Ephemeral Gully Erosion—
A National Resource Concern

Recommendations for the Development of Technology and Tools for Prediction and Treatment of Ephemeral Gully Erosion

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Ephemeral gully erosion and severe sheet and rill erosion on unprotected field in northwest Iowa.

Executive Summary

What's the problem?	Recent studies indicate that ephemeral gully erosion may be a significant form of erosion and source of sediment on cropland in the U.S. (averaging around 40% of the sediment delivered to the edge of the field in some documented studies).
Don't we already measure or account for ephemeral gully erosion now?	No. No field tools are available, only ad hoc modifications of watershed models. NRCS has developed support practices for sheet and rill erosion that are also applied to treat ephemeral gully erosion, but technology and tools do not exist to account for the benefits and effects of these practices on soil and water quality by treating ephemeral gullies. Practices specifically developed to treat ephemeral gully erosion need further testing, including when used in conjunction with sheet and rill erosion control practices.
What happens if we don't measure or account for ephemeral gully erosion?	The Agency cannot take full credit for the benefits and effects of conservation practices on soil and water quality. The Agency will lose credibility as the premier agency that has historically been the authority in the prediction and control of soil erosion, because we ostensibly neglected a very significant source of erosion. Subjective observations will continue to be used to satisfy quality criteria in lieu of scientifically defensible, quantitative methods. Non-scientific methods for accounting for and treating ephemeral gully erosion will be used, such as applying a simple multiplier factor to sheet and rill erosion predicted by RUSLE2 or WEPP.
Impact on field staff?	Intent is to minimize additional work required in conservation planning and reporting. The vision is that the field staff would continue to use a tool such as RUSLE2 or WEPP and, if funded, will include an ephemeral gully erosion component, driven from essentially the same field data already collected. Field planners would be able to account for the effects of treatments in the PRS.
Actions needed?	The team that produced this paper was tasked to assess the national scope of ephemeral gully erosion using existing data from NRI, CEAP, PRS, national surveys and watershed studies. This paper and results are intended to provide direction for the development of ephemeral gully technology and its inclusion into NRCS tools and models. NRCS needs to emphasize to ARS the need to expedite ephemeral gully erosion research that will result in technology that NRCS will include in field and watershed models.
Resources needed?	Resources are needed to incorporate ephemeral gully erosion prediction and treatment technology into RUSLE2 or WEPP, watershed models, national assessment procedures such as NRI, and CEAP national and watershed assessment studies. At targeted locations, NRCS field office staff will be needed to collaborate with ARS in collecting supplemental ephemeral gully erosion data sets for use in tool development and calibration. Additional funding will be needed to conduct research on selected watersheds for characterizing ephemeral gully erosion sites, and for developing and testing conservation practices specifically designed for ephemeral gully erosion control.

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Problem Statement

The Natural Resources Conservation Service (NRCS) (formerly the Soil Conservation Service and initially the Soil Erosion Service) has been the authority on erosion prediction and control since the Dust Bowl days. For 70 years, the NRCS has assisted private land users to protect land from excessive erosion. Many types of erosion processes degrade soil, air, and water quality, including irrigation-induced erosion, ephemeral gully erosion, classical gully erosion, streambank and bed erosion, tillage translocation erosion, wind erosion, and sheet and rill erosion.

NRCS currently focuses primarily on sheet and rill erosion to set conservation planning goals and for measuring, predicting, assessing, and reporting water erosion control. The NRI (National Resources Inventory) tracks the status and trends of sheet and rill erosion. Concentrated flow paths (where ephemeral gullies may recur) are also recorded. Reductions in sheet and rill erosion are reported in the PRS (Progress Reporting System), and conservation treatment needs for water erosion control are typically expressed in terms of sheet and rill erosion rates.

Recent studies show that ephemeral gully formation is very common on cropland, especially in conventional tillage systems without support practices. See Appendix A1, Cheney Lake Watershed Study, a CEAP (Conservation Effects Assessment Project) Special Emphasis Watershed. Ephemeral gully erosion is believed to be as significant as sheet and rill erosion in terms of sediment delivered from cropland acres to streams, rivers, and lakes. Some studies have found that ephemeral gully erosion contributes about 40% of the watershed sediment yield. Sediment delivery from farm fields from all erosion sources is also much higher when ephemeral gullies are present. Research on the extent of contributions from all erosion sources to in-stream sediment loads is sparse. Few models account for and specifically predict ephemeral gully erosion. Although the NRI reports an estimated 42% reduction in sheet and rill erosion over the past 20 years, sediment loads in major rivers remain at high levels, prompting the U.S. Environmental Protection Agency (USEPA) to continue to rank sediment as the predominant cause of non-point source pollution in the country. The reason for this is intuitive: not all sources of sediment are being controlled and accounted for, including concentrated flow sources and especially ephemeral gully erosion.

Accounting for ephemeral gully erosion is a critical problem for the Agency. Ephemeral gully erosion may be addressed in conservation plans with practices such as grassed waterways, terraces, vegetative barriers, etc. Various structures may also be included in conservation plans to control ephemeral gully erosion. However, the amount of soil saved as a result of applying conservation practices to control ephemeral gully erosion is not measured: **the Agency does not have a tool to predict and quantify ephemeral gully erosion, including the potential for nonstructural practices to control the erosion.** Unlike sheet and rill erosion, which occurs as a result of the impact of raindrops and water flowing on the soil surface, ephemeral gully erosion occurs as a result of concentrated flow of surface runoff along a defined channel, and also by subsurface flow by seepage and flow through preferential pathways. Erosion in these channels is not predicted by RUSLE2 (the Revised Universal Soil Loss Equation version 2), and therefore is not accounted for in current soil loss assessments. No systematic way exists to determine the extent of the ephemeral gully erosion problems on a field, watershed, or national basis, or to predict the recurring or new locations of ephemeral gullies prior to their development.

One of the Agency's goals in the NRCS strategic plan is:

> ***By 2010, potential sediment delivery from agricultural operations will be reduced by 70 million tons.***

However, current technology cannot verify nor report such progress in a scientifically defensible manner. Therefore, **gains in controlling ephemeral gully erosion, ancillary water quality effects, and controlling the sediment derived from this source cannot now be counted** toward attaining this goal.

Recommended Actions

Short Term

1. A definitive memo is needed from the NRCS Deputy Chief for Technology to ARS Deputy Administrator for Natural Resources and Sustainable Agricultural Systems to formalize ephemeral gully erosion research needs and technology development, including
    a. Completing or updating ephemeral gully erosion literature review
    b. Engaging business advisory groups for the NRCS' Conservation Engineering Division (CED) and Ecological Sciences Division (ESD)
    c. Engaging the National Conservation Delivery Streamlining Initiative.

Long Term

1. An ephemeral gully erosion component needs to be developed and implemented for NRCS field use.
    a. WEPP (Water Erosion Prediction Project), including an ephemeral gully component, needs to be developed and implemented (including a GIS-type tool).
    b. An alternative is to implement an ephemeral gully calculator in RUSLE2.
    c. WEPP, RUSLE2, and AGNPS (AGricultural Non-Point Source Pollution Model) and other modeling teams must be involved in the development.
2. Field conservation tool technology needs to be integrated into the watershed scale tool development process [improve AnnAGNPS (the Annualized AGNPS model) and other watershed models].
3. Tool(s) must be modular [OMS (Object Modeling System), SOA (Service Oriented Architecture), etc.].
    a. NRCS needs to develop the front-end for the intended field users.
    b. A plan of work needs to be developed by NRCS/ARS in order to enable development of the needed tools.
    c. An improved ephemeral gully erosion "object" or model needs to be developed to calculate erosion where sheet and rill erosion ends, and where the concentrated flow zone begins.
4. Specific data bases need to be developed for model development and testing. NRCS needs to partner with the ARS-National Sedimentation Laboratory (NSL) to develop a data base on soil properties, topography, climate, and land use factors associated with ephemeral gully erosion, based on research pertaining to the associated processes.
5. Funding is needed for research, development, and testing of conservation practices specifically designed for ephemeral gully erosion control, including the integrated system effects when combined with sheet and rill erosion control practices.

Definition of Ephemeral Gully Erosion:

Description and Classification of Ephemeral Gullies According to Processes of Formation

> ***Ephemeral gullies are defined as small channels eroded by concentrated flow that can be easily filled by normal tillage, only to reform again in the same location by additional runoff events (Soil Science Society of America, 2008).***

Soil erosion by water occurs if the combined power of rainfall energy and overland flow exceeds the resistance of soil to detachment. The form of soil erosion may be viewed as a continuum of scales, not necessarily continuous, but in some cases evolving from one to the other, ranging from interrill and rill to gully. Interrill erosion is the removal of a fairly uniform layer of soil by splash due to raindrop impact and by sheet flow. Rill erosion occurs on sloping fields in which numerous and randomly occurring small channels of only several centimeters in depth are formed, and gully erosion is caused by concentrated overland flow or sub-surface flow of water during and immediately following heavy rains (Soil Science Society of America, 2008). Here, the focus is on gully erosion and specifically the processes of formation for a particular subset of gully erosion features known as ephemeral gullies.

Gullies may form in existing channels (valley-floor) or where no previous channel drainage (valley-side) existed. Typically, gullies are a result of the breakdown of equilibrium between the eroding force exerted by concentrated flowing water and the resistance of the earth materials in which it is flowing, caused by either (1) an increase in erosional forces (related to a concentration of flow, constriction of flow, an increase in discharge, or decrease in sediment load) or (2) decreased erosional resistance (related to a decrease in cover or some surface disturbance causing decreased cohesion). A gully is a much more complicated system as its evolution is controlled by water erosion at the gully head and bed, which triggers gravitational mass-movement on gully sidewalls. Historically, studies have focused on growth and formation, relative sediment production, and drainage network development. Variables of importance in these studies included: time; drainage area; surface/subsurface runoff sources and quantities; surface slopes, shapes and lengths; rainfall intensity, duration and frequency; grain size distribution; soil permeability; soil structure and percent organic matter; cropping and land management history; and soil erodibility.

Ephemeral gullies are defined as small channels eroded by concentrated flow that can be easily filled by normal tillage, only to reform again in the same location by additional runoff events (Soil Science Society of America, 2008). These erosion features are often neglected due to the complex problems associated with predicting the timing of their appearance and position on the landscape. Their complex genesis usually involves an inter-relationship between: (1) the volume, velocity and type of runoff; (2) the susceptibility of the materials to erosion; and (3) changes in cover caused by land use and conservation practices. Development is associated with concentrated surface or subsurface flow, generally attributed to topographic variations, soil stratigraphy, tillage marks, or random irregularities affecting flow patterns.

The most obvious mechanisms of headward gully erosion caused by surface runoff are those associated with waterfalls—same mechanisms but on a much smaller scale. The energy of the falling water hitting the soil breaks the soil particles loose and carries them away. This action is most effective when the waterfall hits a bench or slope. If the waterfall is clear of the headwall, its energy is spent digging the plunge pool and in turbulence within the pool. Generally, the greater the flow, the further the plunge pool tends to be centered away from the headwall. Waterfalls in ephemeral gullies are normally very subtle features in terms of size. Plunge pool turbulence is an important mechanism of erosion in ephemeral gullies, though, due to the fact that a plunge pool forms in contact with the toe and undermines the headwall. Undercutting of the headwall occurs if the plunging water is diverted back against the headwall. In the early and waning stages of overland flow events, water flowing over the gully head, in contact with the headwall, causes erosion as water is preferentially drawn into the soil, and then wetted material breaks off from the drier material underneath.

Other mechanisms of ephemeral gully erosion include headwall and sidewall collapse under gravity. Wet soil material is heavier and often weaker than when dry. If tension cracks are present, hydrostatic pressures caused by water filling the cracks may cause the block to fall away. Key to this failure mechanism is a steepened headwall; otherwise, the gully head would become stable. Conversely, a waterfall without collapse mechanisms would also become stable. Downstream gully sidewalls are susceptible to this mechanism following events as the sidewall becomes saturated up to the water level in the gully, then the saturated portion collapses to the flood line undermining the sidewall. Typically, this is the erosion mechanism for clay soils subject to extensive cracking during summer months.

Tension cracks also provide pathways for rapid infiltration adjacent to gully sidewalls, causing seepage erosion of gully walls. Seepage erosion is an erosion process typically involved in gully formation and widening in which subsurface flow exiting the soil (exfiltration) transports soil particles entrained in the seepage water. This mechanism typically occurs where water flows through a layer of loose grains, often due to perching of water above a water-restricting layer, and washes soil out of the permeable layer above. Proximity of the eroding layer to the gully wall or head is critical. Seepage erosion undercuts the gully wall or head and results in sapping or mass wasting of the gully.

Subsurface flow can also affect the initiation of ephemeral gully development on hillslopes. It is not clear under what conditions exfiltration of seepage can be sufficient to entrain particles and directly cause gully development (Huang et al., 1999; Zheng et al., 2000). However, exfiltration at the surface of hillslopes can increase the rate of surface runoff and also affects the surface soil erodibility. The removal of negative soil pore-water pressures by seepage reduces the soil shear strength and increases susceptibility to erosion. In less permeable materials, subsurface flow may be confined to preferential flow paths such as structural features or macropores (cracks, and inter-aggregate pores) and biological features (root-holes and animal burrows). Preferential flow erodes the inner walls of these passageways until tunnel collapse forms an ephemeral gully at a mature stage of development (Faulkner, 2006). Ephemeral gullies formed by pipe flow erosion, which have been filled in by tillage, contain a pre-existing soil pipe at the gully head. Such a soil pipe can facilitate the sudden reestablishment of the gully at the same location due to pressure buildups within the filled-in material during rain events (Wilson et al., 2008).

Most gully heads are a combination of different mechanisms--each acting under different conditions, sometimes at different times of the year, and at different rates. Scouring is mostly caused by rainfall on bare ground. These conditions also cause rapid headward erosion, but the greatest hazard is a prolonged wet period, during which time the ground is almost continually saturated. This results in seepage that causes sapping and tunneling, and also weakens the ground, favoring collapse. The development of tension and desiccation cracks occurs between storms and depends on headwall height, soil properties, and the length of the drying period. When tension cracks are present, only a small amount of runoff is needed to cause large hydrostatic pressures and failure of the headwall.

Within the literature, several conclusions may be drawn concerning gully erosion:

- Gully erosion results not only from surface flow but also from subsurface flow. At this time, there is no complete understanding of the interaction between these mechanisms. Future research priorities should include subsurface flow erosion processes and prediction technology.
- Under many circumstances, gully erosion is the main source of sediment at the catchment or watershed scale. Unlike interrill and rill erosion, gully erosion is often an extension of the

drainage network, connecting field ditches and streams which carry eroded sediment downstream, often leading to water quality and sedimentation issues.

- Research must include cost/benefit comparisons and incentive packages to protect natural resources, as well as to assist the farmer in securing a profitable harvest while adopting conservation measures.
- A research network should be established to verify the current state of gully erosion and actively monitor, initially through small pilot studies, gully erosion at multiple scales so that guidelines concerning prevention, protection, and rehabilitation may be scientifically defensible.

In summary, erosion is the detachment and movement of soil by water, wind, ice, tillage, or gravity. The processes of erosion in gullies are due to:

- Hydraulic shear by overland flow on the rim and on the vertical sidewalls,
- The impact of splash from the plunge pool at the foot of the headwall and the vortex erosion in the pool,
- Mass wasting of the walls due to the development of tension and desiccation cracks,
- Seepage erosion, and
- Pipe flow erosion by tunnel collapse and reestablishment of ephemeral gullies.

Controlling soil erosion and ephemeral gully erosion is therefore a matter of controlling these erosion processes through management of land use, runoff, cover conditions, and soil erodibility.

Literature search and review

Introduction

The National Agricultural Library (NAL) conducted a literature search on abstracts related to ephemeral gully research in September 2007 (Appendix A4). These abstracts indicate the magnitude of the ephemeral gully erosion problem, physical characteristics, modeling approaches, and treatment of these gullies throughout the world. Over 400 abstracts were identified (see references in Appendix A4). This large number covered a variety of related subjects such as location, land use, scale, laboratory studies, theoretical modeling, treatment and prevention, and process descriptions of ephemeral gully erosion.

