTION OF GULLY NETWORKS ON BOTH SLOVAK AND MORAVIAN FORELANDS OF THE WHITE CARPATHIANS

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1. Introduction

The main objective of the contribution is to present the preliminary results of comparison of historical evolution of gully networks in both Slovak and Moravian forelands of the White Carpathians. This geomorphic unit represents the flysch mountain range situated in the boundary zone of Slovakia and the Czech Republic, reaching the elevation 970 m. The Slovak foreland of the White Carpathians, i.e. the Myjava Hill Land, belongs among those areas in Slovakia that were the most affected by disastrous gullying in the past. This fact was one of the main reasons to choose precisely this area for detailed investigation of historical gullies, lasting at the moment approximately one decade. The study of the Moravian foreland of the White Carpathians, i.e. Hluk Hill Land, started in 2006. Its first goal was to find out if the density of gully network on the Moravian side is comparable with that at the Slovak side. Beside the density of gully networks also the age of gullies and causes of their formation on both sides of the frontier were subjects of this comparison. Comparison of gullies on both forelands of the White Carpathians is introduced in the context of the review of the research dealing with the historical evolution of gullies in Slovakia and Czech Republic.

2. State-of-the-art of research dealing with historical evolution of gullies in Slovakia and Czech Republic

The territory of the former Czechoslovakia is typical for the extensive areas with a relatively dense network of old, historical, relic gullies. Recent research concentrated mostly on spatial organisation of gullies with a special attention to the density of gully networks. At the beginning of the second half of the 20th century, the maps of spatial distribution of gully networks were elaborated, namely separately for Moravia and Silesia (Gam and Stehlík, 1956), Czechia (Gam, 1957) and Slovakia (Bučko and Mazúrová, 1958). Comparison of these maps suggests a generally higher density of gully networks in Slovakia than in the Czech Republic.

Much lesser attention was dedicated to the assessment of the relation of the gully network to the land use pattern, to individual elements of natural landscape, to causes of gully formation and to their dating.

Among the Czech scientists only Láznička (1957) dealt with dating of gully formation in the territory of the Czech Republic. On the basis of the analysis of old maps he documented the growth of existing gullies in the Jihlava River valley (southern Moravia) in the period 1785–1877. Stehlík (1981) identified the phase of accelerated erosion (including gullying) for the Czech Republic as a whole in the 1750-1850 period. However, contrary to the mentioned authors, Slovak Zachar (1970, p.332) found on the basis of the study of historical sources that in the Rakovník region (western Czechia), the majority of larger local gullies were formed in the 17th century and only a minority date to the 18th century.

Some historical framework of gully formation in Slovakia was indicated by Bučko and Mazúrová (1958) who suggested that overgrazing associated mostly with the Walachian colonisation (that penetrated into the Slovak territory in the 15th century and culminated in the 16th and 17th centuries) and the *kopanitse* settlement (taking place since the middle of the 16th until the middle of the 19th centuries) resulted in formation of a dense road and path network that provoked increased water erosion on deforested slopes. Unfortunately, they did not date the gullying itself. According to Midriak and Lipták (1995), the accelerated water erosion (including gullying; the comment of authors), was a frequent phenomenon in the period of the last three centuries. So far the most detailed investigation of historical gullies has been carried out since the second half of the 1990s in the territory of the Myjava Hill Land (cf. Stankoviansky, 2003a, b, c). Aim of this research was the search for the regularities of spatial organisation of gully networks, relative dating of the origin and further growth of gullies on the basis of the analysis of old maps and local historical sources as well as the elucidation of causes of gully formation. It was found out that gully networks are linked mostly to the elements of the old, pre-collectivisation land use, that gullies were formed predominantly in the period since the second half of the 16th until the middle of the 19th centuries and that the cause of gully formation was the cumulated influence of both land use and climate factors in the same period. It was also revealed that gullies were formed in stages, at least in two phases of disastrous gullying, however neither of them affected the whole study area. Identified local disparities in the increase of gully networks suggest that the gully growth was not areawide in

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individual stages. The research with the same aims was extended also to the northern part of the Nitra Hill Land in the last two years (cf. Papčo, 2005).

3. Preliminary conclusions of comparison of historical evolution of gully networks on both Slovak and Moravian forelands of the White Carpathians

The Slovak foreland of the White Carpathians, namely the Myjava Hill Land shows predominantly plateau-like relief with elevations ranging over a span 543–300 m. It is built mostly of flysch-like rocks of medium to low resistance resulting in relatively thick fine-textured regolith. Islands of loess and loess loams are spread locally. Cambisols and luvisols are the most frequent soil types. The mean annual precipitation is 550–800 mm. The natural vegetation was represented predominantly by the oak and hornbeam forests, locally by beech forests.

For the whole area of the Myjava Hill Land, the gully network with an average density approximately 1.2 km km^{-2} is characteristic, while extensive islands show values of 2–3 km.km^{-2} (Bučko and Mazúrová, 1958) and the field research revealed the maximum local density of even almost 11 km km^{-2}. The field reconnaissance and the analysis of old cadastral maps (scale 1 : 2 880) suggest that the pattern and density of these gullies have been controlled primarily by artificial linear landscape elements typical for the original land use from the pre-collectivisation era (access roads, parcel borders, lynchets, drainage furrows etc). The locality with the above mentioned highest density of gully network is the exception as gullies in this place are linked with areal element of the old land use pattern, namely with overgrazed pasture. The old military maps from years 1782, 1837 (scale 1 : 28 800) and 1882 (scale 1 : 25 000) and both regional and local historical sources indicate at least two main periods of gully formation, namely sometime between the middle of the 16th century and the 1730s and between the 1780s and the middle of the 19th century. It is supposed that conditions for gully erosion were created by extensive forest clearance and expansion of farmland due to the *kopanitse* settlers, as well as by overgrazing due to Walachian colonists, but the triggering mechanisms of gullying was represented very probably by extreme rainfalls and snowmelts during the Little Ice Age. Especially colder and wetter fluctuations with increased precipitation totals and greater probability of increased frequency of significant events provided more opportunities for gully formation (Stankoviansky, 2003a, b, c).

The Moravian foreland of the White Carpathians, namely the Hluk Hill Land, shows similar features as the Myjava Hill Land, though it is a little lower. Relief is predominantly smoothly shaped, flat-topped, with average elevation 272 m and highest point 429 m. It is built by flysch rocks of low resistance; quite extensive area of loess is in the SW part. Mean annual precipitation is 600–800 mm, original forest cover was represented by oak-hornbeam and locally by oak forests.

The average density of the gully network on the Moravian foreland of the White Carpathians is considerably lower than in the Slovak part of the boundary zone, it is ranging over a span 500–750 m km^{-2} (Gam and Stehlík, 1956). Comparison of old maps from years 1768, 1836 and 1882 showed that in general, the gullies on the Moravian side are a little younger; it seems that the main period of their formation was sometime between the first and second military mapping, i.e. approximately between the 1760s and 1840s what corresponds well with the younger of two phases of gully formation identified on the Slovak side (Stankoviansky and Létal, 2006).

The next research stage will be aimed at finding the causes of disparities between the different density of gully networks and their age on the Slovak and Moravian forelands of the White Carpathians.

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References

Bučko, Š. and Mazúrová, V. 1958. Výmoľová erózia na Slovensku, In Zachar, D., (ed.), *Vodná erózia na Slovensku*, Vydavateľstvo SAV, Bratislava: 68-101.

Gam, K. 1957. Přehledná mapa rozšíření strží v Čechách. *Vodní hospodářství*, *1*: 26-27.

Gam, K. and Stehlík, O. 1956. Příspěvek k poznání stržové erose na Moravě a ve Slezsku. *Sborník Československé společnosti zeměpisné*, *61*, 3: 214-216.

Láznička, Z. 1957. Stržová erose v údolí Jihlavy nad Ivančicemi. *Práce Brněnské základny ČSAV*, *29*, 9/362: 393-421.

Midriak, R. and Lipták, J. 1995. Erosion and reforestation of abandoned lands in the Slovak karst biosphere reserve. *Ekológia*, *Supplement, 2*: 111-124.

Papčo, P., 2005. Geomorfologická odozva zmien využívania krajiny (na príklade záujmového územia topoľčiansko-duchonského mikroregiónu. In *Acta Facultatis rerum naturalium Universitatis Comanianae*, *Geographica*, *Suppl*., *3*, Univerzita Komenského, Bratislava: 432-436. (CD-ROM).

Stankoviansky, M. 2003a. Historical evolution of permanent gullies in the Myjava Hill Land, Slovakia. *Catena*, *51*, 3-4: 223-240.

Stankoviansky, M. 2003b. Gully evolution in the Myjava Hill Land in the second half of the last millennium in the context of the central-European area. *Geographia Polonica*, *76*, 2: 89-107.

Stankoviansky, M. 2003c. *Geomorfologická odozva environmentálnych zmien na území Myjavskej pahorkatiny*. Univerzita Komenského, Bratislava.

Stankoviansky, M. and Létal, A. 2006. Historical evolution of gully network on the foreland of the Biele/Bílé Karpaty Mts. In Létal, A. and Smolová, I. (eds.), *Geomorfologický sborník 5 : Sborník abstraktu*, Univerzita Palackého v Olomouci, Olomouc: 61.

Stehlík, O. 1981. Vývoj eroze pudy v ČSR. *Studia Geographica*, *72*: 3-37.

Zachar, D. 1970. *Erózia pôdy*. Vydavateľstvo SAV, Bratislava.

SOME EXAMPLES OF EPHEMERAL GULLY EROSION IN AN ATLANTIC AREA OF NW SPAIN

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1. Introduction

This study aimed to describe types of ephemeral gullies and to determine their origin, evolution and importance as sediment sources in Galicia (Northwest Spain).

Concentrated erosion was surveyed on medium textured soils, developed over basic schist of the Ordenes Complex series (Corunna province, Spain) from 1997 to 2006.

The studied region has a humid Atlantic climate with a mean annual rainfall of about 1000-1500 mm. Precipitation distribution is uneven, with a maximum between October and March and a minimum in the summer. The geological materials of the study area consist of basic metamorphic rocks and granite.

Gullies formed within the field where runoff starts, gullies collecting the runoff from an upstream area and discontinuity gullies due to abrupt slope changes were identified (Valcárcel, M. et al., 2003).

Ephemeral gullies formed by incision along linear elements generally showed large sections in zones with high slope, so that a gradual decrease from the maximun cross-section, both toward the head and downstream, occurred. This variation from head-cut to outlet of the gully may be attributed to the small flow rates at the upstream and saturation of the transport capacity downslope, where sedimentation initiates (Casalí et al, 1999).

2. Material and methods

The study area was located in Northwest of Spain, near the Atlantic cost, 30 km around Corunna.

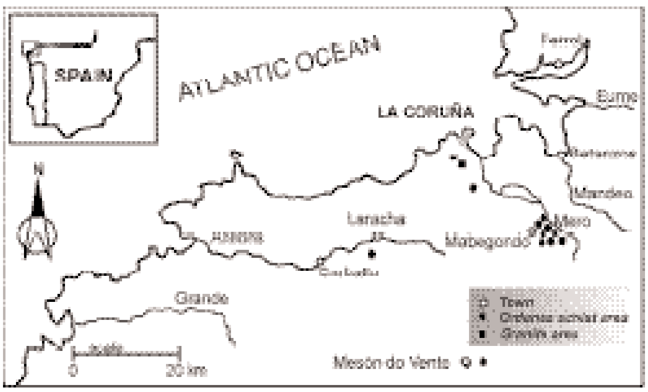

Fig. 1. Location of the study sites.

Concentrated erosion took place mainly on seed beds and recently tilled surfaces on late spring and by autumn or early winter (Valcárcel, 1999).

Main dominant cultivations in the study sites were maize and grassland, but some small fields were used for winter cereals, potatoes, orchards and rape; in addition some fields were left fallow during winter, after maize. In the Ordenes Basin area rotations during the study period were maize-fallow, grassland-maize, maize-winter cereals; in the granite area potatoes followed rape or winter cereals (Valcárcel, M. et al., 2003). Winter fallow was also observed, both in old landscapes and after land consolidation.

For appreciate the importance of the gully erosion, we are placing, topography and measuring the section and length for one of the erosion linear elements in the field. Then, we calculate the erode volumes (Poesen & Govers, 1990).

The losses by gulling was between 0,74 m^3/ha and 26,14 m^3/ha. Mean ephemeral gully cross-sections oscillated between 0,13 and 0,26 m^2. Average values of width-depth ratio were in the range between 1,63 and 11,97.

3. Conclusions

The main cause of gully formation is the lack of any proper waterway for conveying water excess.

In the medium textured soils of the Ordenes Basin, occurrence of concentrate flow erosion was related to development surface of surface crusting. Human impact is demonstrated through variations caused by crop rotation and tillage procedures.

Concentrated erosion may transport large amounts of sediment to streams, unless buffer zones between the eroded surface and the permanent water courses. Conventional tillage practices and seedbed preparation enhanced concentrated flow erosion and gully occurrence, whereas the maintenance of vegetation cover completely prevented soil surface incision and channel formation (Valcárcel, 1999). The study of the development of the gully system in time showed that main gullies tend to reappear at the same position.

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References

Casalí, J., López, J. J., Giráldez, J. V., 1999. *Ephemeral gully erosion in southern Navarra (Spain).* Catena 36: 65-84.

Poesen, J. W. A., 1989. Conditions for gully formation in the Belgian loam belt and some ways to control them. In: *Schwertmann, U., Rickson, R. J., Auerswald, K. (Eds.), Soil Erosion and Protection Measures in Europe. Soil Technology Series 1.* Catena Verlag, Cremlingen-Destedt, Germany: 39-52.

Poesen, J. W. A., Govers, G., 1990. Gully erosion in the Loam belt of Belgium: tipology and control measures. In: *Boardman, J., Foster, I. D. L., Dearing, J. A. (Eds.), Soil Erosion on Agricultural Land. Wiley, Chichester, UK: 513-530.*

Souchere, V., King, D., Daroussin, J., Papy, F., Capillon, A., 1998. *Effects of tillage on runoff directions: consequences on runoff contributing area within agricultural catchments.* Journal of Hydrology *206: 256-267.*

Valcárcel-Armesto, M., 1999. *Variabilidade espacial e temporal da erosion en solos de cultivo.* Ph.D. Thesis. EPS de Lugo, Univ. of Santiago de Compostela, Spain, p. 266.

Valcárcel-Armesto, M., Paz-González, A., Dafonte-Dafonte, J. and Taboada-Castro, Mª. T., 1999. Importancia de las prácticas agrícolas en el control de los procesos erosivos y evaluación mediante modelos de la incidencia de las mismas. In: *Paz-González, A., Taboada Castro, Mª. T. (Eds.), Avances sobre el estudio de la erosión hídrica. Colección Cursos, Congresos e Simposios, 52. Universidade da Coruña, Coruña, Spain:* 7-42.

Valcárcel, M., Taboada, M., Paz, A., Dafonte, J, 2003. *Ephemeral gully erosion in northwestern Spain*. Catena 50: 199-216.

A GENERAL SEDIMENT TRANSPORT MODEL FOR LINEAR INCISIONS

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1. Introduction

Previous research has shown that the functional relationship between sediment transport and shear stress, discharge and slope is non-linear. The different datasets that support this hypothesis are however all derived from flume experiments or river channels. No calibration was done at the field scale. Recently, Istanbulluoglu et al. (2003) succesfully calibrated the sediment transport function with field data from eroding gullies in the Idaho Batholith. However, the field data presented covered only a relatively limited range of condition. In this study, more field data is presented that supports the field-scale calibration over a wider array of shear stress conditions in the lower range.

2. Materials and methods

2.1. Theoretical background

Sediment transport is often described by a power relation of shear stress or of discharge and slope. Many existing bedload and total load equations can be written in a similar functional form:

$$q_s^* = \beta \tau_*^p \tag{1}$$

where q_s^* is the dimensionless sediment discharge,

$$q_s^* = \frac{q_s}{\sqrt{g s' d^3}} \tag{2}$$

With q_s is the sediment discharge rate, g is the acceleration of gravity, s' and d are, respectively, the submerged specific gravity and the diameter of the sediment particles. τ_* is the dimensionless shear stress.

$$\tau_* = \frac{\tau}{\gamma s' d} \tag{3}$$

τ is the shear stress and γ the unit specific weight of the soil particles. β and p are coefficients, the first defined by the equation:

$$\beta = \kappa\left(1 - \tau_{*_c}/\tau_*\right)^p \qquad \tau_* > \tau_{*_c} \tag{4}$$

τ_{*_c} is the dimensionless critical shear stress and κ is another coefficient. Although this expression was originally proposed for the description of the bed load, it was successfully applied for total load sediment transport capacity by Istanbulluoglu et al. (2003) for the description of eroding gullies. These authors estimated the q_s^* and τ_* pairs from field data.

$$q_s^* \propto \frac{V_S}{A^{m_{q*}} S^{n_{q*}}} \tag{5}$$

$$\tau_* \propto A^{m_\tau} S^{n_\tau} \tag{6}$$

Where V_S is the volume of lost soil, A is the runoff contributing area, S is the local slope and m_{q*}, n_{q*}, m_τ and n_τ are coefficients.

2.2. Study area

The goodness of fit of the sediment transport relationship described above was computed using field data from an olive orchard near Baena in Andalucia, Spain, (Fig. 1). In a hillslope of 6600 m^2 under olive plantation, draining towards a large, permanent gully, detailed map was prepared of linear incisions. Total station was used to measure local topography and eroded volumes were measured with tape measures.

Fig. 1. Location of the study area within Spain.

3. Results and discussion

The pattern of the linear incision is shown in Fig. 2.

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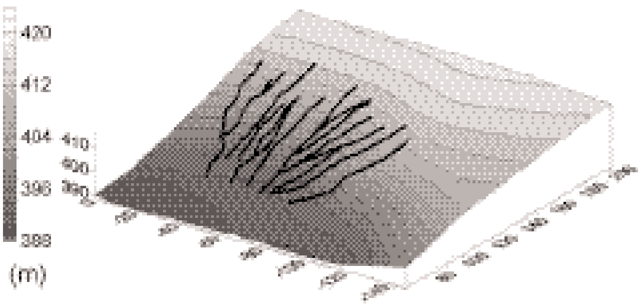

Fig. 2. Spatial distribution of the linear erosion features.