Current analytical tools are not adequate to evaluate the ephemeral gully erosion problems on cropland and are not adequate for evaluation of treatment alternatives or designs. Because there is no “tolerable level” of ephemeral gully erosion, NRCS field staff recommends treatment of ephemeral gully erosion through application of various conservation practices on a site-by-site basis whenever recognized. These practices naturally have a wide range of effectiveness in solving the ephemeral gully erosion problem. NRCS also has supported many years of research and application of conservation measures to control sheet and rill erosion with less attention on developing conservation measures specifically for ephemeral gully erosion control. However, because no prediction tool is available to quantify the magnitude of ephemeral gully erosion, no cost/benefit determinations can be made.

Erosion processes are difficult to analyze due to the many factors impacting the physical system such as climatic, soil, slope, vegetation, conservation treatment, etc. A fairly robust empirical system of USLE and RUSLE uses the factors R, K, S, L, C, and P. These tools were developed based on thousands of research plot years of data. The erosion plots, however, were not big enough to have ephemeral gully erosion, so no similarly simple empirical prediction technology exists for ephemeral gully erosion. Most existing modeling approaches rely on process-based representations. Ephemeral gully erosion processes are influenced by the same factors affecting sheet and rill erosion, including drainage area, peak discharge for storm events (concentrated flow), subsurface properties (layering and flow), topographical features (drainage networks), and sediment transport and deposition. The 400+ abstracts discuss in depth the factors contributing to ephemeral gully erosion, the magnitude of the problem throughout the world, modeling techniques, and treatment methods. The abstracts also reveal research and data gaps in being able to predict the magnitude of ephemeral gully erosion in a particular situation and the downstream impacts on the larger watershed. In deciding where to focus future data collection and research on ephemeral gully erosion, further review of these abstracts, their papers, and research products would be very beneficial.

Quantitative or Qualitative Evaluation of Ephemeral Gully Erosion:

Research on gully erosion has included techniques for monitoring gully erosion (Poesen et al., 2003; Wu and Cheng, 2005), gully retreat rates (Oostwoud and Bryan, 2001; Vandekerckhove et al., 2003; Hu et al. 2007), topographic thresholds for gully erosion (Patton and Schumm, 1975; Vandaele et al.,1996; Nachtergaele et al., 2001, 2003; Poesen et al., 2003; Wu and Cheng, 2005) and contribution of gullies to soil loss and sediment yield (Li et al., 2003; Nyssen et al., 2008). Poesen et al. (2003) noted that gully erosion rates are highest at their initiation and decline exponentially with time as gully growth stabilizes. However, filling of gullies by tillage can result in maintaining a high level of erosion. Gordon et al. (2008) demonstrated how filling-in of gullies by tillage reactivates the gully erosion, thereby producing an intermittent step-wise increase in gully erosion that ultimately is greater in soil loss with time than not filling the gully. The result is that ephemeral gullies can be a significant source of sediment yield in a catchment or watershed. USDA-Natural Resource Conservation Service (1997) found for 17 States in the USA that ephemeral gully erosion accounted for an average of 38% of the total erosion, with a range from 18 to 73%. This is comparable to the world-wide ranges of 10 to 94% and 19 to 80%, with a median value of 44% for all conditions reported by Poesen et al. (2003) and Capra and Scicolone (2002), respectively.

Ephemeral Gully Erosion (Percent of Total Watershed Erosion)		**Source**
Range	**Median**	
18% to 73%	38%	USDA-NRCS (1997)(17 statesP
10% to 94%	44%	Poesen et al. (2003)
19% t0 80%	44%	Capra and Scicolone (2002)

Modeling Approaches

Several physically-based ephemeral gully erosion models have been developed (Knisel, 1980; Foster and Lane, 1983; Wang, 1992; Street and Quinton, 2001; Gordon et al., 2007), and other models have been proposed for the larger-scale headcut advancement in the scale of dam breaching and spillway erosion (De Ploey, 1989; Temple, 1992; Robinson and Hanson, 1994). Normally, headcut erosion can take the form of either retreat or rotation, depending on the flow conditions and soil properties near the headcut (Gardner, 1983; Stein and Julien, 1993). Wu and Wang (2005) established a numerical model to simulate the vertical two-dimensional headcut migration details, which considers the hydraulic erosion on the vertical headwall of the headcut and the geotechnical failure of the headcut due to the scour at its toe. The model does not, however, consider concentrated overland flows or lateral bank erosion.

The ephemeral-gully processes currently in USDA erosion models include the channel component of CREAMS (Chemicals, Runoff and Erosion from Agricultural Management Systems) (Knisel, 1980), WEPP (Ascough et al., 1997), and REGEM (Revised Ephemeral Gully Erosion Model) (Gordon et al., 2007), which is used with modification [as TIEGEM (Tillage-Induced Ephemeral Gully Erosion Model)] in AnnAGNPS. CREAMS simulates ephemeral gully erosion through a procedure that takes into account detachment of soil through the shear force of flowing water, sediment transport capacity, and changing channel dimensions. The equations that describe change in channel dimensions were developed by Foster and Lane (1983). REGEM incorporates analytic formulations for plunge pool erosion and headcut retreat (Alonso et al., 2002) within single or multiple storm events in unsteady, spatially varied flow at the sub-cell scale. REGEM addresses five soil particle-size classes to predict gully evolution, transport-capacity and transport-limited flows, and gully widening based on discharge (Nachtergaele et al., 2002).

TIGEM is an improved ephemeral gully model developed from REGEM, based upon the research done by Alonso et al (2002) and Gordon et al (2007 & 2008), that assumes that ephemeral gullies (1) form as a result of a headcut that is restricted by a non-erodible layer, which is the depth of the tillage layer; (2) erodes a single channel with drainage area a function of the hydraulic geometry of the decreasing channel flow length from the hydraulically most distant point (Theurer et al, 1996); (3) have five optional ephemeral gully width algorithms, one of which came from Nachtergaele et al (2002) and two from Woodward (1999); and (4) allows for gully repair when the fields are tilled.

Scale Effect

One of the difficulties in assessing the significance of gully erosion is recognizing the distinction between the various scales of gullies. Ephemeral gullies are widely accepted as “small channels eroded by concentrated flow that can be easily filled by normal tillage, only to reform again in the same location by additional runoff events,” (Soil Science Society of America, 2008). In contrast to an ephemeral gully, a gully (or classical gully, to further distinguish the type) is defined as “deep enough (usually > 0.5 m) to interfere with, and not be obliterated by, normal tillage operations,” (Soil Science Society of America, 2008). Normal field operations are conducted around and not through classical gullies. These are working definitions that have proven effective for communication purposes. However, what is lacking in defining ephemeral gully erosion is a clear understanding of the processes driving ephemeral gully erosion.

Current Status of Erosion Prediction

Until WEPP becomes functional for field office use, NRCS plans to use RUSLE2 as the primary tool for estimating sheet and rill erosion on cropland for conservation planning purposes (estimate 2011/2012). NRCS will need to continue support for the ARS development and maintenance of the soil erosion prediction technology during this time, plus provide additional resources to WEPP software developers to include additional ephemeral gully erosion technology into the field office version of WEPP.

At an ARS customer-focus meeting in Oxford MS in 2005, NRCS requested that ARS consider researching and developing technology that NRCS can include in science-based tools and models to predict ephemeral gully erosion. This request was repeated again in October, 2005, and included irrigation-induced erosion and ephemeral gully erosion. ARS has included the development of this technology in their 5-year Current Research Information System (CRIS) cycle.

Research, Tools, and Software Development

AnnAGNPS

AnnAGNPS (the Annualized version of the AGricultural Non-Point Source Pollution Model) is a continuous-simulation, mixed-land use, watershed-scale computer model designed to predict the origin and movement of water, sediment, and chemicals at any location in primarily agricultural watersheds. It distinguishes between erosion caused by sheet and rill (from RUSLE1.06), tillage-induced ephemeral gullies (TIEG), other gully processes, and streambed and bank sources. It also predicts the amount of each pollutant (sediment and chemical loads) at any location in the watershed; i.e., how much of each pollutant comes from where and arrives at any location in the watershed. Erosion from gullies is estimated using procedures describing the depth, width, and migration rate of the headcut (Alonso et al., 2002). Sediment delivered to the mouth of the gully is estimated using the HUSLE procedure (Hydro-geomorphic Universal Soil Loss Equation) (Theurer and Clarke, 1991).

TIEGEM (Tillage-Induced Ephemeral Gully Erosion Model) is a new addition to AnnAGNPS that incorporates recent ARS research. It is state-of-the-art technology that cannot be found in any other tool. Several algorithms are used to determine the minimum gully width for each event: (1) previously determined width by a prior event; (2) Nachtergaele et al.'s (2002) equation 10; (3) the hydraulic geometry relationship for the gully's concentrated flow; (4) non-submerging tailwater depth at the crest of the headcut; (5) Woodward's (1999) equilibrium gully width; and (6) Woodward's (1999) ultimate gully width.

Features within AnnAGNPS can be used to determine the probability and amount of a pollutant reaching any location within the watershed, including tillage-induced ephemeral gullies. To include the tillage-induced ephemeral gully feature in an AnnAGNPS analysis requires locating the mouth of each potential TIEG. Preliminary studies have been performed to identify the mouth of a gully headcut based on topographic analysis and have been integrated into AGNPS GIS components (Parker et al., 2007).

AnnAGNPS with ephemeral gully erosion capabilities is currently available to quantify the magnitude and extent of tillage-induced ephemeral gully erosion, sediment yield, and sediment load in watersheds. These results could be correlated through land use, soils, and climate to indicate the magnitude and risk associated with pollutants originating from tillage-induced ephemeral gullies.

APEX

The APEX model (Agricultural Policy Environmental eXtender) was developed by the Blacklands Research and Extension Center in Temple, Texas. APEX is a flexible and dynamic tool that is capable of simulating a wide array of management practices, cropping systems, and other land uses across a broad range of agricultural landscapes, including whole farms and small watersheds. The model can be configured for novel land management strategies, such as filter strip impacts on pollutant losses from upslope cropfields, intensive rotational grazing scenarios depicting movement of cows between paddocks, impacts of vegetated grassed waterways in combination with filter strips, and land application of manure from livestock feedlots or waste storage ponds. A description of the APEX model is provided at the Website: http://epicapex.brc.tamus.edu/.

The APEX daily time-step model simulates weather, farming operations, crop growth, and yield, plus the movement of water, soil, carbon, nutrients, sediment, and pesticides. Weather events and their interaction with crop cover and soil properties are simulated to produce effects on the fate and transport of water and chemicals through the soil profile and over land to the watershed outlet. Soil erosion is simulated over time, and includes wind erosion, sheet and rill erosion, and irrigation-induced erosion.

The APEX sediment routing component transports sediment through channels and floodplains, computing both degradation and deposition. The quantity of sediment produced by ephemeral gully erosion is calculated by using two of the runoff-based soil erosion equations available in APEX: MUSLE (Modified Universal Soil Loss Equation) and MUSS (small watershed version of MUSLE). Runoff variables increase the prediction accuracy, eliminate the need for a sediment delivery ratio, and enable the model to estimate sediment yield for a single storm.

MUSLE was developed to simulate sediment yield from small agricultural watersheds. Some of the watersheds used in its development contained natural channels, so the sediment yield estimate is composed of both upland and channel erosion. MUSLE uses a sediment delivery ratio to estimate the amount of eroded soil that actually leaves the boundary of the field. A portion of the eroded material is redistributed and deposited within the field or trapped by conservation buffers or other forms of conservation treatment that promote deposition. This is taken into account in the sediment delivery calculation.

A second soil erosion routine in the APEX model, MUSS, is used with MUSLE to account for the quantity of material being transported by ephemeral gully erosion. MUSS is an equation developed by fitting small watershed data where no channel erosion occurred. In APEX, the MUSS soil erosion in the small watershed is subtracted from the MUSLE erosion to estimate ephemeral gully erosion on the field.

CONCEPTS

The channel evolution computer model, CONCEPTS (CONservational Channel Evolution and Pollutant Transport System), simulates the long-term evolution of incised and restored or rehabilitated stream corridors (Langendoen, 2000). The physically-based model simulates the three main processes that shape incised streams: hydraulics, sediment transport, and streambed and bank adjustments. Channel cross sections are of any shape and include a main channel with left and right overbank sections. Streambed and streambank material can be composed of layers with different material properties such as grain-size distribution, resistance to hydraulic erosion, or shear-strength parameters. Channel hydraulics is represented by the full Saint-Venant equations of gradually-varying flow or its diffusion wave form in case of high Froude numbers. The equations are solved using the Preissmann (1960) scheme.

CONCEPTS calculates fractional sediment transport similarly to KINEROS2 (KINematic runoff and EROSion model, see below). However, CONCEPTS (1) adds an additional source term in the sediment mass balance that accounts for lateral inputs from streambank erosion and (2) distinguishes between the different erosion characteristics of cohesive and cohesionless sediments (Langendoen and Alonso, 2008). Sediment transport capacity for each particle size class is calculated by the SEDTRA model using optimal transport equations for each size class: Laursen (1959) for silts, Yang (1973) for sands, and Meyer-Peter and Mueller (1948) for gravels. Deposition or erosion of sediment deposits is uniformly distributed over the wetted part of the bed. Bed erosion is limited by bed rock. Erosion of streambanks is a combination of: (1) lateral erosion of the bank toe by fluvial entrainment of in situ bank materials, often termed hydraulic erosion; and (2) mass failure of the upper part of the bank due to gravity (Langendoen and Simon, 2008). The amount of hydraulic erosion is calculated separately for each soil layer comprising the streambank by an excess shear stress equation, using an average boundary shear stress exerted by the flow on each soil layer.

CONCEPTS performs stability analyses of planar and cantilever failures, which are most widely observed in the incised stream systems of the midcontinent of the United States. The stability of the bank is determined by the bank's geometry, bank stratigraphy, soil properties, pore-water pressures, confining pressure exerted by the water in the stream, and riparian vegetation (Langendoen and Simon, 2008). In case of bank failure, the failed material becomes part of the bed-material load, and the cross-sectional geometry is updated accordingly.

EGEM

A method for estimating ephemeral gully erosion was developed under the direction of Dr. John Laflen, USDA-ARS, which used regression equations to predict outputs of the CREAMS model (Watson et al., 1985). The computer program developed was named Ephemeral Gully Erosion Estimator (EGEE). The model is based on research on erosion from concentrated flow conducted by Foster (1982) and Franti, et al., (1985). EGEE estimated the quantity of soil eroded from a single ephemeral gully (ephemeral gully). Erosion computation routines from EGEE were added to the existing NRCS Engineering Field Manual Chapter-2, EFM-2 computer program (USDA-NRCS, 1989), resulting in the EGEM model (Merkel et al., 1988). EGEM has a user-friendly screen design with on-line help and peripheral functions such as load/save data sets and print, besides having standard NRCS procedures for estimating volume of runoff and peak discharge for small agricultural watersheds. A user manual was written for EGEM (USDA-NRCS, 1992) and covers primarily input data descriptions and where to obtain data. It contains a general description of the computational processes, use for branched and unbranched gullies, and use of the computer program.

The two options within EGEM are to estimate ephemeral gully erosion from a single storm event or average annual. Various options allow for more flexibility in estimating average annual ephemeral gully erosion. The year may be divided into up to three seasons representing such conditions as fallow, cover crop, and row crop. Computation of average annual ephemeral gully erosion is based on four concepts: (1) the largest storm of the year causes the ephemeral gully to reach its maximum dimensions; (2) the ephemeral gully is filled with soil once per year through a tillage operation; (3) a single ephemeral gully is assumed with user-defined length (no dendritic pattern); and (4) the average annual ephemeral gully erosion may be computed based on a probability relationship.

Although ephemeral gully erosion processes are very complex, time and space dimensions are modeled in a simplified manner in EGEM. The initial width and maximum width of the ephemeral gully are first estimated. Based on the volume of runoff, peak discharge, and soil properties, the ephemeral gully first deepens until it reaches the less-erodible soil layer (typically tillage depth or topsoil depth), then widens until it reaches the estimated maximum width.

Hairsine and Rose

The rates of entrainment, re-entrainment, and deposition are continuous dynamic processes which occur simultaneously through an erosion event. An erosion model that considers deposition as a separate rate process was developed by Hairsine and Rose (1992a, 1992b). The model incorporates a specific description of the role of cohesion, the capability to deal with a range of sediment sizes and settling velocities, and an explicit representation of the layer formed by deposition; i.e., the formation and evolution of deposited sediment has a different cohesive strength than the original uneroded soil. The transport capacity of the flow is determined as a limiting outcome of the evolution of the deposition and erosion processes. Conditions of net erosion and net deposition are merely a change in the balance of these processes. When cohesion plays no role in limiting the transport of sediment, the expression for sediment concentration has been shown to have similarities to the sediment transport equation of Yang (1973). An examination of the data of Meyer and Harmon (1985) showed that the rill erosion extension theory provides consistent parameter values across an extensive set of experiments. Rill shape was shown not to affect the sediment concentration at the entrainment limit; however, sediment concentration at the transport limit was sensitive to rill shape.

HUMUS

The Hydrologic Unit Model for the United States (HUMUS) is a decision support system designed for making national and river basin scale resource assessments. The components of the HUMUS system include: (1) the basin-scale Soil and Water Assessment Tool model (SWAT); (2) a GIS to manage spatial inputs and outputs; and (3) relational databases of climate, soil, crop and management properties.

The HUMUS project was designed to provide the technical basis for conducting the appraisal of water resources for the 1997 RCA Appraisal Report. It is intended to provide detailed information about the uses of water on irrigated and non-irrigated agricultural lands and of the physical and economic effects of changing agricultural practices and cropping patterns on future water needs and supplies.

Recent advancements in computer-based natural resource simulation technologies give the opportunity to do comprehensive regional and national water resources assessments. The HUMUS system is expected to be a prototype for other national natural resources policy development forums and for uses of the technology at the regional level by natural resources agencies. HUMUS includes information about local weather, soil properties, topography, natural vegetation, cropped areas, runoff, erosion, ground water, irrigation, and agricultural practices for approximately 2,150 watershed areas (the 8-digit hydrologic accounting units delineated by the Water Resources Council in the Second National Assessment). Water flows are routed from the 2,150 watershed areas through the 18 major river basins. The system is calibrated by comparing simulated water outflows with actual stream flows derived from gauging records at 350 locations (the 6-digit hydrologic unit areas).

KINEROS2

The kinematic runoff and erosion model, KINEROS, is an event-oriented, physically-based model describing the processes of interception, infiltration, surface runoff, and erosion from small agricultural and urban watersheds (Woolhiser et al., 1990). The watershed is represented by a cascade of planes and channels. The partial differential equations describing overland flow, channel flow, erosion, and sediment transport are solved by finite-difference techniques. KINEROS2 routs flow and mixed-size sediments through channels with a compound cross section (trapezoidal main and overbank sections). The kinematic wave form of the Saint-Venant equations describe channel hydraulics and are solved using the Preissmann scheme (e.g., Cunge et al., 1980). Fractional sediment transport is described by a mass balance equation for each size fraction that accounts for storage in the water column, advective transport, and exchange of sediment between bed and water column. The latter is a function of the difference between current sediment concentration and the equilibrium concentration (Bennett, 1974). Transport capacity is computed using the Engelund and Hansen (1967) total load formula. Resulting changes in channel depth and width are calculated by minimizing stream power (Chang, 1982). KINEROS2 assumes a maximum erodible depth and fails banks if they become too steep.

REGEM

Gordon et al. (2007) 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 (Alonso et al., 2002), (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 revised ephemeral gully erosion model approach incorporates analytic formulations for plunge pool erosion and headcut retreat within single or multiple storm events in unsteady, spatially varied flow at the sub-cell scale, and addresses five soil particle-size classes to predict gully evolution, transport-capacity and transport-limited flows, gully widening, and gully reactivation. REGEM was the basis for the ephemeral gully components within AnnAGNPS.

RHEM/KINEROS

Because on most undisturbed rangelands, the rill-interrill concept is not applicable and rainfall splash and sheet erosion are the dominant erosion processes, Wei et al. (2009) developed a new equation that will be used in the Rangeland Hydrology and Erosion Model (RHEM). The equation proposed is: $\mathbf{D_{ss} = K_{ss}\ I^{-1.052} q^{0.592}}$, where $\mathbf{K_{ss}}$ denotes the splash and sheet erosion coefficient, $\mathbf{I}$ is rainfall intensity, and $\mathbf{q}$ is runoff rate.

RUSLE2

RUSLE2 currently simulates a channel at the bottom of a one-dimensional hillslope and estimates deposition in the channel if a low channel gradient is specified. RUSLE2 uses soil management and climatic information to estimate sediment load and runoff from a location's 10-yr 24-hr precipitation amount ($P_{10y,\ 24h}$) to determine transport capacity and sediment yield from channels. However, RUSLE2 does not predict erosion in the channels, no matter how steep the gradient or how large the discharge. Dabney et al. (2008) demonstrated how an alternative sequence of index storms could be derived from RUSLE2 databases and linked with a process-based ephemeral gully erosion model such as that used by CREAMS or WEPP. Appendix A3 presents a proposal to develop a 2-D version of RUSLE that could employ this approach beyond the scale of the current one-dimensional hillslope RUSLE2.

SWAT

The Soil and Water Assessment Tool model (SWAT) (Arnold et al., 1998) was developed by the U.S. Department of Agriculture–Agriculture Research Service (USDA-ARS) as a basin-scale continuous time-scale management evaluation tool. The CREAMS, GLEAMS, and EPIC models (Knisel, 1980; Leonard et al., 1987; Williams et al., 1984) were used in developing the watershed scale components. Sediment delivery to the edge of the field is estimated from the MUSLE equation. The use of MUSLE lumps all sediment sources from the fields based on USLE parameters and flow characteristics. The SWAT model adjusts the MUSLE sediment yield by considering snow cover effects and the sediment lag in surface runoff. The SWAT model also calculates the lateral and ground water contributions to channel flow. Sediment is routed downstream through the channel system.

SWAT is an enhancement of the SWRRB model (Arnold et al., 1990) that allows simulation of water quality and quality in large, complex basins. A detailed description of the model is given in Arnold et al. (1998a). It was designed to predict the impact of topography, soils, land use, management, and weather on yields of water, sediment, nutrient (nitrogen and phosphorus), and agricultural chemicals for large ungauged watersheds. To meet these design criteria, the model (a) does not require calibration (which is impossible on ungauged watersheds), (b) uses inputs that are readily available for large areas, (c) is computationally efficient in order to simulate the interaction of hundreds of sub-basins using a daily time step, and (d) is capable of simulating hundreds of years in a continuous time mode to assess the long-term impacts of change. The command structure is used to route water, nutrients, and chemicals through streams and reservoirs and to input measured data for point sources of water and nutrients. Basins can be subdivided into grid cells or subwatersheds to increase detail for input and output.

Model sub-basin components can be divided into the following: hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management. Simulated hydrology processes include (1) surface runoff estimated from daily rainfall using the SCS curve number, (2) percolation modeled with a layered-storage routing technique combined with a crack flow model, (3) lateral subsurface flow, (4) ground water flow to streams from shallow aquifers, (5) potential evapotranspiration by the Hargreaves, Priestley-Taylor, and Penman-Monteith methods, (6) snowmelt, (7) transmission losses from streams, and (8) water storage and losses from ponds.

Weather variables that drive the hydrologic model include daily precipitation, maximum and minimum air temperatures, solar radiation, wind speed, and relative humidity. A weather generator can be used to simulate all or several variables based on monthly climate statistics calculated from long-term measured data. Different weather data can be associated with specific sub-basins. Sediment yield is computed for each sub-basin with the Modified Universal Soil Loss Equation. Soil temperature is updated daily for each soil layer as a function of air temperatures; snow, plant and residue cover; damping depth; and mean annual temperature.

Crop growth is simulated with a daily time-step using a simplification of the EPIC crop model which estimates phenological development based on daily accumulation of heat units, harvest index for partitioning grain yield, Monteith's approach for potential biomass, and adjustments for water and temperature stress. Different crops, both annual and perennial, can be simulated by using crop-specific input parameters.

Nitrate losses in runoff, percolation and lateral subsurface flow are simulated. Organic nitrogen losses are estimated from soil losses and an enrichment ratio. A nitrogen transformation model modified from EPIC includes residue mineralization, organic matter mineralization, nitrification, denitrification, volatilization, fertilization, and plant uptake. Phosphorus processes include residue and organic matter mineralization, losses with runoff water and sediment, fertilization, fixation by soil particles, and plant uptake. Pesticide transformations are simulated with a simplification of the GLEAMS model approach and include interception by the crop canopy; volatilization; degradation in soils and from foliage; and losses in runoff, percolation, and sediment.

Simulated agricultural management practices include tillage effects on soil and residue mixing, bulk density, and residue decomposition. Irrigation may be scheduled by the user or applied automatically according to user-specified rules. Fertilization with nitrogen and phosphorus can also be scheduled by the user or applied automatically.

Pesticide applications are scheduled by the user. Grazing is simulated as a daily harvest operation.

Simulated stream processes include channel flood routing, channel sediment routing, and nutrient and pesticide routing and transformations modified from the QUAL2E model. Components include algae as chlorophyll-a, dissolved oxygen, organic oxygen demand, organic nitrogen, ammonium nitrogen, nitrite nitrogen, organic phosphorus, and soluble phosphorus. In-stream pesticide transformations include reactions, volatization, settling, diffusion, resuspension, and burial.

The ponds and reservoirs component includes water balance, routing, sediment settling, and simplified nutrient and pesticide transformation routines. Water diversions into, out of, or within the basin can be simulated to represent irrigation and other withdrawals from the system.

WEPP/CREAMS

Haan et al. (1994) provide a clear conceptual derivation of the channel erosion theory represented by the process-based equations used in CREAMS to describe ephemeral gully erosion. Essentially the same theory is used in the watershed version of WEPP and GeoWEPP to describe channel erosion. The theory is based on several assumptions: (1) that Manning's equation applies, (2) that the shear stress distribution around the cross section of a channel can be represented by a hard-coded dimensionless distribution, (3) that the soil consists of a uniform erodibile layer with characteristic erodibility and critical shear stress values overlying a non-erodible layer at a specified depth, (4) that potential detachment rate is proportional to excess shear stress (Eq 3, below), (5) that actual detachment is proportional to the unsatisfied transport capacity of a steady-state runoff rate, (6) that transport capacity can be determined by the set of equations proposed by Yalin (1963), and (7) that deposition occurs if sediment load exceeds transport capacity.

In application, the runoff hydrograph is converted to an effective steady-state runoff rate with corresponding duration. The shear stress is calculated from discharge using channel slope, Manning's n, and channel dimensions to determine velocity and hydraulic radius and assuming shear stress is proportional to the product of slope, hydraulic radius, and the unit weight of water. Application of the detachment/transport coupling relationships, together with the assumption of a rectangular channel shape, leads to the determination of an effective channel width prior to the intersection of the eroding surface with the non-erodible layer. The effective channel width depends on critical shear stress but not on soil erodibility. The time to reach the non-erodible layer is determined (depending on available transport capacity and soil erodibility), and the total time of the event is divided into a period before reaching the non-erodible layer and a period after reaching the layer. After the non-erodible layer is reached, the channel widens, asymptotically approaching the width where shear stress at the toe of the channel bank is equal to the specified critical stress. This allows application of a rapidly-solved analytical calculation of soil loss at several cross sections down the channel. Two limitations of this approach are that (1) the non-erodible layer remains forever non-erodible, and (2) any deposition of sediment predicted from one event is neglected in subsequent erosion calculations.

WinSRFR

WinSRFR is an integrated hydraulic analyses application for surface irrigation systems that combines a simulation engine with tools for irrigation system evaluation, design, and operational analysis (ALARC, 2006). Its simulation engine, SRFR, simulates the unsteady hydraulics and morphology of trapezoidal furrows in a single soil (Strelkoff and Bjorneberg, 2001). SRFR solves the Saint-Venant equations for one-dimensional open-channel flow, either in its diffusion or kinematic form, hence neglecting the effects of inertia, while accounting for infiltration. The length of the surface stream is computed as part of the solution. The detachment, transport, and deposition of mixed-sized sediments largely follow the WEPP approach. However, SRFR uses the Laursen transport capacity equation because it was found that the Yalin transport capacity equation greatly over-predicts the transport of silt-sized sediments. SRFR assumes a constant boundary shear stress along the wetted perimeter of each furrow section, which includes the furrow bottom and sidewalls. Therefore, the eroded or deposited sediments are distributed uniformly across the wetted perimeter.

Object Modeling System (OMS)

The Object Modeling System (OMS) is an agro-environmental modeling framework maintained by the U.S. Department of Agriculture (USDA), jointly by the Agricultural Research Service (ARS) Agricultural Systems Research Unit (ASRU) and the Natural Resources Conservation Service (NRCS) Information Technology Center (ITC). The framework provides scientists a consistent and efficient way to create science components, build models, calibrate and test them, and modify and re-purpose them as the science advances. The framework also enables the user to run models in support of action agency program delivery. OMS is an important part of the USDA technical architecture supporting technology transfer from research to program delivery agencies.

OMS fills the strong business need to deliver the best science to these decision makers and their advisors in as efficient and responsive manner as possible. It provides the technology bridge to information systems that support the decision making process.

OMS provides a standardized, consistent platform to build and manage models and modules that support the business interests and mission of USDA. The platform provides for deploying models and modules as services in a production environment integrated with agency business applications. The platform allows models to be linked with agency data collection and management infrastructure.

Reporting

NRCS Performance Results System (PRS)

The NRCS **Performance Results System (PRS)** provides web-based detailed performance accomplishment data, updated daily. It tracks and monitors agency-wide performance goals and progress toward achieving those goals. The system is streamlined and user-friendly and aligns the agency performance measurement with the Government Performance and Results Act. Reports are available on a national, regional, or state basis.

The Agency's annual performance measures provide a link between day-to-day activities on the landscape and the agency's long-term strategic objectives outlined in the NRCS Strategic Plan, 2005–2010. Annual measures reflect the annual increment of progress toward the long-term performance targets. These annual measures provide the foundation for the agency's annual performance budget formulation, budget and performance integration (BPI) reporting, and Program Assessment Rating Tool (PART) process. Essential data elements gathered through these measures make it possible to meet agency reporting requirements, from Civil Rights reports to congressional inquiries.

Data Entry Points. Data entry is primarily through the appropriate business tools, Customer Service Toolkit, ProTracts, or POINTS. However, direct entry is also enabled using a PRS data entry screen. In addition, several measures can only be reported through PRS. These instances of specialized reporting should diminish over time, as business tool development continues. Specific data entry points are noted in the measure definition. Basic customer information, including customer name and status (race, gender, ethnicity, etc.), will be entered and maintained through the Service Center Information Management System (SCIMS) application and linked to the reported performance for that customer.

Reporting Frequency. Reporting is automatic for performance data harvested from existing business tools. Where progress must be entered using PRS screens or program tracking business tools, performance should be updated as reportable items are completed. Performance reports are issued weekly to top leadership for review. These reports summarize national level Fiscal Year (FY) performance data posted through the prior week. Regular reporting allows leadership to evaluate agency performance using the most current information.

Natural Resources Inventory

Since 2000, information on the presence or absence of ephemeral gullies (as well as classic gullies) has been recorded for sample points in the NRI under the NRI category "Resource Concerns." More precisely, evidence of concentrated flow paths on fields (a surrogate for ephemeral gullies) is observed and recorded. Remote sensing/photo interpretation methods are used. The area of consideration includes portions of the field surrounding the point that would be considered in conservation planning. The ability to detect evidence of ephemeral gullies is sometimes limited by vegetative cover, seasonal field conditions, and the weather when the photography was obtained. Land use cover for which this information is collected includes: cropland, hayland, pastureland, CRP, and rangeland. NRI data summaries will report the acres for which ephemeral gullies may be a resource concern. To date, NRI data summaries on ephemeral gullies have not been released.

NRCS Field Office Needs

During the planning process, if an active ephemeral gully is observed, it is planned for treatment. No assessment tool is used to predict its erosion rate or degree of concern. Treatment is based on site hydrology, soil conditions, and farming enterprise. General treatments include grassed waterways, vegetated barriers, terraces, grade control structures, and impoundments.