Once the proper values of the coefficients were computed, the dimensionless shear stress and sediment discharge data were inserted into the same figure of Istanbulluoglu et al. (2003), shown in Fig. 3. Note that the abscissa of this figure is not the dimensionless shear stress but a transformed version τ_*'

$$\tau_*' = \tau_*\left(1-\tau_{*c}/\tau_*\right) \tag{7}$$

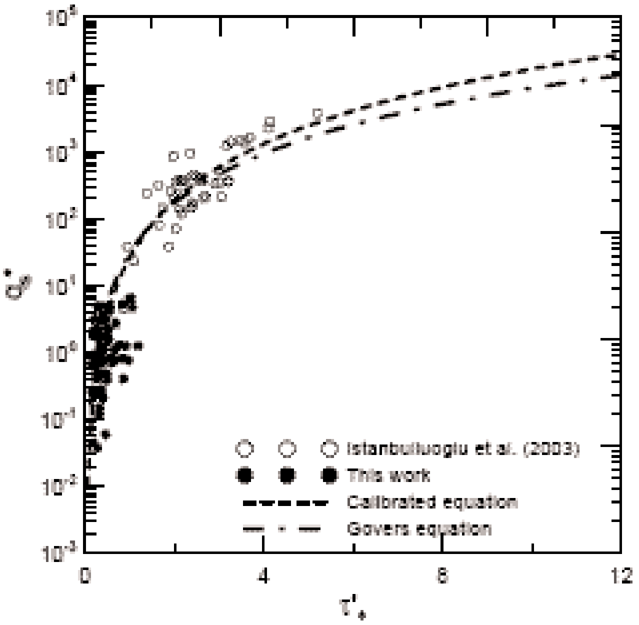

Fig. 3. Relationship between the dimensionless sediment discharge and transformed shear stress for linear incisions under Baena field conditions.

The calibrated equation of Fig. 3 corresponds to a linear regression curve fitted to the original Istanbulluoglu et al. (2003) data, whose equation was

$$q_s^* = 26.6\left(\tau_*'\right)^{2.81} \tag{8}$$

The data from Baena fit well in this equation. Fig. 3 also includes the Govers (1992) empirical relationship

$$q_s^* = \kappa_G\left(\tau_*'\right)^{2.457} \tag{9}$$

As remarked by Istanbulluoglu et al. (2003), this equation is fairly close to the calibrated equation.

4. Conclusions

The acquired results, plotted in Fig. 3, agree well with the relationship for the lower range of values of (8). The agreement of the data is remarkable given the different conditions and the small dimension of the linear incisions. These data correspond to the boundary between rills and gullies and show the universal applicability of this sediment transport equation. Although a more detailed study is required to confirm these observations, the presented conclusions are relevant for the development of erosion models.

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References

Govers, G. 1992. Evaluation of transporting capacity formulae for overland flow, in A. J. Parsons and A. D. Abrahams (eds.), *Overland Flow Hydraulics and Erosion Mechanics*, pp. 243– 273, Chapman and Hall, New York.

Istanbulluoglu, E., Tarboton, D. G., Pack, R. T., Luce, C. H., 2003. A Sediment Transport Model for Incision of Gullies On Steep Topography. *Water Resour.* Res., 39(4), 1103, doi:10.1029/2002WR001467

GULLY EROSION RISK ZONING: PROPOSAL OF A METHODOLOGY AND CASE STUDY

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1. Introduction

Gullying is the most advanced, complex stage of erosion processes, with more local destructive power than other types of erosion (São Paulo, 1990). In this paper, we propose a method to generate gully erosion risk zoning in the far south plateau of Brazil, based on geological characteristics, soils and geomorphology.

2. Methodology

The methodology can be divided into three different stages: data acquisition, data integration using geoprocessing techniques and validation of results.

The data acquisition stage includes mapping the gullies and characterizing the variables that we suppose as they may control gully development. These variables include lithology, lineaments, terrain slope, curvature of the slope on the plane and in profile, catchment area and soils

The gullies were mapped on 1:25,000 scale based on the analysis of aerial photographs (1:60.000), taken in 1996, and field studies. This stage is very important since it indicates areas where the behaviors of variables involving geology, geomorphology and soils should be recognized, as well as the regions that will constitute the samples for two situations or classes: areas with erosion and areas without erosion.

The lithological characterization was based on the description of outcroppings, on geological profiling and petrographic analysis.

The lineaments were extracted from aerial photographs on the 1:110,000 and 1:60,000 scales and analyzed using a rosette diagram to identify the preferential directions.

The geomorphology variables were estimated based on the Numerical Model of the Terrain derived from the planialtimetric map on a 25,000 scale.

Soil distribution was based on surveys performed on a 50,000 scale (Carvalho *et al.,* 1990) and on the description of toposequences (Boulet *et al,*1993).

The data integration stage used geoprocessing procedures to integrate the gully map and the variables data. The result was a gully erosion risk zoning.

The spatial data integration model used was Bayesian (Eastman, 1999), which expresses the *a posterior*i probability that an hypothesis that is previously known will be true according to new evidence. The *a priori* probability, i.e., the probability that the hypothesis will turn out to be true despite the evidence, for *potential area for gullying*, was estimated to be 7% based on the sum of gullies catchment areas. Consequently, the probability for *potential area of the non-occurrence of gullying* was 93%.

Using *a posteriori* probability for *potential area for gullying,* we empirically determined five potential risk classes for gully erosion, ranging from very low to very high (Table 1).

Table 1. Risk of erosion considering the probability of gullying.

Probability (%)	Potential risk
0 – 30	Very low
30 – 50	Low
50 – 70	Moderate
70 – 90	High
90 – 100	Very High

3. Description of the Area

The methodology proposed was applied in the Taboão Creek Catchment, in the far south of Brazil, a part of the Prata Basin drainage system, with an area of approximately 100 km?.

The rocks in the area are mainly volcanic with basic composition intercalated by volcanogenic sedimentary horizons.

The relief is characterized by homogeneous dissection and consists of mild, well-rounded hills. Basin relief ranges from 330 to 495m. The mean slope in the basin is 8%, although in the valleys the slope varies from 10 to 20%.

The soils are predominantly clayey (mainly Oxisols). These soils have inherent resistance to erosion in their natural state due to the high degree of clay flocculation, high porosity, good permeability, and to the fact that they occur in areas with a mild relief. However, if badly managed, they tend to develop a dense surface layer which favors water runoff and consequently erosion.

The regional climate is temperate, without distinct wet and dry seasons (Nimer, 1989). Mean annual precipitation is 1,700 mm and the monthly distribution of precipitations is remarkably uniform, between 120 and 160 mm from 1945 to 1985. (Chevallier and Castro, 1991). However, major annual and monthly variations were recorded in 1992 and 1997, due to the El Niño effect (Castro *et al*., 1993).

Concerning to agriclutural landuse, 90% of the area is used for crop and cattle production, with soybean as the main crop. The planting technique used is no-till, where the number of times the machines pass over the soil has

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diminished compared with the practices used until the 1990s, which were greatly responsible for the onset of erosion. (Castro *et al.*, 1993, 1999).

4. Results

The zoning of potential risk areas for gully erosion in the Taboão Catchment indicates that most of the area (78%) presents a very low risk of erosion and only 12% of the area presents high and very high risk for gully erosion.

The characterization of five potential gully erosion risk classes based on the variables that describe the geology, geomorphology and soils, showed that the relationships between these variables and risk classes are not completely linear. An example would be the mean slope of the terrain in the areas occupied by different risk classes. Although erosion risk shows a tendency to rise as the mean slope of the terrain increases, the mean slope values found in the areas with low erosion risk does not follow this trend.

A clear linear relationship was found between gully catchment area and erosion risk. The values for the different classes show that the portions of the basin that are more susceptible to erosion are with larger contributing areas.

The behaviors of the slope curvatures in profile and on plane are different from expected. While the percentages of slopes with a convex profile are approximately constant in all risk classes, the concave and plane shapes vary greatly and irregularly from class to class. Despite this, the concave slope shows a tendency to increase as the erosion risk becomes higher, and reaches up to 54% of the area occupied by the very high risk class. On the other hand, the plane slope tends to occur less frequently, as the risk of erosion increases, it varies from 85% in the very low risk class to approximately 33% in the very high erosion risk class. Concerning to slope curvature on plane, the plane shapes become less frequent as the risk of erosion increases. This trend was also observed on concave slopes, although not so clearly. The convex shapes diminished as the risk of erosion increases, but from the moderate risk on they are more frequent.

There are very clear relationships between the geology in the Taboão Catchment and erosion risk. Sandstones are more frequent as the potential risk for gully erosion increases. This relationship is much clearer if the lineaments are considered since 82% of the areas at a very high risk of erosion are related to lineaments whereas these occur in only 3% of the very low risk areas. For the lineament direction, we found that the NE direction is linked to the very low and low erosion risk classes, and this association significantly diminishes as the risk increases. On the other hand, lineaments in the NW direction are more profound with the increased risk of erosion and they predominate in the high and very high erosion risk classes.

The most significant relationship between soil and erosion risk zoning is demonstrated by the soils of the mapping units related to higher terrain slope, which show a considerably increased surface as the potential erosion risk increases.

The validation of zoning of the potential gully erosion risk can be performed by identifying the potential risk in places where gullies have been mapped. It is observed that about 78% of the gullies are located in areas with *high and very high erosion risk*.

Lithology and soils are main factors responsible for gully development in areas where erosion risk is moderate, low and very low. Sandstones are the substrate of 70% of these gullies and the soils of mapping unit related to higher terrain slopes are much more frequent in these cases than in the others.

5. Conclusions

The methodology used to look at the risk of gully erosion as a function of geology, geomorphology and soil is proved appropriate for the study area. That was shown by the validation of zoning of the potential gully erosion risk.

The results obtained show that the variables control in different ways the development of gullies and that their characteristics which determine the classes of erosion risk indicate their interactive nature. However, the fact that there is no full agreement between the gullies and areas with *high* and *very high erosion risk* may indicate that the variables chosen are not the only ones that control the phenomenon of gully erosion in the study area.

The clear relationships between the gullies and the lithology, lineaments, and soils indicate that subsurface flow can be a very significant component in gully erosion and it should be further studied.

References

Boulet, R., Leprun, J.C., Chevallier, P., Sánchez y Vacas, A.M. 1993. Reconnaissance pedologique sur les bassins du Projet Potiribu, Rapport provisoire. (Inédito)

Carvalho, A.P., Abrao, P.U.R., Fasolo, P.J., Potter, R.J. 1990. Levantamento Semidetalhado dos Solos da Bacia do Arroio Taboão (Pejuçara/ Ijuí-RS). Multigr. 1 mapa. Escala 1:25.000. 41p.