A quality criterion for ephemeral gully erosion is currently subjective in that it is assumed that a practice (terrace, waterway, etc.) effectively treats the problem. This leaves little room for interpretation of the potential solutions offered by other conservation management and tillage alternatives. Additionally, the application of a structural practice may not effectively treat the entire ephemeral gully erosion problem on the field. A quantitative tool is needed to estimate the "before" and "after" practice effects. Conservation programs often require this information in determining program eligibility and ranking for limited cost share resources.

The Conservation Practice Physical Effects (CPPE) matrix assesses the effects of approximately 164 conservation practices, both positive and negative, in a qualitative way. The CPPE matrix identifies concentrated flow erosion as a resource concern. Conservation practices are judged to have "slight," "moderate," or "significant" impact on concentrated flow erosion. This presents the question, "how much impact from treatment is necessary to warrant the implementation of the practice."

Currently, NRCS reports only the treatment practices (e.g., acres of grassed waterway, feet of vegetative barriers and terraces) and not their effectiveness in reducing ephemeral gully erosion. Field planners currently do not have a procedure or method to capture the effects or benefits of ephemeral gully erosion treatments in PRS.

Research Needs

Ephemeral Gully Erosion Location Research

Understanding the processes governing ephemeral gully erosion should lead to the development of a method for predicting where these occur on the landscape and measurable criteria for distinguishing between ephemeral gullies and classic gullies. There is a need to predict where an ephemeral gully occurs on the landscape for both modeling purposes and conservation planning. Montgomery and Dietrich (1988) stated that "a key component of channel network growth and landscape evolution theories as well as models… should be the prediction of where channels (i.e. gullies) begin." Much has been accomplished in the last 20 years regarding data bases for estimating soil loss from gullies, and to a lesser degree from ephemeral gullies, but very little success has been achieved in developing methods to predict their location. The most common approach applied to gullies is the relationship between the upslope drainage area ($\boldsymbol{A}$) and the local slope gradient ($\boldsymbol{S}$) immediately above the gully head, such as

$$S = aA^{-b} \tag{1}$$

where $\boldsymbol{a}$ and $\boldsymbol{b}$ are empirically determined fitting parameters. Montgomery and Dietrich (1988, 1992) are most often credited with developing threshold criteria in the form of $\boldsymbol{AS^2}$, although the concepts go back to Horton (1945). The upper and lower thresholds for the point of gully initiation correspond to $\boldsymbol{AS^2}$ values of 4000 and 500 m^2, respectively. Numerous recent papers (Morgan and Mngomezulu, 2003; Moeyersons, 2003; Valentin et al. 2005; Wu and Cheng, 2005) have been devoted to the application of this approach with various degrees of success. However, this method has not been applied to locating ephemeral gullies.

The landscape position where ephemeral gullies are prone to develop is determined by the integrated contributions of the topography, soil pedology, climate, and land use characteristics. Prediction of ephemeral gully locations based on any single component apart from the others will inevitably have limitations and may lead to erroneous conclusions. For example, Zeverbegen and Thorne (1987) developed the compound topographic index (CTI) for locating ephemeral gullies, which is based on topography alone, such that

$$CTI = A * S * PLC \tag{2}$$

where $\boldsymbol{A}$ is the contributing area, $\boldsymbol{S}$ is the slope and $\boldsymbol{PLC}$ is the planform curvature. Ruiz et al. (2007) found that the CTI technique was adequate for many gullies but had limitations at other locations that they proposed were due to failure to incorporate the soil pedology component.

Souchere et al. (2003) developed a model, called “STREAM ephemeral gully,” for predicting the location and volume of ephemeral gullies by combining field measurements with knowledge of erosion processes. Their model is based on the excess shear stress concept in which erosion occurs when the overland flow discharge produces a shear stress that exceeds the critical soil shear stress:

$$q_s = K(\tau - \tau_c)^{\lambda} \tag{3}$$

where the sediment flux, q_s (kg $s^{-1}m^{-2}$), is the product of the excess of the shear stress, τ (kg $m^{-1}s^{-2}$), above a critical shear stress, τ_c (kg $m^{-1}s^{-2}$), and the soil erodibility coefficient, K (s m^{-1}). It is generally assumed that the exponent, λ, is unity.

STREAM is based on a classification scheme for the various factors that affect ephemeral gully erosion. Others, (Imeson and Kwaad, 1980; Sidorchuk et al., 2003) have proposed classification schemes for describing types of gullies and predicting soil loss by gully erosion but not the location of ephemeral gullies. The SLOPE factor in STREAM is separated into four classes, < 2%, 2-4%, 4-8%, and >8%, represented by values 1 through 4, respectively. Land use is represented by a FRICTION factor with values of 1 through 5 assigned to each land use depending on the percent plant cover (3 levels) and the surface roughness (5 levels). Surface roughness is based on the classification scheme developed by Ludwig et al. (1995). Soil surface conditions, including soil properties and residue cover/roughness, control water infiltration to a large extent. The infiltration excess, or runoff, is the main driving force for gully erosion, so the surface roughness affects the FRICTION factor. The critical shear stress is represented as a COHESION factor by values of 1 through 5 based on the land use, plant cover, and four levels of crusting. The qualitative descriptors for crusting were developed by Bresson and Boiffin (1990). STREAM uses an expert-based approach in which decision rules relate the factor tables to represent the erosion processes.

The watershed of interest is divided into pixels based on a digital elevation model (DEM), and the runoff collection network is extracted using a discriminant function developed by Souchere et al. (1998). The discriminant function determines the network of topographical and agriculturally induced furrows, ditches, wheel tracks, flow paths, etc. A minimal drainage area threshold and segment length threshold are applied by the user to obtain the final flow path network. From the flow path network the total runoff volume ($\boldsymbol{Ro}$) for a rainfall event is calculated for any pixel in the catchment. The sensitivity to gully erosion ($\boldsymbol{S}$) for a pixel is calculated from

$$S = Ro * SLOPE\ factor * FRICTION\ factor * COHESION\ factor \tag{4}$$

Souchere et al. (2003) concluded that their model could be used to predict the level of ephemeral gully erosion but that the value for COHESION factor did not take into account the impact of compaction from agriculture machinery or the co-dependence of properties on the factors. A new model is being developed to address this.

AnnAGNPS includes an ephemeral gully model (TIEGEM), based on the research done by Alonso et al (2002) and Gordon et al (2007 & 2008). TIEGEM assumes that ephemeral gullies (1) are formed as a result of a headcut that is restricted by a non-erodible layer (depth of tillage layer); (2) erode a single channel with drainage area a function of the hydraulic geometry of the decreasing channel flow length from the hydraulically most distant point; (3) have optional ephemeral gully width algorithms; and (4) can be modeled as repaired when the fields are tilled. While TIEGEM is an improvement for US agronomic analyses, continued research is needed to improve the model for use as a field-prediction tool.

Process Model Development and Knowledge Gaps

Existing ephemeral gully models have limitations. For example, some gully models allow for the locations of the gully channel(s) and of gully initiation to be user-specified. These models then draw information from databases to determine the gully's drainage area, soil properties, land use, etc. Other models require the user to provide all of the necessary input parameters in order to predict the location and dimensions of the gully.

Some models assume that the gully width does not depend on soil properties or bank height. Models that assume ephemeral gully erosion proceeds as a single headcut do not adequately address gullies that form in a branching or network pattern. Models assume that a non-erodible layer limits the depth of an ephemeral gully, which leads to predictions of wide and shallow ephemeral gullies. Observations by Nachtergaele et al. (2000, 2001, and 2002) indicate that this may be an appropriate morphology for summer gullies. However, some winter gullies in Belgium, Portugal, and Spain are not limited by the same non-erodible layer. In reality, several soil layers with varying resistance to erosion may exist within and below the tilled zone, and the erodibility and critical shear values of the "less erodible" layers may vary seasonally with soil water content. Also, erosion of sediment deposited in channels during smaller events or after passage of head cuts are not considered in any existing ARS ephemeral gully erosion model. Additionally, and probably of equal importance, very little is known regarding the erosion resistance properties associated with the soil (physical, chemical, moisture content, etc.), vegetation (cover, root mass, etc.), and land use (tillage operations, etc.).

All existing headcut models depend, implicitly or explicitly, on an estimate of transport capacity to determine the amount of detachment and the amount of deposition. Available theories and mathematical descriptions of soil erodibility, soil critical shear stress, or sediment transport relationships are often conflicting, and no single generally accepted theory is available for the transport capacity of shallow erosive flows in agricultural fields (Ferro, 1998; Strelkoff and Clemmens, 2005; Hessel and Jetten, 2007). It is generally assumed, based on sediment transport studies in rivers and streams, that transport capacity is a function of the flow rather than of the surface. Research is accumulating, however, that seepage or drainage conditions can influence not only soil erodibility and critical shear stress, but also transport capacity as well (Huang et al., 1999; Zheng et al., 2000). Therefore, all of these properties may vary over time and between landscape positions, even if the soil and management are uniform within a field. The next-generation process-based ephemeral gully model should reflect the main trends of such variation as reflected by the likelihood of seepage versus drainage conditions.

The effects of subsurface soil properties or subsurface flow processes can play significant roles in gully development. Duplex soils, layered soils with a shallow water restricting horizon, are prone to seepage and soil piping, contributing to gully development. Numerous studies have shown that perched water tables have developed over restrictive layers, resulting in preferential lateral flow (Wilson et al., 1990, 1991). This subsurface flow can contribute to gully formation and growth in ways not necessarily represented by surface topography, such as gully bank failure (Collison, 2001; Wilson et al., 2007) due to seepage, tunnel collapse by soil pipe erosion (Faulkner, 2006; Wilson et al., 2009), and pop out failures by pipe flow (Wilson et al., 2008).

Even in a simplistic sense, duplex soils have a limited soil water storage capacity that, once filled, will result in seepage at the surface, contributing to surface runoff or affecting the erosion properties of the soil surface (Huang and Laflen, 1996; Darboux and Huang, 2005). In addition to the probability of subsurface flow directly affecting gully erosion in duplex soils, either by soil-piping or seepage, a water restricting layer near the surface is more likely to result in rainfall impacting the shear stress, $\boldsymbol{\tau}$, at the surface. The role of subsurface flows in gully erosion has been attributed to the decrease in shear stress as the soil water tension, $\boldsymbol{\psi}$, decreases as described by the Mohr-Coulomb equation (Fredlund et al., 1978):

$$\tau = c' + (\sigma - \psi_a)tan\phi' + (\psi_a - \psi_w)tan\phi^b \quad (5)$$

where c' is effective cohesion, $(\sigma - \psi_a)$ is the net normal stress [σ is total stress and ψ_a is pore-air pressure], ϕ' is effective angle of internal friction, $(\psi_a - \psi_w)$ is soil-water suction [ψ_w is pore-water pressure], and ϕ^b is effective angle of shearing resistance relative to an increase in soil suction. Therefore, the depth to a restrictive layer may be a critical variable in predicting gully locations. This restrictive layer may be a genetic feature of the soil, such as an argillic horizon, fragipan, caliche layer, or may be anthropogenic, such as a plow pan or depth of tillage. The increase in clay content with depth may not be large enough to qualify as an argillic horizon, yet lateral movement may occur. Wilson et al. (2007) found that just a 16% increase in clay content caused over two orders of magnitude decrease in **Ks** which resulted in seepage erosion at bank faces. Heeren et al. (2009) showed that only one order of magnitude decrease in **Ks** between layers was sufficient to cause seepage. Subsoil properties such as these have not been incorporated into ephemeral gully erosion models to date.

Research and development are needed to reconcile and build on the best capabilities of all existing ephemeral gully models and to develop tractable representations of important ephemeral gully erosion processes. Studies on ephemeral gullies have identified needs for further development, including: (1) a procedure to better determine the ephemeral gully width, (2) improvements for the soil resistance to erosion and rate of headcut advancement; (3) ability to represent the effect of root mass and above-ground vegetation on erosion resistance; (4) incorporate the effects of subsurface flow on gully erosion; (5) ability to identify the initiation point of gullies; and (6) ability to separate sediment measurements at gauging stations into sources that represent the erosion process (sheet, rill, gullies, and stream beds and banks) and also determine their point of origin.

Data Bases

In order to develop a model for predicting the location of ephemeral gullies, a database is needed that includes variables describing all of the soil, topographic, climate, and land use components. The model may be developed by data mining, using statistical techniques or empirical relationships based on simple mechanistic descriptions of the governing processes such as used in STREAM. The problem is the lack of a complete database for developing such a model. Databases that do exist may be complete in one component, e.g. topographic parameters, but have limited to no data on the other components.

A research team has been formed at the USDA National Sedimentation Lab that will work in collaboration with the USDA-NRCS to conduct field characterization of ephemeral gullies. An array of measurements will be made to establish a complete database that includes topographic variables, surface and subsurface soil properties, land use, and climate variables. Locations with ephemeral gullies will be sampled along with adjacent locations without gullies.

GIS, LiDAR, 2D-RUSLE2

Appendix A3 presents a working draft of a concept being developed to extend RUSLE2 into a GIS context. Proper identification of potential ephemeral gullies and channels is critical to the success of this work because these channels represent the end of the RUSLE2 hillslope length. Separate calculation of erosion in the channel system, using a physically based ephemerally gully model, is needed to supplement the RUSLE2 sheet and rill erosion computations.

Object Modeling Systems (OMS)

In February 2008, the ARS administrator presented OMS version 2.1 to the NRCS Chief in a hand-off ceremony at Washington, DC, and both signed a Memorandum of Understanding (MOU) containing the responsibilities and duties for maintaining the modeling framework over the long term. During 2008, OMS 2.2 added more features to support the ongoing modeling projects.

Practices to Treat Ephemeral Gully Erosion: Existing and Innovative

Nearly 40 watershed studies are currently ongoing through ARS, NRCS, Universities, and others in support of the CEAP project. Their goal is to monitor, document, and research the effects of conservation practices on natural resources. Some of these watershed studies include accounting for ephemeral gully erosion, as well as other types of erosion, both at the field and watershed scale. The efforts to date are mostly customized field observations or ad hoc applications of aerial photographic interpretation approaches, and limited use of models specifically geared for ephemeral gully erosion prediction and analysis. Final reports of these watershed studies are due in the few next years, and results regarding ephemeral gully erosion control and effects of those treatments are still yet to be quantified.

Ephemeral gullies are addressed in a practical sense by land users who fill the gully void with soil adjacent to the gully by normal tillage equipment. Gordon et al. (2008) demonstrated that filling-in gullies by tillage reactivates ephemeral gully erosion, producing an intermittent step-wise increase in gully erosion with time. Numerous conservation practices have been developed and extensively tested for cost effectiveness in the control of sheet and rill erosion. However, less research has been conducted on developing and testing the cost effectiveness of practices specifically to control ephemeral gully erosion. Terraces, grass waterways, and drop pipes applied to ephemeral gully areas have had generally good success but can fail if subsurface properties and processes specific to ephemeral gully erosion are not properly assessed. The benefits of installing these practices are not fully accounted for by RUSLE2, and such practices can fail catastrophically in a manner that is difficult to predict.

New and innovative practices, such as internal drainage systems, soil strengthening with vegetative reinforcement materials, and incorporation of biofibers, need to be tested under a range of conditions that include subsurface flow. The USDA-National Sedimentation Laboratory has developed plans for adapting their existing research facilities at the Mississippi Agricultural and Forestry Experiment Station (MAFES) facilities at Holly Springs for testing innovative control practices. Permission has been granted by MAFES for such facilities, and construction will proceed as funds permit.

Conclusions

It is clear from the literature review that ephemeral gully erosion is a critical problem that significantly damages and deteriorates agricultural lands worldwide. Several abstracts refer to long term degradation of agricultural land, even to the point of removing the land from production. Others (Nyssen et al., 2004; Valentin et al., 2005; Lui et al., 2009) documented the degree that ephemeral gully erosion reduced the soil depth adjacent to the gullies and thereby reduced crop yield. Based on the large number of abstracts and associated research focused on ephemeral gully erosion, this is clearly a significant worldwide problem to be investigated.

With much recent research on ephemeral gully erosion, it seems the technology is still in the development stage. Much more work is needed, as well as increased cooperation and coordination between researchers. The major factors related to ephemeral gully erosion seem to be so variable across the world that addressing ephemeral gully erosion from a physical modeling approach could have the most promise. Variation in climate, soil types, farming practices, and topography cause ephemeral gully erosion processes to be extremely complex. The previously listed recommended action items are needed to address this complexity.

References

Alonso, C.V., S.J. Bennett, and O.R. Stein. 2002. Predicting headcut erosion and migration in upland flows, Water Resources Research, 38:1-15.

Arid-Land Agricultural Research Center (ALARC) 2006. WinSRFR 2.1 User Manual. U.S. Department of Agriculture, Agricultural Research Service, Arid-Land Agricultural Research Center, Maricopa, Arizona, 142 pp.

Arnold, J.G., Srinivasan, R., Muttiah, R.S., and Williams, J.R. 1998. Large area hydrologic modeling and assessment part I: model development. J. American Water Resources Association 34(1):73-89.

Ascough J.C., Baffaut C., Nearing M.A., and Liu B.Y. 1997. The WEPP watershed model: I. Hydrology and erosion. Transactions of the American Society of Agricultural Engineers 40(4): 921-933.

Bennett, J.P. 1974. Concepts of mathematical modeling of sediment yield. Water Resour. Res., 10(3):485–492.

Bresson, L.M., and J. Boiffin. 1990. Morphological characterization of soil crust development stages on an experimental field. Geoderma, 47:301-325.

Capra A, and Scicolone B. 2002. Ephemeral gully erosion in a wheat-cultivated area in Sicily (Italy). Biosystems Engineering 83:119-126.

Chang, H.H. 1982. Mathematical model for erodible channels. J. Hydr. Div. 108(5):678-689.

Collison, A.J.C. 2001. The cycle of instability: stress release and fissure flow as controls on gully head retreat. Hydrol. Proc., 15:3-12.

Cunge, J.A., F.M. Holly Jr., and A. Verwey. 1980. Practical aspects of computational river hydraulics, Pitman, Boston.

Dabney, S.M., D.C. Yoder, and D.A.N. Vieira. 2008. Predicting ephemeral gully erosion with RUSLE2. In Proceedings, The National Sedimentation Laboratory: 50 Years of Soil and Water Research in a Changing Agricultural Environment. 3-5 September, Oxford, MS.

Darboux F, and C.H. Huang. 2005. Does soil surface roughness increase or decrease water and particle transfer. Soil Sci. Soc. Am. J. 69:748-756.

De Ploey, J. 1989. A model for headcut retreat in rills and gullies. CATENA, Supplement 14, pp. 81-86.

Engelund, F., and E. Hansen. 1967. A monograph on sediment transport in alluvial streams. Teknisk Forlag, Copenhagen, 62 pp.

Faulkner H. 2006. Piping hazard on collapsible and dispersive soils in Europe. In: Soil Erosion in Europe, J. Boardman, J. Poesen (Editors) John Wiley & Sons, Ltd.

Ferro, V. 1998. Evaluating overland flow sediment transport capacity. Hydrological Processes 12 (12):1895-1910

Foster, G. R., 1982. Modeling the Erosion Process, In: C.T. Haan, H.P. Johnson, and D.L. Brakensiek (editors), Hydrologic Modeling of Small Watersheds, Monograph Number 5, American Society of Agricultural Engineers, St. Joseph, MI, p. 305.

Foster,G.R. and L.J. Lane. 1983. Erosion by concentrated flow in farm fields. In Proceedings of the D. B. Simons Symposium on Erosion and Sedimentation. Colorado State University: Ft. Collins; 9.65–9.82.

Franti, T.G., Laflen, J.M., and Watson, D.A., 1985. Soil Erodibility and Critical Shear Under Concentrated Flow, American Society of Agricultural Engineers, Paper No. 85-2033.

Fredlund D.G., N.R. Morgenstern, and R.A. Widger. 1978. The shear strength of unsaturated soils. Canadian Geotechnical J. 15:313-321.

Gardner, T. W. 1983. Experimental study of knickpoint and longitudinal profile evolution in cohesive, homogeneous material. Geological Society of American Bulletin, Vol.94, pp.664-672.

Gordon LM, Bennett SJ, Alonso CV, and Bingner RL. 2008. Modeling long-term soil losses on agricultural fields due to ephemeral gully erosion. Journal of Soil and Water Conservation 63(4): 173-181.

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 ASABE, 50(3):857-866.

Haan CT, Barfield BJ, Hayes JC. 1994. Design Hydrology and Sedimentology for Small Catchments. Academic Press: San Diego, CA.

Hairsine, P.B. and C.W. Rose. 1992a. Modeling water erosion due to overland flow using physical principles: 1. Sheet flow. Water Resour. Res., 28, 237-243.

Hairsine, P.B. and C.W. Rose. 1992b. Modeling water erosion due to overland flow using physical principles: 1. Rill flow. Water Resour. Res., 28, 245-250.

Herren, D.M., G.A. Fox, M.L. Chu-Agor, and G.V. Wilson. 2009. Predicting streambank seepage flows: Sensitivity to soil properties and layering. J. Hydrol. (in review).

Hessel, R. and V. Jetten. 2007. Suitability of transport equations in modeling soil erosion for a small Loess Plateau catchment, Engineering Geology. 91(1):56-71.

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

Hu, G., Wu, Y.Q., Liu, B.Y., et al., 2007. Short-term gully retreat rates over rolling hill areas in black soil of Northeast China. Catena 71, pp. 321-329.

Huang C.H., and J.M. Laflen. 1996. Seepage and soil erosion for a clay loam soil. Soil Sci. Soc. Am. J. 60:408-416.

Huang, C., Wells, L.K., Norton, L.D. 1999. Sediment transport capacity and erosion processes: Model concepts and reality. Earth Surface Processes and Landforms 24 (6):503-516.

Imeson, A.C., and F.J.P.M. Kwaad. 1980. Gully types and gully prediction. K.N.A.G. Geografish Tijdschrift XIV 5:430-441.

Knisel, W.G., ed. 1980. CREAMS: A Field-Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems. U.S. Dept of Agric., Conservation Research Report No. 26, 640 pp.

Langendoen, E.J. 2000. CONCEPTS—Conservational channel evolution and pollutant transport system. Research Rep. No. 16, U.S. Dept. of Agriculture, Agricultural Research Service, National Sedimentation Laboratory, Oxford, MS.

Langendoen, E.J., and A. Simon. 2008. Modeling the evolution of incised streams: II. Streambank erosion. J. Hydr. Eng. 134(7):905-915.

Langendoen, E.J., and C.V. Alonso. 2008. Modeling the evolution of incised streams: I. Model formulation and validation of flow and streambed evolution components. J. Hydr. Eng. 134(6):749-762.

Laursen, E. 1958. The total sediment load of streams. J. Hydr. Div., 84(1):1–36.

Leonard, R. A., W. G. Knisel, and D. A. Still, 1987. GLEAMS: Ground water loading effects of agricultural management systems. Transactions of the American Society of Agricultural Engineers. 30(5): 1403-1418.

Li, Y., Poesen, J., Yang, J.C., Fu, B., Zhang, J.H., 2003. Evaluating gully erosion using 137Cs and 210Pb/ 137Cs ratio in a reservoir catchment. Soil and Tillage Research 69 (1–2), pp. 107– 115.

Liu, H., T. Zhang, B. Liu, G. Liu, and G.V. Wilson. 2009. Effects of gully erosion on soybean yield. Catena. (submitted)

Ludwig, B., J. Boiffin, J. Chadoeuf, and A.V. Auzet. 1995. Hydrological structure and erosion damage caused by concentrated flow in cultivated catchments. Catena, 25:227-252.

Merkel, W.H., Woodward, D.E., Clarke, C.D., 1988. Ephemeral Gully Erosion Model (EGEM), In: Modeling Agricultural, Forest, and Rangeland Hydrology, International Symposium, Publication 07-88, American Society of Agricultural Engineers, St. Joseph, MI, pp. 315-323.

Meyer, L.D. and W.C. Harmon. 1985. Sediment losses from cropland furrows of different gradients. Trans. ASAE, 28, 448-453.

Meyer-Peter, E., and R. Mueller. 1948. Formula for bed-load transport. Proc., Int. Association for Hydraulic Research, 2nd Meeting, Stockholm, Sweden.

Moeyersons, J. 2003. The topographic thresholds of hillslpe incisions in southwestern Rwanda. Catena. 50:381-400.

Montgomery, D.R., and W.E. Dietrich. 1988. Where do cannels begin? Nature. 336:232-234.

Montgomery, D.R., and W.E. Dietrich. 1992. Channel initiation and the problem of landscape scale. Science. 255:826-829.

Morgan, R.P.C., and D. Mngomezulu. 2003. Threshold conditions for initiation of valley-side gullies in the Middle Veld of Swaziland. Catena. 50:401-414.

Nachtergaele J., J. Poesen, A. Sidorchuk, and D. Torri. 2002. Prediction of concentrated flow width in ephemeral gully channels. Hydrol. Process. 16:1935–1953.

Nachtergaele, J., J. Poesen, L. Vandekerckhove, D.O. Wijdenes, M. and Roxo, M. 2000. Testing the ephemeral gully erosion model (EGEM) for two Mediterranean environments. Earth Surface Processes and Landforms, 26(1), 17-30.

Nachtergaele, J., Poesen, J., Steegen, A., Takken, I., Beuselinck, L., Vandekerckove, L., Govers, G., 2001. The value of a physically based model versus an empirical approach in the prediction of ephemeral gully erosion for loess-derived soils. Geomorphology 40, pp. 237–252.

Nyssen, J., Poesen, J., Moeyersons, J., Deckers, J., Mitiku, H., Lang, A., 2004. Human impact on the environment in the Ethiopian and Eritrean highlands—a state of the art. Earth Science Reviews 64 (3–4), pp. 273– 320.

Nyssen, J., Poesen, J., Moeyersons, J., Haile, M., Deckers, J., 2008. Dynamics of soil erosion rates and controlling factors in the Northern Ethiopian Highlands towards a sediment budget. Earth Surface Processes and Landforms 33, pp. 695-711.

Oostwoud Wijdenes, D.J., Bryan, R., 2001. Gully-head erosion processes on a semi-arid valley floor in Kenya: a case study into temporal variation and sediment budgeting. Earth Surface Processes and Landforms 26, pp. 911-933.

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

Patton, P.C., Schumm, S.A., 1975. Gully erosion, Northwestern Colorado: a threshold phenomenon. Geology 3, pp. 88–90.

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

Preissmann, A. (1960). Propagation des intumescences dans les canaux et riviers, 1er Congrès d'association Française de calcul, 433-442, Grenoble, France.

Robinson, K. M. and G. J. Hanson, G. J. 1994. A deterministic head-cut advance model. Transactions of the ASAE, Vol. 37, No. 5, pp. 1437-1443.

Ruiz, E.V.T., Y.Yuan, R.E. Bingner, A.P. Acevedo, J.L.A. Munoz, and R.P. Alcantara. 2007. Evaluation of the compound topographic index (CTI) for the location of ephemeral gullies on Olive orchards at the microcatchment scale. Lugo, Spain, September 2007.

Sidorchuk, A., M.Marker, S. Moretttie, and G. Rodolfi. 2003. Gully erosion modeling and landscape response in the Mbuluzi River catchment of Swaziland. Catena, 50:507-525.

Soil Science Society of America. 2008. Glossary of Soil Science Terms. Soil Science Society of America, Madison, WI.

Souchere, V., D. King, J. Daroussin, F. Papy, and A. Capillon. 1998. Effect of tillage on runoff direction: Consequences on runoff contributing area within agricultural catchments. J. Hydrol., 206:256-267.

Souchere, V., O. Cerdan, B. Ludwig, Y.L. Bissonnais, A. Couturier, and F. Papy. 2003. Modelling ephemeral gully erosion in small cultivated catchments. Catena, 50:489-505.

Stein, O. R. and P.Y. Julien 1993. Criterion delineating the mode of headcut migration." J. Hyd Eng., ASCE, Vol. 119, No. 1, pp. 37-50.

Street, L. and J.N. Quinton. 2001. Development of an Ephemeral Gully Erosion Model: The Role of Undercutting in Bank Failure of Small Channels In Ascough, J.C. and D.C. Flanagan (eds.) Proceedings of the International Symposium on Soil Erosion Research for the 21st Century, 3-5 Jan 2001, Honolulu, HI. American Society of Agricultural Engineers, St. Joseph, MI. pp.338-341.

Strelkoff, T.S. and A.J. Clemmens. 2005. Transport capacity for eroded silts in irrigation furrows. J Hydr. Engr., 131(10):921-926.

Strelkoff, T.S., and D.L. Bjorneberg. 2001. Hydraulic modeling of irrigation-induced furrow erosion. In: Sustaining the Global Farm. Selected Papers from the 10th International Soil Conservation Organization Meeting, May 24-29, 1999, Purdue University, D.E. Stott, R.H. Mohtar, and G.C. Steinhardt, Eds., 699-705.

Temple, D. M. 1992. Estimating flood damage to vegetated deep soil spillways. Applied Engineering in Agriculture, Vol. 8, No. 2, pp. 237-242.

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.

Theurer, F.D., C.V.Alonso, & J.M.Bernard. 1996. Hydraulic Geometry for Pollutant Loading Computer Models Using Geographical Information Systems to Develop Input Data. In Proceedings of the sixth federal interagency sedimentation conference, March 1996, 8 pg.

USDA, NRCS, 1989. Engineering Field Manual Chapter 2 (EFM 2), Estimating Runoff and Peak Discharge, Washington, DC.

USDA, NRCS, 1992. Ephemeral Gully Erosion Model, Version 2.0 DOS, User Manual, Washington, DC.

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

Vandaele, K., Poesen, J., Govers, G., van Wesemael, B., 1996. Geomorphic threshold conditions for ephemeral gully incision. Geomorphology 16 (2), pp. 161– 173.

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, pp. 329–352.

Vandekerckhove, L., Poesen, J., Oostwoud Wijdenes, D., Gyssels, G., 2001. Short-term bank gully retreat rates in Mediterranean Environments. Catena 44, pp. 133–161.

Wang, Y. 1992. Prediction of ephemeral gully formation and erosion on hillslopes. Ph.D. Thesis. University of Minnesota. 185 pp.

Watson, D.A., Laflen, J.M., Franti, T.G., 1985. Ephemeral Gully Erosion Estimator (Unpublished).

Wei, H., M.A. Nearing, J.J. Stone, D.P. Guertin, K.E. Spaeth, F.B. Pierson, M.H. Nichols, C.A. Moffett. 2009. A new Splash and Sheet Erosion Equation for Rangelands. Soil Sci. Soc. Am. J. (in press)

Williams, J. R., C. A. Jones, and P. T. Dyke. 1984. A modeling approach to determining the relationship between erosion and soil productivity. Transactions of the American Society of Agricultural Engineers. 27: 129-144.

Wilson, G.V. 2009. Ephemeral Gully Erosion by Preferential Flow Through Continuous Soil-Pipes. Earth Surface Processes and Landforms, (accepted 11/6/2008).

Wilson, G.V., P.M. Jardine, R.J. Luxmoore, and J.R. Jones. 1990. Hydrology of a forested hillslope during storm events. Geoderma 46:119-138.

Wilson, G.V., P.M. Jardine, R.J. Luxmoore, L.W. Zelazny, D.A. Lietzke, and D.E. Todd. 1991. Hydrogeochemical processes controlling subsurface transport from an upper subcatchment of Walker Branch Watershed during storm events: 1. Hydrologic transport process. J. Hydrol. 123:297-316.

Wilson, G.V., R.F. Cullum, and M.J.M. Römkens. 2008. Preferential Flow Through a Discontinuous Soil-Pipe Results in Mass Wasting and Reestablishment of Ephemeral Gullies. Catena, 73:98-106.

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.

Woodward, D.E. (1999). Method to predict cropland ephemeral gully erosion. Elsevier Science B.V., Catena 37: 393-399.

Woolhiser, D.A., R.E. Smith, and D.C. Goodrich. 1990. KINEROS, A kinematic runoff and erosion model: Documentation and user manual. U.S. Department of Agriculture, Agricultural Research Service, ARS-77, 130 pp.

Wu, W. and S. S. Y Wang. 2005. Empirical-numerical analysis of headcut migration. Int. J. Sediment Research, Vol. 20, No. 3, pp. 233-243.

Wu, Y., and H. Cheng. 2005. Monitoring of gully erosion on the Loess Plateau of China using a global positioning system. Catena, 63:154-166.