Castro, N. M. dos R., Auzet, A.V., Chevallier, P., Leprun, J.C. 1999. Landuse change effects on runoff and erosion from plot to catchment scale on the basaltic plateau of southern Brazil. *Hydrological Processes*, v. 13:1621-1628.

Castro, N. M. dos R., Chevallier, P., Silveira, A.L.L. da. 1993. Agriculture on the Brazilian basaltic plateau: cultivations practices and soil conservation: first results of the Potiribu project. Farm Land Erosion: in temperate plains environment and hills. Elsevier, Amsterdam, p.403-414.

Chevallier, P., Castro, N.M.R. 1991. As precipitações na região de Cruz Alta e Ijuí (RS-Brasil). In: SIMPÓSIO BRASILEIRO DE RECURSOS HÍDRICOS, 5, Rio de Janeiro. Anais... ABRH/ABRH, Rio de Janeiro. v.3: 183-192.

Eastman, J.R. 1999. Guide to GIS and Image Processing. Clark University, Worcester. v.1. 193p.

Nimer, E. 1989. Climatologia do Brasil. 2.ed. IBGE, Rio de Janeiro. 422p.

São Paulo. Secretaria de Energia e Saneamento. 1990. Controle de Erosão: bases conceituais e técnicas, diretrizes para o planejamento urbano e regional, orientação para o controle de boçorocas urbanas. DAEE / IPT, São Paulo. 92 p.

INFLUENCE OF SOIL STRUCTURE, PORE-WATER PRESSURE, AND TAILWATER HEIGHT ON HEADCUT MIGRATION IN UPLAND CONCENTRATED FLOWS

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1. Introduction

Soil loss from arable fields caused by surface runoff erosion is composed of several components due to different erosion processes. Bennett *et al.* (2000) reported experimental data showing that actively migrating ephemeral-gully headcuts display steady-state migration and self-similar organization in the absence of hardpans and upstream sediment supply. Alonso *et al.* (2002) combined free and impinging jet theory with mass and energy conservation laws to predict soil losses due to headcut erosion and migration in uniform flows. Headcut erosion and migration rates were shown to depend on upstream flow depth and discharge, tailwater depth, and soil and water properties. The hydrodynamic basis for this model was verified experimentally by Bennett and Alonso (2005a, 2005b).

The preceding studies have improved considerably our understanding of headcut erosion and migration mechanisms. Obviously, there is a critical need for research aimed at characterizing the influence of varying soil structures, tailwater height, pore-water pressure, dirty water inflow, and channel widening on head cut erosion. The primary objective of this study was to determine the impact of soil texture, soil pore-water pressure, and tailwater height on scour hole dimensions, migration rate and sediment yield in headcuts migrating under steady surface runoff conditions.

2. Experimental Methods and Materials

All experimental runs were conducted in a 5.5-m long, 0.165-m wide non-recirculating, tilting flume. The soils used in this study were a fine sandy loam (Ruston series), a silt loam (Atwood series), a silt loam (Dubbs series), and a silty clay loam (Forestdale series).

A subsurface drainage system made out of perforated pipes was installed then covered by a porous fabric and a 0.06m thick layer of 25-35 μm sand. 10 kg soil lifts (0.03 m thick) were sequentially placed in the soil cavity, leveled, and then packed by vibration transmitted through a Plexiglas plate. After packing to a prescribed depth (0.22 m), an aluminum headcut (forming) plate was installed 1.7 m downstream of the rigid floor. Once this headcut plate was in position, soil was packed upstream of the plate in 6 kg lifts, packed, and leveled with the upstream rigid floor, thus producing a preformed vertical step in the bed profile.

Following the rainfall application, two five-gallon Marriott bottles filled with the same water used for overland flow were connected to the subsurface drain. The water was allowed to reach equilibrium at a prescribed height and then maintained 24 hours prior to the release of overland flow. Tailwater height was controlled using an adjustable gate (1mm accuracy) at the downstream end of the soil sample.

3. Results

During each run, clear water was released onto the channel bed at a constant rate (70 L/min). At the brinkpoint of the preformed headcut, water was redirected downward by gravity over the face of the preformed step onto the surface of the soil bed downstream of the preformed step, similar to an impinging jet. As the water impacted the soil surface, the jet split, shearing the soil surface and initiating scour downstream of the preformed step. A hydraulic jump moved upstream from the downstream boundary and became trapped by the impinging jet in the scour hole, initiating upstream migration of the headcut. Two processes control the upstream migration of the headcut: erosion of the basal material (caused by the action of the captured upstream eddy created by the impinging jet) and mass failure by gravity (cantilever failure) of the headcut face following removal of the basal material. These processes occurred continuously, in seamless order, as the headcut began to grow and migrate upstream.

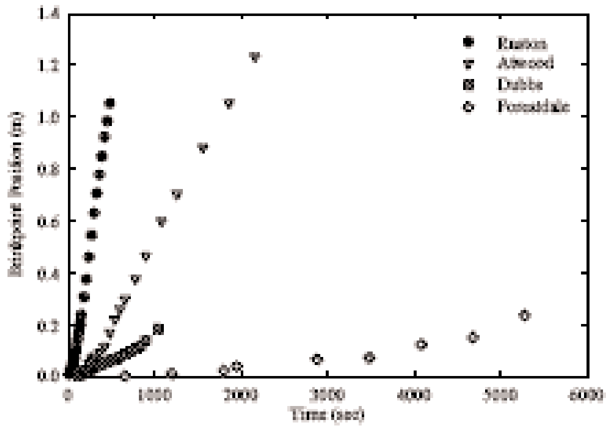

Fig. 1. Comparison of migration rates from four soils.

A significant period of steady state propagation was easily defined with the Ruston and the Atwood soils operating under fully drained conditions. The morphology of the scour hole within each run remained unchanged

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during a substantial portion (>0.5 m) of the available upstream migration length (1.5 m). A second set of morphologically similar responses was obtained from fully drained Dubbs and Forestdale soils. Following initial development of the scour hole, the face of the scour hole became the focal point of erosion. The migration rate in the Ruston soil was greater than those for the Atwood soil, followed by the Dubbs and Forestdale soils (Fig. 1).

The morphological response due to a change in soil pore-water pressure was examined in the Atwood soil. The Atwood soil displayed a tendency for scour hole development similar to that in the full drainage case. However, the maximum scour depth increased with decreasing pore-water pressure (Fig. 2). Both brinkpoint migration and sediment yield attained essentially similar constant rates after roughly 22 minutes into the runs, and in both instances the migration rate was quite similar, although three times slower than observed under full drainage.

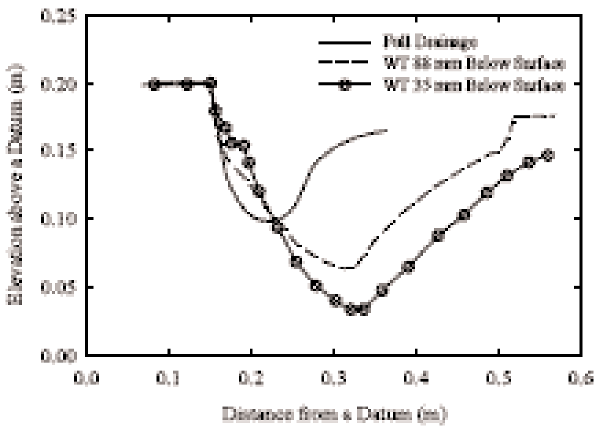

Fig. 2. Scour hole dimensions for full drainage compared to variable water table heights.

The impact of the downstream boundary was examined using the Ruston soil by manipulating the tailwater height at the outlet of the soil flume. After steady-state migration was achieved (asymptotic sediment yield), the gate was raised, samples were taken and the gate was lowered (Fig. 3). Sediment concentrations dropped dramatically each time the gate was raised and the upstream migration rate declined nearly 3 orders of magnitude.

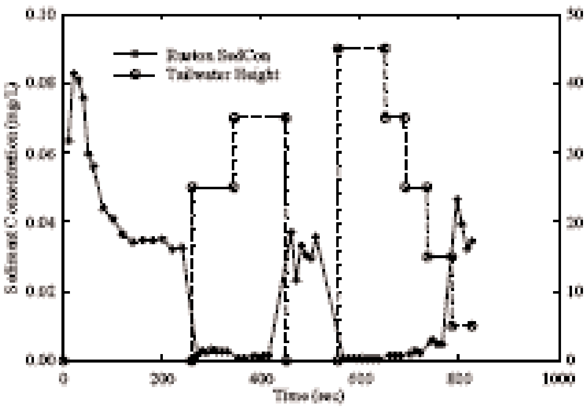

Fig. 3. Impact of tailwater height on sediment concentration.

4. Conclusions

Soil erosion and sedimentation by water are major problems that reduce cropland productivity, degrade water quality, and clog water conveyance structures. The present investigation sought to examine the effect of soil structure, the impact of pore-water pressure and tailwater height on headcut development and migration. These runoff and soil controlling parameters resulted in two distinct modes of headcut growth and migration. The Ruston and Atwood soils attained steady-state morphology, constant upstream migration, and sediment yield. The Dubbs and Forestdale soils developed scour geometries characterized by an eroded brickpoint and tilted back headcut face as the overfall nape turned into an attached wall jet. The resulting scour hole shape is at considerable variance with those exhibited by the Ruston and Atwood soils. Maximum scour depth increased with decreasing pore-water pressures and an increase in tailwater height dramatically lowered the sediment yield and migration rate.