Yalin, M.S. 1963. An expression for bed-load transportation. Proc. Am Soc. Civil Eng 89(HY3):221-250.

Yang, C.T. 1973. Incipient motion and sediment transport. J. Hydraul. Div. Am. Soc. Civ. Eng., 99(HY10), 1679-1704.

Zeverbegen, L.W., and C.R. Thorne. 1987. Quantitative analysis of land surface topography. Earth Surface Processes and Landforms. 12:47-56.

Zheng, F.-L., Huang, C.-H., Norton, L.D. 2000. Vertical hydraulic gradient and run-on water and sediment effects on erosion processes and sediment regimes. Soil Science Society of America Journal 64 (1):4-11.

APPENDICES

Appendix A1. CEAP Watershed, Cheney Lake, KS

Cheney Lake Watershed, Kansas—Ephemeral Gully Erosion Conservation Effects Assessment Project (CEAP) Special Emphasis Watershed

Significant Findings

- Approximately 10% of the Cheney Lake watershed contributes 70% of the sediment load to Cheney Reservoir.
- Computer models can predict areas of the watershed that have the highest potential for sediment loading.
- Treating all the ephemeral gullies in the Cheney Lake watershed can potentially reduce the sediment load to the reservoir by 35%.
- Focused voluntary implementation of management practices that reduce soil losses in the areas with the highest potential for sediment loading will improve water quality more rapidly and at less cost than random implementation of practices across the watershed.

A Task Force created by the Reno County Conservation District prepared a master plan for watershed pollution management to reduce phosphorus and sediment and double the life of the reservoir. Implementation of the plan began in July l994 under the leadership of the Citizen's Management Committee (CMC) which operates as a subcommittee of the Reno County Conservation District. All members of the CMC are farmers and landowners in the watershed. The Cheney Lake Watershed incorporated and received status as a 501(c)(3) non-profit corporation in 1998. It is the goal of the project management team that the cost to implement management practices on the land will be financed with little or no cost to the landowner or operator.

A five-year comprehensive water monitoring study was implemented in the watershed in l996 through a partnership arrangement with the City of Wichita, U.S. Geological Survey, and U.S. Bureau of Reclamation. A two-year macroinvertebrate study complements the USGS water quality data. All AnnAGNPS modeling within this project has been validated and calibrated to the U.S. Geological Survey data collected in 1996--2000.

Cheney Reservoir is currently designated a high priority impaired water body under the Clean Water Act, with impairments listed for eutrophication and sedimentation. The Citizens' Management Committee of Cheney Lake Watershed has established goals of 40-45% reductions in sediment and phosphorus loading for the watershed. As a Special Emphasis watershed in the Conservation Effects Assessment Project (CEAP), the Cheney Lake watershed has been investigated by the Natural Resources Conservation Service using the AnnAGNPS computer modeling system. The entire scope of the NRCS investigation will determine the effects of the Conservation Reserve Program, tillage practices, irrigation-scheduling practices, concentrated but unconfined animal feeding operations, atrazine management practices, and the contribution of sediment from ephemeral gullies within this watershed in south central Kansas. This publication presents significant findings regarding the impact of ephemeral gullies.

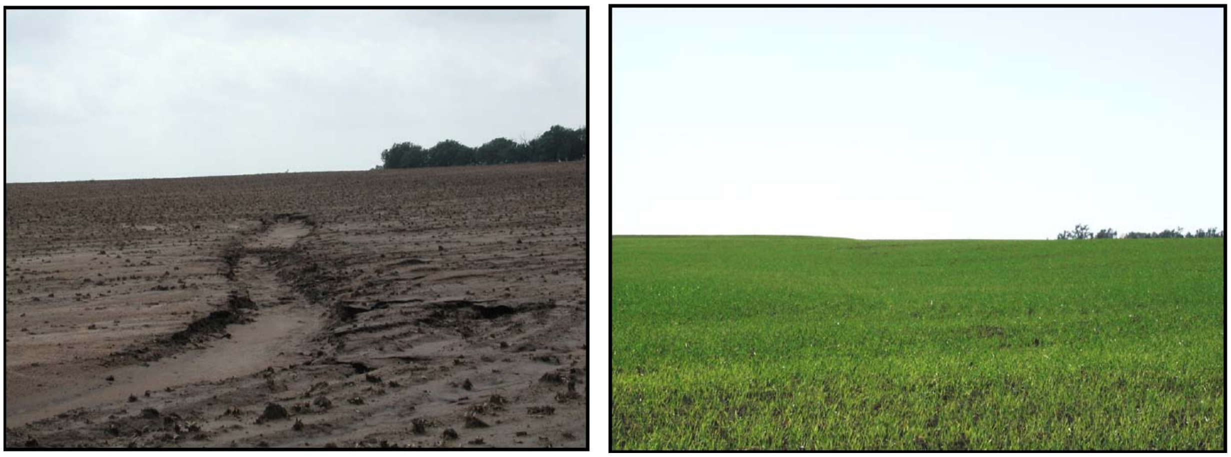
Potential Sources of Sediment

Sediment is a concern within the Cheney Lake watershed with regard to both water quality and to reservoir storage capacity. Cheney reservoir was designed to provide sediment storage for 100 years. Sources of sediment within this agricultural watershed include sheet and rill erosion, ephemeral gully erosion, and streambank erosion.

Sheet and rill erosion is defined as the removal of layers of soil from the land surface by the action of rainfall and runoff. Sheet and rill erosion can be erased by tillage practices and the next erosive action may form in a different place. Typically sheet and rill erosion creates shallow, parallel channels that are uniformly spaced and sized. The Natural Resources Inventory (NRI) estimates for soil loss from sheet and rill erosion are calculated using the Universal Soil Loss Equation (USLE) model. Examples of management practices to address sheet and rill erosion include conservation tillage, gradient terraces, and field buffers.

Ephemeral gully erosion results from concentrated flow upstream from incised channels. Soil is removed along a narrow flow path to a depth of a less-erodible layer. These temporary gullies may be obscured by tillage but they will reform in the same location at the next rainfall event. As soil is moved into the voided area by tillage, an area wider than the actual gully is damaged. Erosion from ephemeral gullies beyond the calculated sheet and rill erosion loss are not included in the Universal Soil Loss Equation (USLE) model.

Photos below show the same crop field in the Cheney Lake Watershed on August 26 and October 17 of 2005. The ephemeral gully in the first photo has been obscured by tillage and planting operations in the second photo.



Examples of management practices that will address ephemeral gully erosion include grassed waterways or shaping and seeding the affected area with permanent vegetation.

Stream bank erosion pertains to the loss of soil from the incised banks of a perennial stream system. Stream bank losses are best determined by a physical assessment of the stream system. Treatment for stream bank erosion includes some form of bank stabilization.

Investigation of Sediment Origin

As watershed residents attempt to reduce suspended solids within the Cheney Lake watershed stream system, it is useful to determine the primary sources of sediment. Early modeling efforts in the watershed assumed two primary sources – stream bank loss and soil erosion as calculated using the Universal Soil Loss Equation (USLE) model.

Estimates of stream bank erosion were based on a 1996 investigation by the Kansas Natural Resources Conservation Service state geologist. A survey of the North Fork Ninnescah stream system at that time determined that less than 15% of the sediment load originated from the stream banks. When the AnnAGNPS model results of the Cheney Lake watershed were validated with U.S. Geological Survey stream monitoring data, there appeared to be a gap between the sediment load predicted by the model and the actual sediment load measured by USGS. Other outputs predicted by the model were in agreement with the USGS data. Figure A1-1 shows the difference in tons of sediment measured by USGS and the sediment predicted by the model. On investigation it was determined that the USLE model did not capture erosion as a result of ephemeral gullies within crop fields. The hypothesis was that ephemeral gullies would prove to be the source of the sediments that were not accounted for within the early modeling studies. Within the CEAP investigation, the AnnAGNPS model has been enhanced with the addition of a method to account for ephemeral gully erosion. As predicted the results of the CEAP modeling closely match the predicted sediment load with the actual measured sediment load.

With this enhancement that includes contributions from ephemeral gullies, the CEAP investigation has been able to rank land area within the watershed according to its predicted sediment contribution to the overall loading of the North Fork Ninnescah River. Using this ranking, it is possible to see the relationship between the percentage of sediment load and the percentage of contributing cells. The graph in figure A1-2 illustrates this relationship showing that roughly 10% of the 200-acre cells in the watershed are contributing approximately 70% of the sediment load. The graph further illustrates the difference between the sediment load when ephemeral gullies are included or excluded from the equation. This graph indicates that approximately 35% of the sediment load in this watershed could be eliminated by treating the ephemeral gullies. The relationship between sediment and contributing cells can also be illustrated spatially with the watershed map shown in figure A1-3. The areas representing 10% of the watershed that contribute 70% of the sediment are shown in purple. Areas of the watershed shown in green indicate those areas that are contributing less than the highest 10% but higher than the mean contribution.

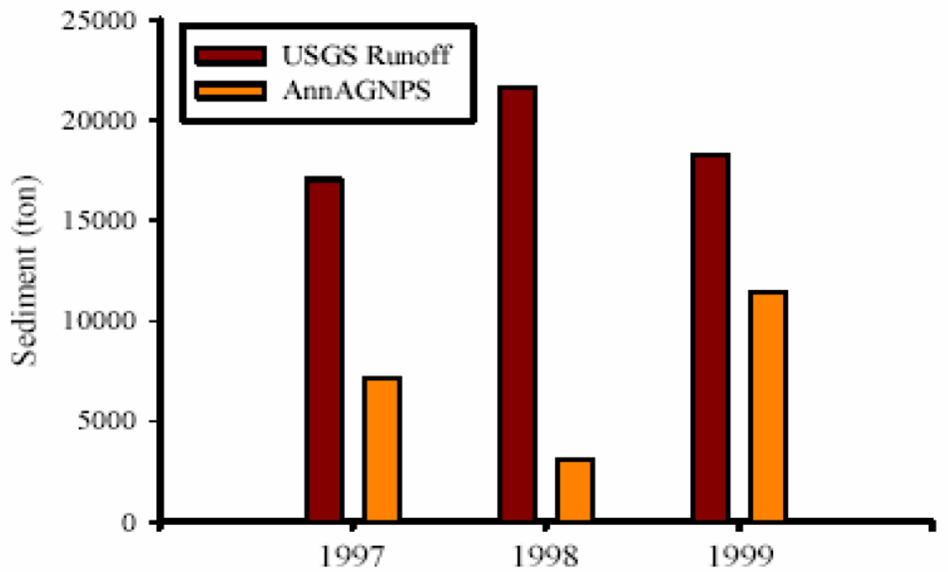


Figure A1-1. Comparison plots of observed and predicted sediment yield at the USGS gauging station (07144780) on the North Fork Ninnescah River above Cheney Reservoir during 1997-–1999.

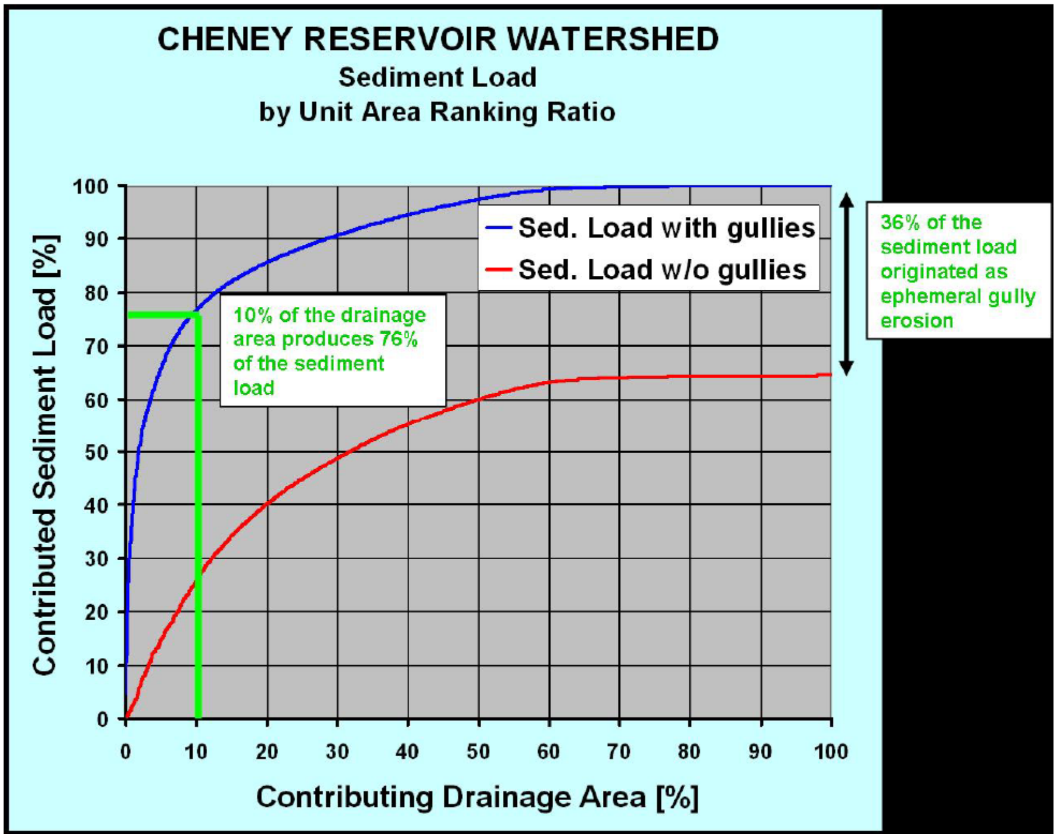


Figure A1-2. Sediment Load Contribution by Ranked Unit Areas

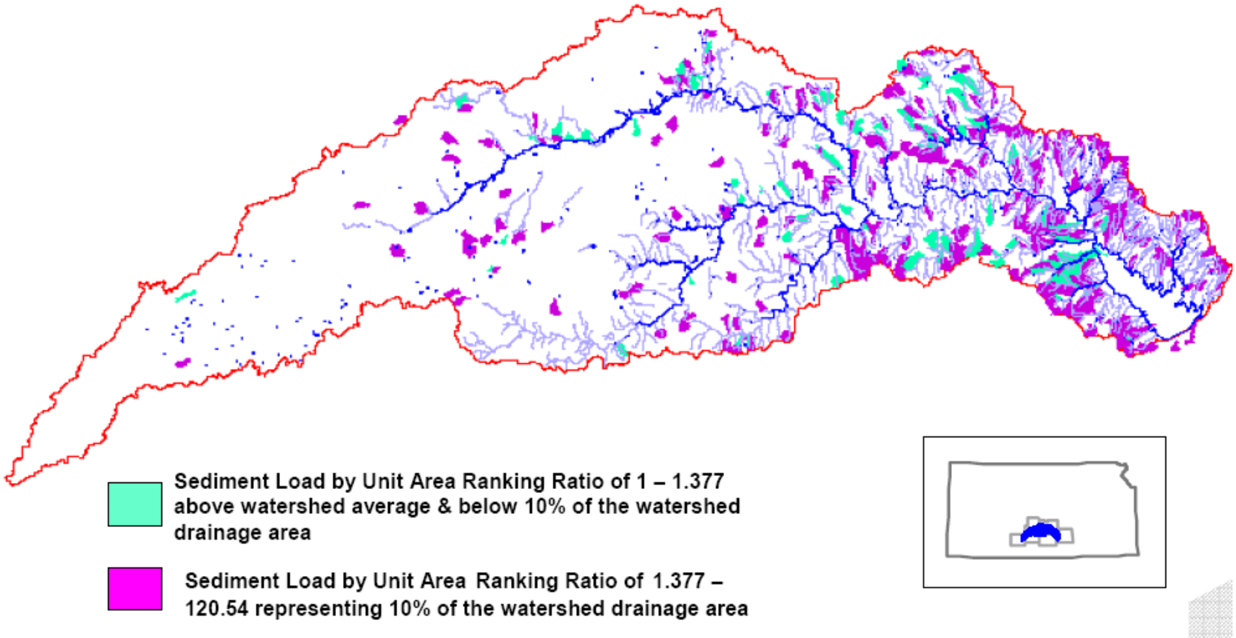


Figure A1-3. Cheney Lake Watershed ranking of sediment load by unit area with respect to the watershed outlet.