References

Alonso, C.V., S.J. Bennett, and O.R. Stein, Predicting head cut erosion and migration in concentrated flows typical of upland areas, *Water Resour. Res.*, 38, 1303-1317, 2002.

Bennett, S.J., C.V. Alonso, S.N. Prasad, and M.J.M. Romkens, Experiments on headcut growth and migration in concentrated flows typical of upland areas, *Water Resour. Res.*, 36, 1911-1922, 2000.

Bennett, S.J. and C.V. Alonso, Modeling headcut development and migration in upland concentrated flows, *International J. of Sediment Res.*, 20, 281-294, 2005.

Bennett, S.J., and C.V. Alonso, Kinematics of flow within headcut scour holes on hillslopes. *Water Resources Research*, 41, W09418, doi:10.1029/2004WR003752, 2005.

SEEPAGE EROSION IMPACTS ON EDGE-OF-FIELD GULLY EROSION

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1. Introduction

Concentrated flow is generally considered the controlling mechanism for gully erosion whereas subsurface flow is often overlooked. The two mechanisms of subsurface flow attributed to gully erosion are seepage flow and preferential flow through soil-pipes. Seepage erosion typically occurs in duplex soils in which a perched water table develops above a water-restricting horizon. The effect of seepage is usually considered to be limited to the production of surface runoff and the impact of increasing soil water pressures on reducing soil shear strength. However, recent studies by Wilson et al. (2007), Fox et al (2006, 2007), and Chu-Agar et al. (2007) have demonstrated that seepage erosion can be the controlling process of streambank failure and by analogy may be a significant contributor to gully erosion. Seepage erosion is used to describe the process of sediment transport out of the gully face by liquefaction of soil particles entrained in the seepage. The undercutting of the gully face by seepage erosion results in bank failure which may be a contributing factor to headcut migration and gully widening. This paper will review this recent work on seepage erosion.

2. Methodologies

2.1. In situ measurements

Seepage flow and erosion were measured after selected rainfall events at both the Little Topashaw Creek (LTC) and Goodwin Creek (GC) in northern Mississippi using 50- cm wide lateral flow collection pans installed into the streambank face. A time discrete sample was collected at steady-state sediment transport out of the pan.

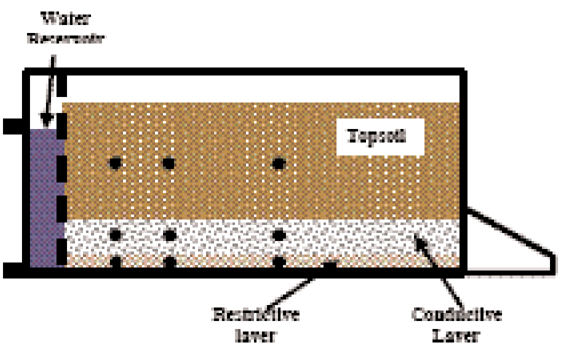

Fig. 1. The artificial streambank profile lysimeter (100 cm long by 15 cm wide) with a constant head water reservoir and tensiometers (solid circles) in each layer.

2.2. Lysimeter experiments

Lysimeter experiments were conducted to simulate seepage erosion at LTC. The simulated LTC streambanks consisted of a silt loam topsoil of varying bank height, a 0.10 m conductive loamy sand layer, and a 0.05 m clay loam restrictive layer at the bottom (Figure 1). Lysimeter experiments were performed by varying the inflow water head (30, 40, and 60 cm), bank height of topsoil (30, 50, and 80 cm), and lysimeter slope (0%, 5%, and 10%).

2.3. Stability Modeling

Bank stability with variably-saturated flow modeling was presented by Chu-Agor et al. (2007). SEEP/W, a 2D Richards' equation model, was integrated with SLOPE/W, a bank stability model, to simulate the mass wasting due to seepage erosion. SEEP/W model was calibrated with the measured soil-water pressures and cumulative discharges of the lysimeter experiments by slightly adjusting the hydraulic conductivity, K_s, and water retention parameters (α and n). Changes in the geometry of the flow domain to reflect the undercutting by seepage erosion was accomplished by changing the material properties of segments, Figure 2. In SEEP/W, the region was treated as a void in the flow domain by not assigning a material property, whereas in SLOPE/W the eroded area was treated as a null region without soil strength properties specified.

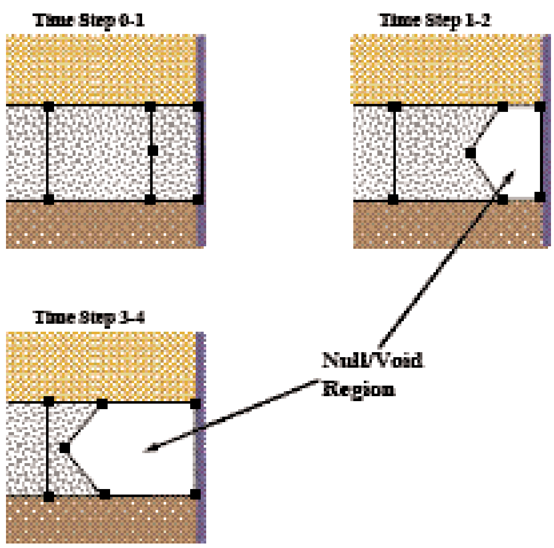

Fig. 2. Changes in flow and stability model domains as a result of seepage erosion undercutting banks.

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SLOPE/W uses the theory of limit equilibrium of forces and moments to compute the factor of safety (Fs) against failure:

$$F_s = \frac{\sum \left((c' \beta \cos \alpha + (N - u\beta) \tan \phi' \cos \alpha \right)}{\sum N \sin \alpha - \sum D \cos \omega} \quad (1)$$

where c' = effective cohesion, ϕ' = effective angle of internal friction, σ_n = total normal stress, u = soil-water pressure, W = slice weight; D = line load; β and ω = geometric parameters; N = normal force at the base of the slice, and α = inclination of the base. Fs< 1.0 indicate mass failure. A probabilistic slope stability approach was used in solving for Fs. A normal probability density function (pdf) was assigned to input parameters based on expected values of cohesion, angle of internal friction, and total unit weight.

3. Results and Discussion

3.1. In Situ measurements

Seepage flow and erosion were measured after selected rainfall events by Wilson et al. (2007) and Fox et al. (2007) at both the LTC and GC stream sites, respectively. Seepage erosion, due to liquefaction of soil particles, was evident along both streams by locations with undercut banks. In general, average seepage flow rates were significantly greater at GC (388 L d^{-1}) than LTC (174 L d^{-1}). However, average sediment concentrations at LTC (246 g L^{-1}) were significantly greater than at GC (69 g L^{-1}) as a result of differences in soil strength of eroding layers.

3.2. Lysimeter Experiments

The results of the lysimeter experiments for LTC were reported by Wilson et al. (2007) and Fox et al. (2006). The time to flow initiation and the flow rate were linearly related to the slope of the restrictive layer. Seepage erosion began within minutes of flow initiation with sediment concentrations as high as 4500 g L^{-1}. A sediment transport model was derived based on a dimensionless sediment discharge and dimensionless seepage flow shear stress to describe the seepage erosion. Seepage erosion resulted in substantial (7 to 20 cm) undercutting of the banks which was linearly related to the slope. Bank failure occurred when undercutting reached 10 to 20 cm and prior to the removal of negative pore-water pressures in the topsoil layer. This suggests that seepage erosion was the controlling mechanism and not the loss of soil strength. Mass wasting occurred as cantilever failures that averaged 0.2, 25.0, and 29.0 kg for the 30, 50, and 80 cm bank heights, respectively, which is substantial for a 15 cm wide bank.

3.3. Stability Modeling

Chu-Agar et al. (2007) demonstrated a procedure for incorporating seepage undercutting into stability models. Undercutting was simulated by changing the geometry of the flow domain based on the measured dimensions and timing of the undercut caused by seepage erosion.

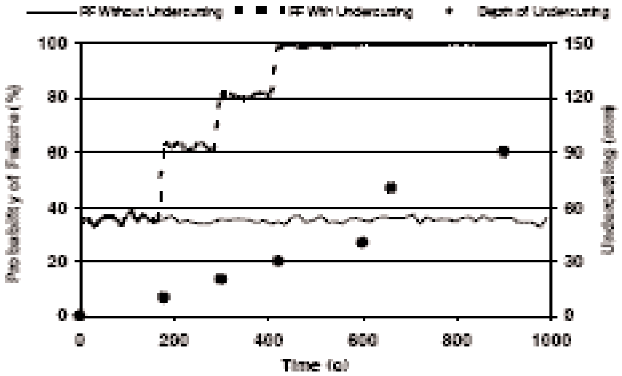

Fig. 3. Simulated probability of failure (PF, %) of lysimeter experiments with 0.8 m bank, 0% slope, and a 0.3 m constant head with and without seepage undercutting.

Loss of soil strength by increased soil-water pressures during seepage were not sufficient to contribute to bank failure. However, the mean factor of safety decreased significantly (42 to 91%) as the degree of undercutting increased. Stable banks were shown to become significantly unstable when seepage undercutting was included. For stable banks, the probability of failure reached 100% when the degree of undercutting reached approximately 30 to 50 mm. Bank height and bank slope controlled the initial stability of the bank while the established constant head controlled the degree of undercutting and the mean factor of safety as undercutting progressed.

4. Conclusions

These results indicate that the mean factor of safety is related to the degree of undercutting. These results show that mass wasting of gully banks, can be the result of seepage erosion undercutting gully walls. This process was shown to be of equal or greater importance than the impact of seepage on soil strength properties. The question remains as to what role this process plays in ephemeral gully erosion. It is common to observe ephemeral gullies formed on duplex soils, i.e. an erodible surface layer over a water restrictive layer, which are naturally conducive to seepage erosion processes.

References

Chu-Agor, M.L., G.V. Wilson, and G.A. Fox. 2007. Numerical modeling of bank instability by seepage erosion. J. Hydraulic Engineering. (in review).

Fox, G.A., G.V. Wilson, R.K. Periketi, and R.F. Cullum. 2006. Sediment transport model for seepage erosion of streambank sediment. J. Hydrologic Engineering, 11(6):603-611, ASCE 1084-0699.

Fox, G.A., G.V. Wilson, A Simon, E.J. Langendoen, O. Akay, and J.W. Fuchs. 2007. Measuring streambank erosion due to groundwater seepage: correlation to bank pore water pressure, precipitation and stream stage. Earth Surface Processes and Landforms. (in press).

Wilson, G.V., R.K. Periketi, G.A. Fox, S. Dabney, F.D. Shields, and R.F. Cullum. 2007. Soil properties controlling seepage erosion contributions to streambank failure. Earth Surface Processes and Landforms, 32:447-459. DOI:10.1002/ESP.1405.

THE ROLE OF PREFERENTIAL FLOW THROUGH SOIL-PIPES IN EPHEMERAL GULLY EROSION

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1. Introduction

Estimates by the USDA for 17 States suggest that ephemeral gully erosion ranges from 18 to 73% of the total erosion with a median of 35%. Poesen et al. (2003) found that ephemeral gully erosion contributed from 10 to 94% of total field soil loss, with a median estimate of 44%. Concentrated flow is generally considered the controlling process and subsurface flow is often overlooked. The two mechanisms of subsurface flow attributed to gully erosion are seepage flow and preferential flow through soil-pipes. The term piping is often used to refer collectively to both mechanisms of subsurface flow erosion (Bryan and Jones, 1997). However, the processes can be distinguished by referring to piping as strictly erosion resulting from flow through a discrete macropore or soil-pipe.

Preferential flow through soil-pipes has been attributed to about 60% of the cases of gully erosion under agronomic conditions in European fields (Bocco, 1991). A common feature for pipe-erosion is the existence of water-restrictive layers, which Faulkner (2006) termed duplex soils, that focus flow through soil-pipes. Wilson et al. (2007) reported field observations for a duplex loess soil where ephemeral gullies were eroded down to the fragipan layer with a 3 cm diameter soil-pipe at the gully head. They observed soilpipe flow rates following rainfall events, with rainfall and runon excluded, that were typically 1.4 L h^{-1}. Sediment concentrations were between 8.5 to 0.2 g L^{-1} with values typically less than 1 g L^{-1}. Tillage operations fill-in the ephemeral gully thereby leaving the soil-pipe that was previously at the gully head, buried and discontinuous.

The objective of this study was to quantify the hydrologic conditions under which discontinuous soil-pipes reestablish ephemeral gullies and continuous soil-pipes initiate ephemeral gullies.

2. Materials and Methods

Experiments were conducted on soil beds in a 100 cm wide by 150 cm long flume (Figure 1). Bulk soil was collected from a depth of 0 to 10 cm from a Providence silt loam (fine-silty, mixed, active, thermic Oxyaquic Fragiudalfs) soil on the Holly Springs Experiment Station in North Mississippi. The soil contains 15, 69, and 16% sand, silt, and clay, respectively. Soil was sieved to < 2 mm and maintained in field-moist conditions for packing in 2.5 cm lifts. The bottom 5 cm of the soil bed mimicked a water restrictive layer by packing silty clay loam material to the average bulk density (1.57 g cm^{-3}) of fragipans in this area. The topsoil was packed to a bulk density of 1.35 g cm^{-3}, typical of surface conditions.

Experiments were conducted on a discontinuous soilpipe (2 cm i.d.) that extended 50 cm into the soil bed with 30 cm topsoil depth and a 5% slope. The following combinations of experiments were conducted: (1) pipe flow only with 15 cm pressure head, (2) pipe flow only with 30 cm pressure head, (3) rainfall only, (4) rainfall and pipe flow with a 15 cm head, and (5) rainfall and pipe-flow with a 30 cm head. Experiments were also conducted on a continuous soil-pipe (1 cm i.d.) that extended the entire length of the soil bed with 10 cm topsoil and 15% slope. These experiments included combinations of pipe-flow with and without rainfall. The soil pipe flow was at steady state flow rates of 190 L/h and 284L/h which equates to a constant pressure of 15 cm and 30 cm on a 1 cm i.d. soilpipe, respectively.

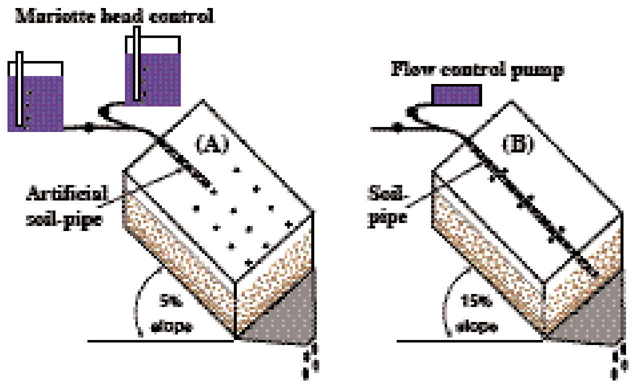

Fig. 1. Illustration of soil bed with tensiometers indicated by solid circles for (A) the discontinuous soil-pipe experiments, and (B) the continuous soil-pipe experiments.

3. Results and Discussion

3.1. Discontinuous Soil-Pipe Impact

The results for experiments mimicking an ephemeral gully with a discontinuous soil-pipe are reported in Wilson et al. (2007) and summarized in Table 1. The flow rate into the artificial soil-pipe for the 15 and 30 cm heads averaged 3.5 L h^{-1} whereas the seepage out of the soil bed averaged 0.5 L h^{-1}. The sediment concentrations from seepage for a discontinuous soil-pipe were essentially zero. In general, seepage flow rates for pipe flow alone were low, sediment concentrations were negligible and the soil bed did not exhibit mass wasting. Therefore soil loss in the runoff from pipe-flow alone was negligible. However, soil-pipe flow alone did result in the development of tension cracks and in one of the two tests it produced mass wasting.

The hydrologic response to rainfall alone was more dynamic than for pipe-flow alone. Surface runoff was

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initiated within 4.5 min and 2.3 min of rainfall for the two tests. The average runoff rate, over the course of the three rainfall events for the two tests was 67.5 L h^{-1}. The average sediment concentration was 22.5 g L^{-1} for a total soil loss by sheet erosion for rainfall alone, under bare soil conditions and a 5% slope, was 3.4 kg. This equates to 25 ton ha^{-1} which is 3.6 times larger than the tolerable soil loss limit established for this soil. Rainfall alone failed to produce mass wasting of the soil bed.

Table 1. Response to flow into a discontinuous soil-pipe, under 15 and 30 cm heads, with and without rainfall.

Treatment	Ro	PF	SC	SL	MW
	L/h	L/h	g/L	kg	kg
rain only	67.5	Na	22.5	3.4	0.0
15 cm head	0.6	2.8	0.2	0.0	12.0
30cm head	0.04	4.1	0.0	0.0	0.0
15cm+rain	78.2	0.8	26.8	4.5	16.2
30cm+rain	78.6	2.9	85.3	13.6	62.9

Time averaged values reported for runoff rate (Ro), pipe-flow rate (PF), sediment concentration (SC), and cumulative soil loss (SL) by sheet erosion, and mass wasting (MW).

The runoff rate for rainfall with pipe flow under a 15 cm head was 5.2 cm h^{-1} and the average sediment concentration was 26.8 g L^{-1}. The total sediment loss by sheet erosion averaged 4.5 kg which is only slightly higher than for rainfall alone. It would appear that soil-pipe flow with rainfall has a negligible influence on erosion. However, both 15 cm and 30 cm heads with rainfall exhibited sudden mass wasting by pop-out failures. For the two 15 cm head tests, the first pop-out failure resulted in 1.6 and 2.3 kg of soil loss by mass wasting in 5 s spans, respectively. These failures were followed by additional pop-out failures for a total of 16.2 kg of soil loss by mass wasting. The 30 cm head with rainfall tests had even more dramatic mass wasting. The first test had seven pop-out failures, each lasting a matter of seconds, with mass wasting ranging from 0.6 to 12.2 kg for a total of 37.4 kg. The second test had 16 pop-out failures for a total soil loss by mass wasting of 88.3 kg.

3.2. Continuous Soil-Pipe

The results presented here for flow through a continuous soil-pipe, Table 2, are preliminary as experiments are ongoing. The flow rates into the continuous soil-pipe (PF) under 15 and 30 cm heads were almost two orders of magnitude higher than observed when the soil-pipe is blocked by filling of the ephemeral gully. Like the discontinuous pipe experiments, pipe flow alone generally failed to cause mass wasting for the continuous soil-pipes. In contrast, the sediment concentrations were fairly high and were in the range observed by Wilson et al. (2007) for similar conditions in the field. The high sediment concentrations were the result of internal erosion within the soil-pipe caused by the high velocity exceeds the shear strength of the pipe walls. The pipe-erosion at times occurred in surges as the soil-pipe became clogged by internal mass wasting until pressure build ups flushed the sediment out of the pipes. The soil pipes were observed to enlarge significantly from 1 cm i.d initially to over 5 cm. However, tunnel collapse was not observed. The combination of rainfall with flow through a continuous soil-pipe produced significant soil losses by mass wasting, although substantially less than the discontinuous soil-pipe.

Table 2. Response to flow through a continuous soil-pipe, at flow rates equal to 15 and 30 cm heads, with and without rainfall.