Conclusions—Implications and Application in the Watershed

The findings of this CEAP investigation could be used to make significant changes in the implementation of conservation measures. The CEAP modeling found that 10% of the watershed is contributing 70% of the sediment load to Cheney Reservoir. A significant portion of the sediment source is ephemeral gullies in crop fields. If all ephemeral gullies within the watershed are treated with conservation practices specifically designed to address this type of erosion, the sediment load to the reservoir could be reduced by 35%.

The voluntary implementation of conservation practices to address specific sources of sediment in specific locations within the watershed will result in more rapid water quality improvement than random voluntary implementation of conservation practices. When funding and technical assistance are limited the ability to identify and rank the pollutant sources will be critical in focusing assistance in areas that will provide the greatest improvements.

Appendix A2. Upper Auglaize River, Ohio

EXERPT FROM

Upper Auglaize Watershed AGNPS Modeling Project Final Report

February 14, 2005

Prepared For: U.S. Army Corps of Engineers—Buffalo District
Prepared By: TOLEDO HARBOR AGNPS PROJECT TEAM

Authors: Dr. Ron Bingner, Agricultural Research Service; Dr. Kevin Czajkowski, Michael Palmer and James Coss, University of Toledo; Steve Davis, Jim Stafford, Norm Widman, and Dr. Fred Theurer, USDA Natural Resources Conservation Service; Greg Koltun, U.S. Geological Survey; Dr. Pete Richards, Heidelberg College; Tony Friona, U.S. Army Corps of Engineers

Ephemeral Gully Issues

The need to include gully erosion in the model was identified early in the project when it was found that model predictions of sheet and rill erosion (even before reductions to account for upland deposition) were significantly lower than the volumes of sediment recorded at the Fort Jennings gauge. Streambank erosion is not major problem in the Upper Auglaize River, and work performed by USACE in the 1980's indicated that streambank erosion on the Cuyahoga River (a river with fairly significant bank erosion problems) represented only about 5% of the annual dredging volume at that time (USACE, 1986). Furthermore, much of the river has a rock bottom, and analysis of suspended samples indicates that roughly 90% of the suspended sediment load consists of clay-sized particles. Therefore, channel erosion sources were deemed unlikely to contribute significantly to sediment measurements at the gauge. This left gully erosion as the sole remaining mechanism capable of generating sufficient sediment to account for the deficit.

Field observations indicated that ephemeral gullies form in many agricultural fields in the watershed, but that classical non-ephemeral gullies were not present. For these reasons a decision was made to utilize the Ephemeral Gully Erosion Model (EGEM) together with AnnAGNPS to estimate ephemeral gully erosion, yield and loading in the Upper Auglaize Watershed. In keeping with the overall watershed modeling project goal of locating sources of erosion, gully erosion for each cell was calculated in an effort to place and prioritize source areas. The capabilities of the GIS-AnnAGNPS interface made possible the development of the required inputs for each of the 1833 cells. Estimated existing gully erosion was 1.772 tons per acre per year averaged over the entire 211,950 acre watershed, or 375,575 tons per year. A delivery ratio of 0.4 was used to calculate the amount of gully erosion entering the stream system (yield) from its upland source. Table A2-1 gives a summary of the output from the AnnAGNPS model.

Table A2-1: Summary of ephemeral gully erosion for existing conditions.

Items	Amount	Units
Average gully erosion	1.772	Tons/ac/yr
Total gully erosion	375,600	Tons/yr
Cell maximum gully erosion	70.350	Tons/ac/yr
Cell minimum gully erosion	0.000	Tons/ac/yr
Average gully sediment yield	0.709	Tons/ac/yr
Total gully sediment yield	150,300	Tons/yr
Average gully sediment load	0.225	Tons/ac/yr
Total gully sediment load	476,700	Tons/yr

The AnnAGNPS model uses a power curve function of runoff volume to model gully erosion. The inputs are the volume of runoff and a coefficient and exponent to apply to the volume. In contrast to this, the EGEM is a more physically-based model of ephemeral gully erosion that requires approximately 15 different parameters for input. EGEM was a more complete and therefore more desirable model for the undertaken analysis. However, it is not incorporated into AnnAGNPS and therefore has to be run outside the model.

Thus, to model gully erosion in the Upper Auglaize Watershed, there were three possibilities. 1) Model erosion by the AnnAGNPS power curve using values for the coefficient and exponent from other studies. 2) Use EGEM in a stand-alone fashion and be satisfied with not modelling the delivery of gully erosion through the watershed stream network to the outlet. 3) Use the AnnAGNPS power curve, but develop the power curve for each cell based on the results of running EGEM on the parameters of each cell. The third alternative was chosen. Figure A2-1is a picture of an ephemeral gully being formed in a recently tilled field.

Figure A2-1. Ephemeral gully forming in the Upper Auglaize Watershed, northwester Ohio.

The GIS interface to AnnAGNPS creates the cell data needed for the watershed model. Some of the parameters developed by the interface for sheet and rill erosion are the same ones needed for EGEM. Thus, area, slope and length parameters were available for each cell from a preprocessing run of the GIS interface. The GIS also determined a dominant soil for each cell. This soil was then cross-referenced in the NASIS soils database to get a soil texture that determined several needed soil properties. Once the parameters were developed, EGEM was run for each cell for a series of rainfall amounts from one to seven inches. A power curve was then fitted through the single storm output points, and the coefficients and exponents were used as input for the AnnAGNPS gully erosion routine. Calibration of the AnnAGNPS model erosion was accomplished through a comparison with the stream gauge data at Fort Jennings (located at the outlet of the Upper Auglaize Watershed.) This calibration corrects for some inadequacies in the modeling process. For instance, some gully erosion could have been missed due to the 20-meter DEM not picking up shorter, smaller slopes. Similarly, only the main drainage of each cell was considered for gully erosion. In other words, if a cell contained a branched gully, the branches were not picked up by the method used since only the length of the main drainage in each cell was determined and used as input to EGEM.

Three types of tillage (conventional, no-till, and “other”, all as provided for by EGEM) were used for each cell to calculate the gully erosion expected under different management scenarios. Tillage for each cell was assigned randomly on a statistical basis to match the proportions determined from the tillage transect data. This same assignment was used for both existing-condition gully erosion and sheet and rill erosion. For alternatives considered, again gullies were given the same tillage as assigned to each cell for the sheet and rill input data. Table A2-2 shows the number of cells having ephemeral gully erosion out of the total 1833 cells in the watershed model. Only cropland cells were considered for gully erosion.

Table A2-2. Number of cells with ephemeral gully erosion

Condition	# of cells per soils and topography	# of Cropland Cells
All cropland cells conventionally tilled	1,129	983
All cropland cells “other” (mulch) tilled	990	843
All cropland cells no-tilled	562	472

Average watershed erosion and sediment yield attributable to ephemeral gullies for various cropland alternatives are given in Table A2-3. Note that the Existing Conditions Scenario B served as the base model to which modifications were made for the development of Scenarios C through K.

Table A2-3. Average ephemeral gully erosion for the watershed under various scenarios

Scenarios		Gully Tons/ac/yr		Reduction[1/] from Existing Conditions Scenario B (%)	
		Erosion	Sediment Yield	Erosion	Sediment Yield
A	All convencional tillage (alt. 17)	3.242	1.297	-83.0	-82.9
B	Existing conditions (alt. 9)	1.772	0.709	0	0
C	12.1% of highest rate cells converted to no-till (alt. 10)	1.166	0.466	34.2	34.3
D	17.4% cropland, chosen randomly, converted to no-till, additionally 7.6% converted to grass (alt. 16)	1.404	0.562	20.8	20.7
E	7.9% of highest slope cells converted to grass (alt. 13)	1.213	0.485	31.5	31.6
F	25.7% of highest rate cells converted to no-till (alt. 11)	0.816	0.326	53.9	54.0
G	39.5% of highest rate cells converted to no-till (alt. 12)	0.739	0.296	58.3	58.2
H	17.4% of highest slope cells converted to grass (alt. 14)	0.773	0.309	56.4	56.4
I	All cropland converted to no-till (alt. 18)	0.562	0.225	68.3	68.3
J	27.1% of highest slope cells converted to grass (alt. 15)	0.495	0.198	72.1	72.1
K	All cropland converted to trees (alt. 19)	0.000	0.000	100	100

[1/] A minus sign indicates an increase.

Appendix A3. 2D-RUSLE2

Following is a description of the RUSLE2 Grid Alternative for predicting ephemeral gully erosion, by Dr. Seth Dabney, USDA-ARS National Sedimentation Laboratory, Oxford, MS.

Goal and Time Line.

We propose a 2-D field-scale conservation planning tool that couples existing RUSLE2 technology with increasingly available LIDAR topographic data. Unlike the current “representative hillslope profile” approaches, this approach will explicitly identify the locations of the highest erosion areas within a field or soil polygon.

The tool will correctly determine slope length and steepness for RUSLE2 erosion computations, thus eliminating one of the greatest uncertainties and training requirements of using RUSLE2.
The tool will reproduce current RUSLE2 results for fields without flow convergence or divergence, but will also allow RUSLE2 to handle those special situations.

The tool will need no additional data, other than detailed topography, than is currently available within RUSLE2 databases, and will require only minor modifications to RUSLE2.

Interface tools are needed to clean up DEMs, identify sinks and potholes, delineate channel networks, and delineate management zones. Agren, Inc. is working on the development of these interface tools.

The tool could provide the framework for future refinements such as calculation of tillage erosion and ephemeral gully erosion.

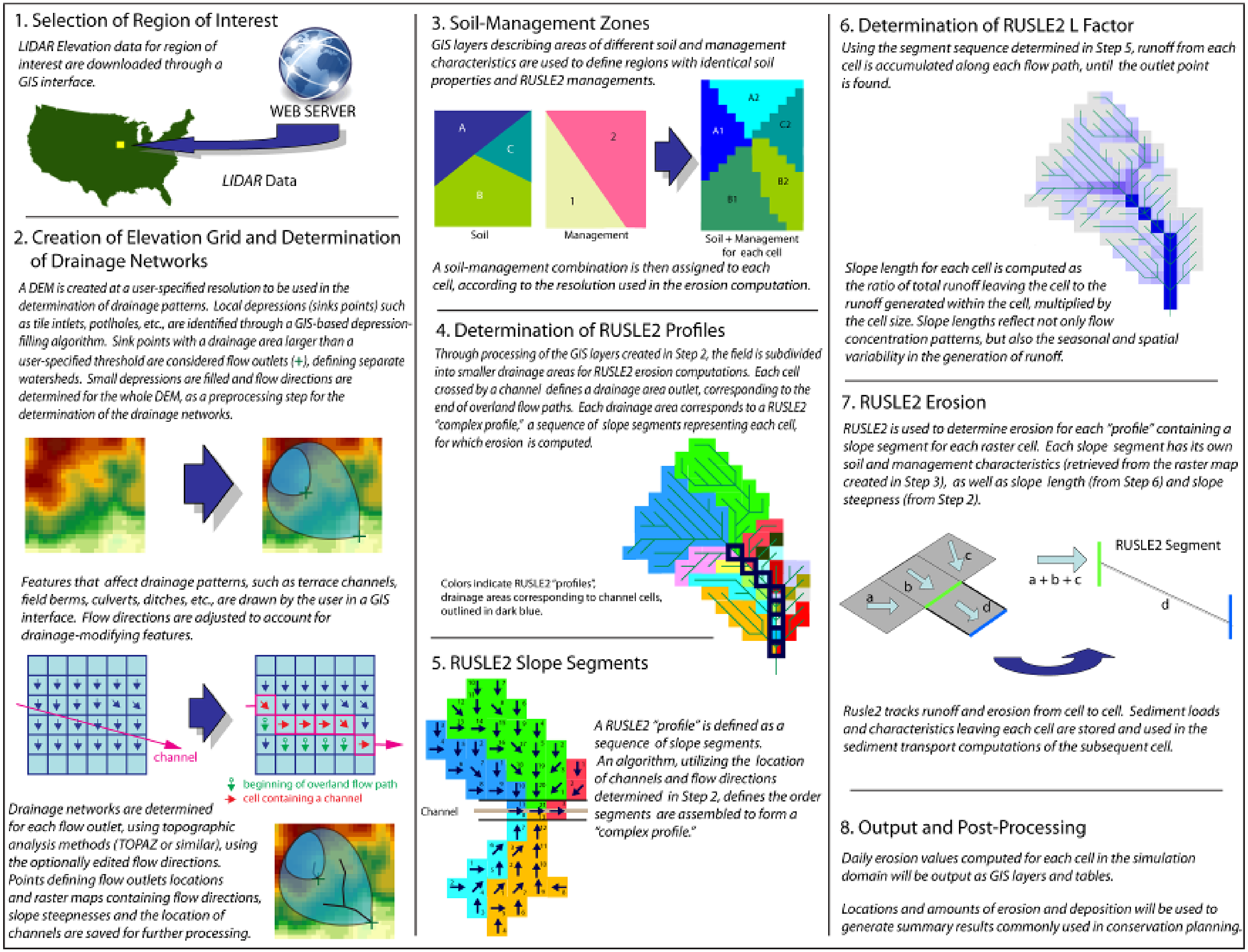
Approach

We envision development of a web-based application that would access the NRCS Web Soil Survey and LIDAR gateways such as http://geotree2.geog.uni.edu/lidar/ which is currently being populated with data for the state of Iowa. At the recent SWCS meeting held in Tucson, AZ, presentations indicated that at least 16 states were currently in various stages of acquiring and making publically available LIDAR-based topographic information.

We propose the development of GIS-based tools for identifying and delineating management features and flow paths and a shell program that will manage erosion computations, utilizing RUSLE2 (with modifications) and its database. The user would follow these steps (Figure A3-1):

Step 1. In a GIS-based interface, select a region of interest from graphical display and the underlying LIDAR data would be obtained.

Step 2. Use a GIS interface with high-resolution data to delineate local sinks (pot holes, tile outlets, culverts) and then determine flow paths with tools such as Topaz, TauDEM, or Tapes-G. By identifying local sinks, excessive filling of pot holes and behind terraces can be avoided. An output of this process will be a raster network of flow vectors within the region of interest. The GIS interface will provide tools for LIDAR data clean-up and to allow the user to draw lines representing features that modify flow patterns. Flow channels will be determined based on flow accumulation criteria. These channels will represent the end of RUSLE2 hillslopes.



1. Selection of Region of Interest

LIDAR Elevation data for region of interest are downloaded through a GIS interface.

2. Creation of Elevation Grid and Determination of Drainage Networks

A DEM is created at a user-specified resolution to be used in the determination of drainage patterns. Local depressions (sinks points) such as tile intlets, potlholes, etc., are identified through a GIS-based depression-filling algorithm. Sink points with a drainage area larger than a user-specified threshold are considered flow outlets (+), defining separate watersheds. Small depressions are filled and flow directions are determined for the whole DEM, as a preprocessing step for the determination of the drainage networks.

Features that affect drainage patterns, such as terrace channels, field berms, culverts, ditches, etc., are drawn by the user in a GIS interface. Flow directions are adjusted to account for drainage-modifying features.

Drainage networks are determined for each flow outlet, using topographic analysis methods (TOPAZ or similar), using the optionally edited flow directions. Points defining flow outlets locations and raster maps containing flow directions, slope steepnesses and the location of channels are saved for further processing.

3. Soil-Management Zones

GIS layers describing areas of different soil and management characteristics are used to define regions with identical soil properties and RUSLE2 managements.

A soil-management combination is then assigned to each cell, according to the resolution used in the erosion computation.

4. Determination of RUSLE2 Profiles

Through processing of the GIS layers created in Step 2, the field is subdivided into smaller drainage areas for RUSLE2 erosion computations. Each cell crossed by a channel defines a drainage area outlet, corresponding to the end of overland flow paths. Each drainage area corresponds to a RUSLE2 "complex profile," a sequence of slope segments representing each cell, for which erosion is computed.

Colors indicate RUSLE2 "profiles", drainage areas corresponding to channel cells, outlined in dark blue.

5. RUSLE2 Slope Segments

A RUSLE2 "profile" is defined as a sequence of slope segments. An algorithm, utilizing the location of channels and flow directions determined in Step 2, defines the order segments are assembled to form a "complex profile."