Treatment	Ro	PF	SC	SL	MW
	L/h	cm/h	g/L	kg	kg
15cm head	160.6	189.0	4.4	2.1	0.0
30cm head	265.5	285.0	6.4	5.3	0.0
15cm & rain	222.4	189.0	8.2	6.0	4.1
30cm & rain	307.0	283.5	11.6	8.8	8.8

Time averaged values reported for runoff rate (Ro), pipe-flow (PF) rate, and sediment concentration (SC), and cumulative values for soil loss (SL) by sheet erosion, and mass wasting (MW).

4. Conclusions

Preliminary findings on continuous soil-pipes did not exhibit sudden development of mature ephemeral gullies by tunnel collapse as suggested by Faulkner (2006) but experiments on discontinuous soil-pipes did exhibit sudden re-establishment of filled in gullies. When pipe flow occurs with rainfall, a synergistic effect is produced that results in cataclysmic pop-out failures which may be up to 20 times higher than sheet erosion. The result of these pop-out failures is the re-establishment of ephemeral gullies with large initial soil losses. These findings explain the reoccurrence of ephemeral gullies in the same locations despite land management efforts to control their development. This work also suggest that conservation practices that focus solely on controlling the surface runoff may be ineffective if subsurface flow is not considered.

References

Bocco, G., 1991. Gully erosion, processes, and models. Progress in Physical Geography, 15:392-406.

Bryan, R. B., Jones, J.A.A., 1997. The significance of soil piping processes: inventory and prospect. Geomorphology, 20:209-218.

Faulkner, H., 2006. Piping hazard on collapsible and dispersive soils in Europe. In: J. Boardman, J. Poesen (Editors), Soil Erosion in Europe, Chapter 2.6, John Wiley & Sons, Ltd.

Poesen, J., Nachtergaele, J., Verstraeten, G., Valentin, C., 2003. Gully erosion and environmental change: Importance and research needs. Catena, 50:91-133.

Wilson, G.V., R.F. Cullum, and M.J.M. Römkens. 2007. Preferential flow through a discontinuous soil-pipe results in mass wasting and reestablishment of ephemeral gullies. Catena, (in review).

HISTORICAL GULLY EROSION WITHIN LOESS AREAS OF SE POLAND – NATURAL CONDITIONS AND HUMAN IMPACT

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1. Introduction

Gullies constitute one of the most characteristic elements of loess relief in SE Poland. Particularly dense net of permanent gullies – in some places more than 10 km?km^{-2} – appears in areas of specific conditions of abiotic environment which favour gully erosion. However, it is generally believed that these conditions were not a natural landscape (Bork 1989, Schmitt et al. 2006, Vanwalleghem et al. 2003). Only after the devastation of the natural plant cover of mixed and deciduous forests, resulting from agricultural expansion, the erosion began to develop dynamically.

The purpose of this article was to determine the influence of natural factors and human activity on the processes of gully erosion (density of permanent gullies). The existing gully systems were examined and the achieved results give an idea about the processes taking place in the past.

2. Area of study and methods used

Three similar in size test areas in south-eastern Poland were chosen for the research ("Markowa", "Wàwolnica", "Wilczyce"). The areas occupy about 100 km in total. The analysed terrain is characterised by the following environmental features: - the domination of the eolian deposits (loess): 59% to 78% of the area; - substantial percentage of the areas where slope angles exceed 6^{o}: 22%-27%; the domination of arable grounds: 55%-66%.

Spatial analyses of gully erosion conditions were carried out within the test areas by means of GIS software. The measurements were taken for 35 gully catchments and for buffer zones of 50 and 100 m in width, adjacent to gully edges. Moreover, within the test area "Wawolnica" the profiles of colluvial and alluvial deposits were studied and the geochemical analysis and radiocarbon dating were carried out.

3. Results

3.1. Catchments features

The statistical calculations presented in this article were carried out for 21 catchments with an area of 10 to 100 ha (smaller and larger catchments were excluded). The analysed catchments are characterised by diverse environmental features, as proved by a wide range of examined parameters. In comparison with all the studied areas, the analysed catchments have a bigger share of loess covered areas and terrains with slope angles exceeding 12^{o} (Table 1). The average density of permanent gullies is 4.2 km·km^{-2}, reaching 10 km·km^{-2} in one of the catchments.

Table 1. Features of gully catchments.

	range	average	test areas
area [ha]	11-84	34	3300
inclinations [°]	2.4-7.2	4.0	3.5
area of loess cover [%]	61-100	79	67
relative heights [m]	24-133	40	80-193
area of steep slopes (>12°) [%]	0-31	6	4
density of gullies [km·km^{-2}]	2-10	4.2	0.9-2.3

3.2. Spatial analysis

The research into the parameters of environmental features of gully catchments did not show any correlation between the density of gullies and the abiotic components. Only a positive relation between the density of the examined forms and the relative heights, as well as the area occupied by loess, was determined. The lack of clear relations can result from the fact that the analysed catchments varied in area, which might have caused averaging of all the relations. The gullies cut into the bottoms of almost all dry valleys – places of flow concentration – in the examined areas.

Frequency of appearance of areas occupied by certain components of abiotic environment in close vicinity of the gullies (buffers of 50 and 100 m) was compared with the frequency of their appearance within the whole test area. It allowed for determining the features favouring the gully formation. The indices were calculated according to the formula:

$$W_x = (P_x \cdot P_x^{-1}) \cdot C_x^{-1} \qquad (1)$$

P_x – the area occupied by the component "x" within the buffer zone; P_b – the area of buffer zone; C_x – the frequency of appearance of component "x" within the whole research area; $W_x \leq 1$ – the component does not favour gully erosion; $W_x > 1$ – the component favours gully erosion.

In all cases the relation between the gully formation and abiotic conditions was stronger for the 50 m buffer. For the areas of "Markowa" and "Wawolnica", the relation of the occurrence of young ravines with colluvia is clearly visible – the gullies cut into the bottoms of dry valleys. For the

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remaining test areas the conditions connected with the type of surface deposits were not that clear cut (Table 2).

Table 2. Abiotic conditions of gully formation.

	50 m buffer			100 m buffer		
	1	2	3	1	2	3
surface deposits						
clays	-	3.3	0.1	-	3.1	0.1
fluvioglacial	0.3	2.0	-	0.8	1.9	-
colluvial	1.8	0.8	3.3	1.4	0.8	2.6
loess	1.1	0.9	0.5	1.1	1.0	0.7
inclinations						
plateaus (0-3°)	0.5	0.4	0.4	0.6	0.6	0.4
gentle slopes (3-6°)	1.7	1.4	0.7	1.5	1.3	0.8
medium slopes (6-12°)	1.9	1.9	2.5	1.7	1.7	2.3
steep slopes (>12°)	1.6	4.1	4.8	1.5	3.1	3.8

test areas:
1 – "Wąwolnica", 2 – "Wilczyce", 3 – "Markowa"

The relations between gully development and the relief were similar in all three tested areas. A component favouring the occurrence of the gullies within the catchment is a big share of steep slopes (Table 2).

3.3. Gully erosion phases

Study of the deposits filling the gullies allows for determining the development phases of these forms. Such studies were carried out in the western part of Lublin Upland (in Kazimierz Dolny area). The determined sequence of colluvial deposits points to four phases of gully erosion connected with periods of strong anthropopressure: Bronze Age, early Middle Ages, 16th–17th c. and the second half of the 19th c. – modern times (Schmitt et al 2004).

River valley bottoms of loess areas are places where intensive redeposition of the material removed as a result of gully erosion processes takes place. For example, the thickness of deposits connected with erosion of loess areas in the bottom of the Bystra river valley (test area "Wawolnica") reaches 3.5 – 5.0 m. The research showed that while single erosion forms could appear in Neolith and Bronze Age, these were only short hilltop gullies. The bottom of the river valley at that time was undergoing organogenetic sedimentation: peat beds were formed. The beginning of filling processes of the valley bottom by deposits connected with gully erosion took place in 10th-11th c. At the beginning, the material accumulated in the valley bottoms was of organic alluvia character. In 14th c., in the bottom of the Bystra river valley, sedimentation of anthropogenic "alluvial soil", as well as the colluvia originated from the denudation of valley slopes took place (Zglobicki, Rodzik, in print). The process of filling of the valley bottom continues up to the present moment. However, the increase of its dynamics occurred in 19th and 20th c. The above-mentioned phases of intensive gully erosion show strong relations with the periods of stronger human influence on the environment of the examined area (increase of population, development of farming). More detailed analyses of the relation between gully formations and deforestation are difficult to carry out because of significantly limited amount of cartographic materials.

4. Conclusions

Natural features of loess areas create favourable conditions for development of gullies on a regional scale. On the catchment scale (the area <100 ha) correlations between the density of gully network and the natural environment factors are not distinct. More clear cut relations appear in the case of direct gully vicinity (buffer zones of 50 and 100 m) – local conditions. Also, it seems that spatial distribution of the examined forms can be to a large extent influenced by human activity. It can be observed in diverse range and intensity of deforestation processes, as well as in agricultural activities and features like field arrangement (Fig. 1).

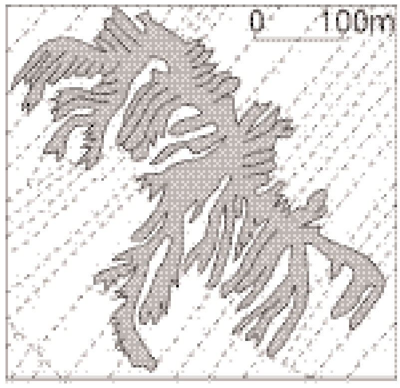

Fig. 1. Gully system against the field arrangement.

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References

Bork H.-R., 1989. Soil erosion during the past Millennium in Central Europe and its significance within the geomorphodynamics of the Holocene. In F. Ahnert (ed.), *Landforms and Landform Evolution in West Germany, Catena Supplement 15*:121-131.

Schmitt A., Schmidtchen G., Rodzik J., Zglobicki W., Dotterweich M., Zamhoffer, and H.-R. Bork 2004. Historical gully erosion in southeastern Poland, an example from the loess area of the Lublin Upland. In Y. Li, J. Poesen, Ch. Valentin (eds.) *Gully erosion under Global Change*: 223-230.

Schmitt A., Rodzik J., Zglobicki W., Russok Ch., Dotterweich M., Bork H.-R. 2006. Time and scale of gully erosion in the Jedliczny Dol gully system, southeastern Poland. *Catena 68*: 124-132

Vanwalleghem T., Van Den Eeckhaut M., Poesen J., Deckers J., Nachtergaele J., Van Oost K, Slenters C., 2003. Characteristics and controlling factors of old gullies under forest in a temperate humid climate: a case study from the Meerdaal Forest (Central Belgium). *Geomorphology 56*:15-29.

Zglobicki W., Rodzik J. (in pr.). Heavy metals in the slope deposits of loess areas of the Lublin Upland (E Poland). *Catena* (10.1016/j.catena.2006.10.008).

SOIL EROSION ON THE BOTTOM OF HOLLOWS IN STEPPE ZONE OF UKRAINE

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Soil erosion, undoubtedly, is one of the main ecological and agricultural problems in the world. Quantity of eroded lands in Ukraine achieves 10.5 millions ha. Annual losses of soil constitutes about 600 millions tons in the country.

Gully erosion and other kinds of soil degradation are very extended in east party of Ukraine. Often forming of gullies begin in the links of primary hydro-graphical network, i.e. on the bottom of the hollows.

In the countries of the former USSR the application of so-called "measures of constant action" (the soil-protection ground hydrotechnical constructions, runoff-regulating forest shelterbelts and other linear boundaries) are the most recognized way of the soil protection.

The aims of the our work are:

1) to define quantitative indicators of soil loss due to water erosion; 2) to study the soil protection role of MCA on the slopes with hollows.

Since 1982 we have been studying the soil erosion processes in the agricultural enterprise "Udarnik". It situated near town Lugansk. In 1980-1990 there were created 153 ha of forest plantations; 19 ha of gullies were made flat, the terraces were located on 20 ha of strong eroded steep slopes; 61.9 km of bank-trenches were created in soil-protective crop rotations; pastures were improved on the area of 373 ha. Except this, banks-terraces with wide base were ploughed on 76 ha of arable lands. More than 2.1 km of water-retaining and water-diverting banks, 5.5 km of trenches including 3.5 km in combination with forest belts, grassland establishment on 24 ha of hollows were made.

The soil cover is middle and hard loamy ordinary chernozemes.

For 22 years there were 26 times of runoff events from snow melting water and rainstorms. Noticeable soil erosion processes were 18 times. Erosive losses of soil have take place at snow melting in 1985, 1986, 1994, 1996-1999, 2002, 2003, 2005 at downpours twice in 1987, in 1989, 1992, 1996, 1998, 2002 and 2003 years. Maximum soil loss from rainstorms achieved 295 t\ha, from the snow melting runoff – 44 t\ha.

The year 1992 was abundant on storm precipitation. On May 23-26 May it fell up to 207 mm in the southern part of Lugansk region. The territories of 13 farms with daily precipitation from 35 to 141 mm (that corresponds to their probability P% of exceeding for 40 to 1%) were inspected.

The inspection shows that the thalwegs of the elementary channel network (hollows) are the most damaged places of the fields. There were rills on the fields with young tilled crops almost in all farms. Rills appeared in winter crops when the daily precipitations was >70 mm (P<3%). Rills were out of hollows (even in the tilled crops) when precipitations were more 115 mm (P<1%). The soil losses under postemergence harrowing of tilled crops along a slope of 3,5º steepness and length 300 m ran up to 295 tons /hectare.

Spatial regularities of soil losses (V, m^3/hectare) are characterized by the next equation (1):

$$V = 1{,}47 I_{\pi}^{1{,}18} L^{0{,}75} K_o \quad (1)$$

I_{π} slope steepness in the places of calculation of soil losses, degrees;
L slope length, m;
K_o coefficient of impact of direction of harrowing after sowing. K_o is 1 when harrowing is executed along the slope, and K_o is 0,23 when harrowing is executed crosswise it.

At poor protective action of vegetation the rills may appear on the hollow bottom (stream-channel erosion) when layer of storm precipitation is 25-30 mm, i.e. annually.

On the fields with tilling along slope the rills appear out of the hollow bottom (slope erosion) when probability of precipitations P% is less then 40%. Under contour-parallel organization of the territory, the rills display out of the hollow bottom when probability of precipitations P% is less then 10-15%.

On the fields with tilling along slope the mass appearance of slope erosion is observed on tilled and winter crops under storm precipitations of 1% probability. The transverse direction of sowing and tilling makes the soil losses 2,4-4 times less.

It is revealed, that degree of erosion risk realization on the slope lands depends not only on their length and steepness, but on steepness of the elementary watersheds across its thalwegs.

On the result of the investigations data for the period from 1986 to 1999 from the slopes with the steepness 1.2 – 3.2 degree the mathematical model of the soil loss was elaborated. Model (2) shows the dependence of the soil loss on the parameters of the hollow watersheds and agrotechnical factors.

$$V = Af^{0{,}68} It^{1{,}20} t^{0{,}37} Lp^{0{,}096} \quad (2)$$

V soil losses for a unit of length of a hollow thalweg in all periods of runoff (V, m^3/running meter)
A efficiency of hydrometeorology, soil, agrotechnical, vegetative and other conditions;
f square of a reservoir part of a hollow, which is set above a cross section line that coincides with a scour cut, hectare;
I_t weighted average of the length of thalweg steepness, hail;

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t auxiliary inclination (steep slope of a gully reservoir in the direction towards a thalweg, weighted average to length and edgewise of a hollow watershed, degree);

L length of flow runaway, m (distance from an insulating or inhibiting hindrance). Variability intervals of these factors on a watershed are the follows: f = 0,05-3,0 hectare; It = 1,9-3,5º; t = 0,4-2,4º; Lp = 10-280 m.

Indicators, allowing to estimate run-off regulating effectiveness of soil control hydrotechnical constructions in conditions of complicated relief are proposed.

Methodics of definition of a relief characteristics on topographical maps is elaborated.

Regularities of a hollow net location on the slope lands were studied.

The dependence of most probable parameters of hollows on slopes length, form of their cross profile, slope exposure and other factors is showed in table 1.

The investigations proves that first hollows appear under steep slope of 0,5-1,0º, at 100-150 meters distance from a watershed line. Mass appearance of hollows is observed under steep slope of 1-2º. And 70% of all hollows originated within interval of 0-3º.

Peculiarities of the soil profile on the slopes with hollows was studied. As a result, mathematical models of the soil profile depth in dependence of morphometrical indicators of the slopes, of granulometrical composition of the soil and exposition of the slopes were obtained.

Study of soil profile showed that depth of humus horizon on the bottom of hollows is bigger (as a rule) than on the watersheds between them. On the bottom of a hollow the cases of burying of humus horizon under alluvial layer (that is identical to the cover of hollow slopes) are often observed. The slopes of hollow, on the contrary, often have not humus and even upper transitional horizons. On the hollow bottom the depth of soil profile may be up to 170 cm or more. Total depth (H) of alluvial, humus and upper transitional horizons on hollow bottoms may be expressed by the following equitation (3):

$$H = (0,48 + 0,059h^3)(1,123 - 4710I_t^3) \qquad (3)$$

h – hollow depth, m;

I_t – local inclination of a hollow thalweg.

Taking into account active erosive process on the bottom of hollows, above-stated phenomena prove the presence of active water and agrotechnical erosion on the slopes of hollows.

To increase water-absorbing capacity of MCA the method was elaborated, which includes fan-shaped mole plowing of hollow slopes. An energy-conservation technology of building of anti-erosion banks was proposed (patent of Ukraine #30243A). The technological ways, which will promote to accelerating of introduction of contour-reclamation agriculture and to increase of anti-erosion stability of agrolandscapes in hard relief conditions are proposed.

The elaborated mathematical models could be used for the grounding of practical measures, regulating water erosion as well as accumulation processes in agrolandscapes.

Table 1. Most probable parameters of hollow network.

Slope steepness	Slope length, m	Cross form of a slope	Parameters of hollow network			
			Hollow depth, m	Slope steepness of hollows	Distance between them, m	Width of their watersheds, m
1-3°	100-500	1-3*	0,3-0,55			
	500-1000		0,5-0,65			
	1000-1500		0,6-0,75			
	100-1500	1		0,007-0,018	100-200	85-170
		2		0,005-0,012	150-260	110-185
		3		0,004-0,010	190-320	110-190
3-5°	100-500	1-3	0,3-0,65			
	500-1000		0,55-0,85			
	1000-1500		0,70-1,00			
	100-1500	1		0,012-0,023	70-150	60-125
		2		0,010-0,018	110-180	75-130
		3		0,008-0,014	130-225	80-135
5-7°	500-1000	1-3	0,7-1,2			
		1		0,018-0,030	60-90	50-75
		2		0,014-0,020	90-130	65-90
		3		0,011-0,018	115-150	75-95

Note: 1* – concave slopes, radius of curvature of contour line R = 250 ÷ 1000 m.
2 – direct slopes, R >1000 m, <-1000 м; 3 – convex slopes, R = -250 ÷ -1000 m.