6. Determination of RUSLE2 L Factor

Using the segment sequence determined in Step 5, runoff from each cell is accumulated along each flow path, until the outlet point is found.

Slope length for each cell is computed as the ratio of total runoff leaving the cell to the runoff generated within the cell, multiplied by the cell size. Slope lengths reflect not only flow concentration patterns, but also the seasonal and spatial variability in the generation of runoff.

7. RUSLE2 Erosion

RUSLE2 is used to determine erosion for each "profile" containing a slope segment for each raster cell. Each slope segment has its own soil and management characteristics (retrieved from the raster map created in Step 3), as well as slope length (from Step 6) and slope steepness (from Step 2).

Rusle2 tracks runoff and erosion from cell to cell. Sediment loads and characteristics leaving each cell are stored and used in the sediment transport computations of the subsequent cell.

8. Output and Post-Processing

Daily erosion values computed for each cell in the simulation domain will be output as GIS layers and tables.

Locations and amounts of erosion and deposition will be used to generate summary results commonly used in conservation planning.

Figure A3-1. Operational steps for the 2D field-scale conservation tool.

Step 3. Intersect the final topographic grid with GIS polygons that identify (a) RUSLE2 soil type and (b) RUSLE2 managements so that each cell has a defined combination of soil and management. The result will be a small number of zones with unique combinations of soil type and management that will be used in the computation of RUSLE2 factors.

Step 4. Determine the RUSLE2 profiles based on the intersection of flow paths with channels determined in step 2. There will be one profile for each channel cell and each profile may extend upslope from both sides of the channel.

Step 5. Each profile will consist of a sequence of slope segments. Starting with cells that receive no runoff from upslope, flow is tracked following the directions determined in step 2 and cell-to-cell connectivity.

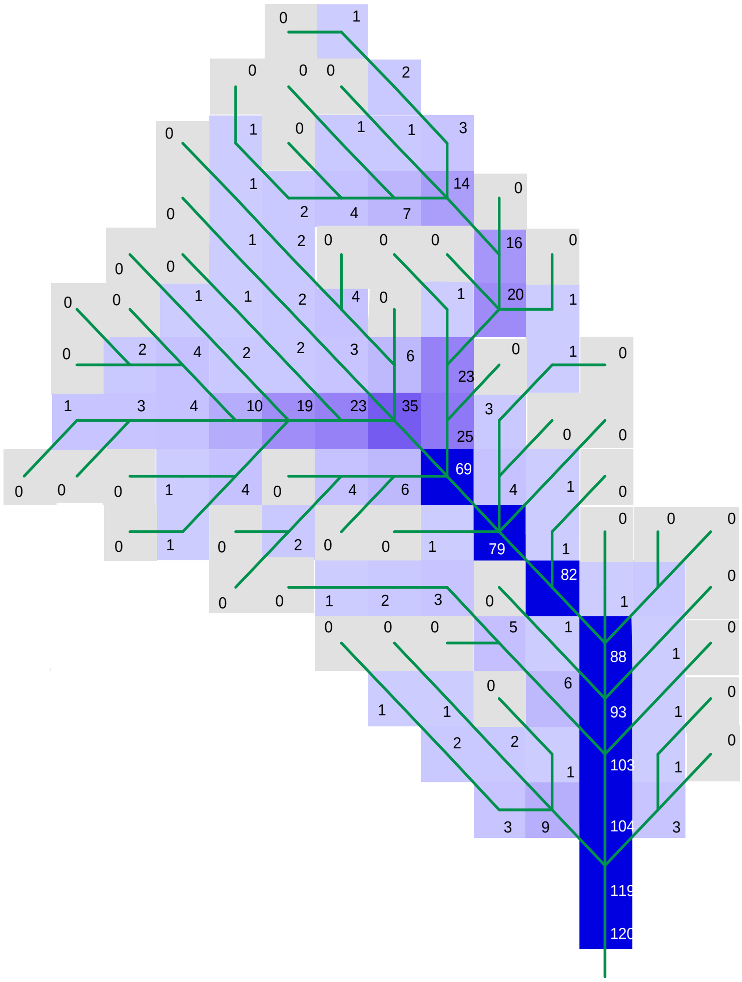


Figure A3-2. Accumulated runoff will be used to determine each cell "L" as the product of cell size and the ratio of runoff leaving the cell to runoff generated inside the cell. If soil and management are the same in every cell so that runoff per cell is everywhere equal to r, the runoff leaving any cell will be (n+1)*r (n is the number of upslope contributing cells illustrated in the figure) and L = (cell size)*(n+1).

Step 6. The equivalent slope length for each cell will be determined by multiplying the grid cell size by the ratio of total runoff leaving the cell to the runoff generated within the cell. If the cell receives no runoff from any other cell, this ratio will equal one and the slope length will be equal to the cell size. If it receives runoff from upslope, an appropriate L factor will be determined that correctly accounts for variation in upslope soil type, upslope management, and topographic convergence/divergence on slope length. Figure A3-2 shows the process of runoff accumulation. This is the key step. If the slope is uniform, this procedure will return the same L factor that RUSLE2 currently calculates. RUSLE2 uses the 10-year storm runoff amount to determine transport capacity and sediment deposition. We propose to also use it also to determine effective slope length.

Step 7. A shell program will call a modified version of RUSLE2 to determine erosion for each cell. The shell program will pass RUSLE2 the particular hierarchy of segments for each profile, including the cell size, steepness, soil, and management. The modified version of RUSLE2 will then compute erosion using standard RUSLE2 procedures, starting from the top of the domain, and will track the runoff and sediment transport from cell to cell following the flow path sequence specified. The key purpose of the shell program is to keep track of the information required by RUSLE2 on a geospatial basis and to set up each profile for RUSLE2 processing. RUSLE2 currently operates on the basis of a profile divided into linear segments, but the science allows just as well for treating things on a cell basis, if a program outside of RUSLE can keep track of the inputs and hierarchy of each cell. RUSLE2 will then treat each cell as an ordinary uniform hillslope segment and compute sheet and rill erosion (or interrill erosion and sediment deposition if transport capacity is exceeded). RUSLE2 will use the local slope steepness and slope length to determine the P factors for ponding, contouring, and buffers. RUSLE2 will return the amounts of erosion, deposition, and sediment load and characteristics leaving the cell.

Step 8. Outputs. The shell program will write output to a GIS layer to display a distributed erosion map and will write summary results to specified text, PDF, or spreadsheet formats. These summary results could include average soil loss (for P-index and national reporting), and the highest 10% loss on soils making up 10% of the field (for conservation planning).

Coding Requirements

The above procedures require re-coding of RUSLE2 to allow external input of hillslope segment hierarchy.

A GIS interface program will need to be developed to obtain soil and LIDAR data, add flow path connectivity (clean LIDAR, if needed), and define RUSLE2 management zones.

The shell program will need to be developed to interface with RUSLE2 to generate profiles and format outputs.

Anticipated Future Enhancements

Tillage erosion could be calculated (and distributed tillage erosion outputs prepared) if the GIS interface allowed the user to specify the directions of tillage operations within the fields.

Ephemeral gully erosion could be determined using procedures outlined by Dabney et al., (2008) by linking the runoff and sediment yield delivered to the channel network in step 8 with a channel erosion model. The development of the flow network in step 2 would provide the information needed to describe the slope and steepness of ephemeral gully segments.

The run-time of the 2D-RUSLE2 could be reduced by computing erosion from a sequence of (10 to 30) events distributed throughout the year using procedures described by Dabney et al. (2008) rather than doing RUSLE2 erosion and sediment transport calculations for every day of the year. This has only minor effects on computed sheet and rill erosion and makes it possible to directly couple the 2D model with an ephemeral gully model.

The run-time of the 2D-RUSLE2 could be further reduced if RUSLE2 were optimized for batch processing.

Reference

Dabney, S.M., D.C. Yoder, and D.A.N. Vieira. 2008. Predicting ephemeral gully erosion with RUSLE2. In Proceedings, The National Sedimentation Laboratory: 50 Years of Soil and Water Research in a Changing Agricultural Environment. 3-5 September, Oxford, MS.

Appendix A4. Literature Review Bibliography

Review Concepts

In trying to organize the abstracts into manageable groups, the following categories were set up to classify the work presented by each abstract. Of interest to CEAP managers, researchers, model developers, and field personnel are:

Category	Description	Number of Abstracts
1	Magnitude of the ephemeral gully erosion problem around the world, impacts of ephemeral gully erosion in watersheds, ephemeral gully erosion as affected by land use, and reporting the amount of ephemeral gully erosion.	81
2	Compare amount of ephemeral gully erosion to sheet and rill erosion.	12
3	Techniques to measure ephemeral gully erosion in fields.	37
4	Simplified modeling techniques.	19
5	Complex modeling techniques and theoretical research.	163
6	Treatment and prevention techniques.	59

Some abstracts cross over into several categories. Although each abstract was brief, information was generally sufficient to place it in the appropriate category. Some abstracts were not placed in any category (these did not directly relate to any of the 6 category topics).

Because identifying the degree of ephemeral gully erosion problems and amounts of ephemeral gully erosion around the world is very important, the 81 abstracts included in category 1 above were read in more detail, and certain characteristics of these studies were recorded. If any of these issues need to be investigated more, the abstract number in the list of 403 is included in Sub-Appendix A4-1. These abstracts describe specific problems and amounts of ephemeral gully erosion, sufficient to increase awareness of the critical situation in which much of the world's agricultural lands are being damaged and deteriorated.

Countries included in abstracts:

North America	United States
South America	Ecuador, Brazil
Europe	Poland, France, Spain, Russia, Belgium, Portugal, Hungary, Scotland, Norway, Germany, Sweden, UK, Italy
Africa	Ethiopia, Tanzania, Sudan, Namibia, Kenya
Asia	China, Japan, Nepal, Singapore
Oceania	Australia

Based on the number of countries listed, ephemeral gully erosion is truly a recognized and researched world-wide problem.

Scale of studies:

Abstracts were classified as to whether they addressed large watersheds, small watersheds, or field-scale problems. 32 abstracts addressed ephemeral gully erosion at the field scale, relatively small drainage areas and ephemeral gully erosion networks. 24 abstracts addressed ephemeral gully erosion at the small watershed scale. These were at the farm, multi-field, or small stream scales. 25 abstracts addressed ephemeral gully erosion at the large watershed scale. Some of these addressed sediment yield impacts of ephemeral gully erosion.

Quantitative or qualitative evaluation of ephemeral gully erosion:

The majority of the abstracts (51) actually estimated a quantity of ephemeral gully erosion either in tons or volume. Abstracts reflect a variety of study approaches, measurement techniques, and reporting formats. 24 abstracts discuss a qualitative analysis of ephemeral gully erosion where the actual quantity was not estimated, but other ephemeral gully erosion characteristics were included, such as length, drainage network, description of formation processes, or growth over time,. Two abstracts included estimates of ephemeral gully erosion from models. Model verification and calibration were not described in the abstracts.

Magnitude of the ephemeral gully erosion problem:

34 abstracts indicate ephemeral gully erosion is a critical problem which significantly damages and deteriorates agricultural land in the study area. Several abstracts refer to long term degradation of agricultural land, even to the point of removing the land from production. However, based on the large number of abstracts and associated research focused on ephemeral gully erosion, a problem or potential problem was being investigated.

What is the definition of an ephemeral gully?

Nine abstracts (17, 21, 26, 49, 54, 55, 85, 104, 300) have a definition of an ephemeral gully implied but not specifically stated. The nine abstracts refer to measuring and comparing sheet and rill to ephemeral gully erosion amounts. The authors decided where the dividing point is. Perhaps by reading the entire article, the definition will become evident.

Another set of abstracts involve measurement techniques for field investigations. These address data collection and analysis in lieu of mathematical and physical process modeling. These abstract index numbers are listed in Sub-Appendix A4-2. The methods most used to measure ephemeral gully erosion are field measurements and from photogrammetry. Other techniques include topographic analysis (DEM), photographs, airborne laser, relating size of ephemeral gullies to measured rainfall-runoff data, GPS, and fingerprinting erosion and sedimentation processes with isotopes of cesium and lead.

Modeling Approaches

Though the vast majority of the abstracts are qualitative and descriptive, or measure actual amounts of ephemeral gully erosion, several include modeling approaches. Some are regression based, relating ephemeral gully erosion to watershed area, slope, etc. Others consider physically based concepts. Several abstracts that could be investigated further are number 72 (EUROSEM), 161, 246 (no model name provided), and 249 (LISEM). More may be learned from these to build a more comprehensive model, including greater definitions for inputs and outputs, assumptions and limitations, and their basic mathematical procedures.

Summary

Based on this cursory review of literature on ephemeral gully erosion, the magnitude of the problem around the world is evident. With much recent research on ephemeral gully erosion, it seems the technology is still in the development stage. Much more progress is needed and more cooperation between researchers. Each abstract showed individual uniqueness and approach. Several researchers, especially based in Belgium, have published significantly more than other research groups. A number of researchers in China have also done extensive research. The major factors related to ephemeral gully erosion seem to be so variable across the world that addressing ephemeral gully erosion from a physical modeling approach could have the most promise. Modeling or predicting ephemeral gully erosion processes is extremely complex, recognizing the world-wide variations in climate, soil types, farming practices, and topography.

Sub-Appendix A4-1. Index number for 81 abstracts included in category 1 above.
6, 9, 14, 17, 18, 19, 20, 21, 23, 25, 29, 30, 31, 34, 35, 37, 38, 44, 48, 49, 54, 55, 56, 61, 65, 75, 77, 79, 82, 83, 85, 90, 93, 94, 105, 108, 109, 110, 111, 122, 125, 132, 133, 138, 149, 150, 154, 155, 159, 160, 162, 170, 176, 177, 178, 180, 181, 184, 199, 204, 209, 221, 225, 256, 259, 294, 296, 298, 300, 307, 317, 328, 330, 338, 341, 343, 347, 350, 355, 356, 384.

Sub-Appendix A4-2. Index number for 37 abstracts included in category 3 above.
1, 3, 4, ,5, 12, 16, 18, 22, 23, 25, 40, 41, 43, 45, 69, 70, 106, 121, 123, 129, 134, 148, 219, 235, 236, 237, 238, 252, 264, 265, 266, 286, 343, 345, 355, 356, 365.

Ephemeral Gully Literature Review Reference List Associated by Abstract Number

1. Casali, J.; Loizu, J.; Campo, M. A.; De Santisteban, L. M., and Alvarez-Mozos, J. Accuracy of methods for field assessment of rill and ephemeral gully erosion. Catena: 2006 Oct; 67, (2): 128-138.
2. de Oliveira, M. A. Adhesion flow and regressive gully-head expansion in southern Brazil: field experiment results. Ascough, J C and Flanagan, D C. Soil erosion research for the 21st century Proceedings of the International Symposium, Honolulu, Hawaii, USA, 3 5 January, 2001. St Joseph, USA: American Society of Agricultural Engineers.: 2001: 603-606.
3. Ritchie, J. C.; Jackson, T. J.; Everitt, J. H.; Escobar, D. E., and Murphey, J. B. Airborne Laser: A Tool to Study Landscape Surface Features. Journal of Soil and Water Conservation: 1992 Jan-1992 Feb 28; 47, (1): 104-107.
4. Ritchie, Jerry C. and Jackson, Thomas J. Airborne laser measurements of the surface topography of simulated concentrated flow gullies. Transactions of the American Society of Agricultural Engineers: 1989; 32, (2): 645-648.
5. Jackson, T. J.; Ritchie, J. C.; White, J., and Leschack, L. Airborne laser profile data for measuring ephemeral gully erosion. Photogrammetric Engineering & Remote Sensing: 1988; 54, (8): 1181-1185.
6. Tamene, L.; Park, S. J.; Dikau, R., and Vlek, P. L. G. Analysis of factors determining sediment yield variability in the highlands of northern Ethiopia. Geomorphology: 2006; 76, (1-2): 76-91.
7. Lei TingWu; Zhang QingWen; Zhao Jun, and Nearing, M. A. Analytic method for determination of detachment rate of concentrated flow in erosion rills. Acta-Pedologica-Sinica: 2002; 39, (6): 788-793.
8. Zhang QingWen; Lei TingWu; Gao PeiLing, and Pan YingHua. An analytic method for determining transport capacity of concentrated flow in eroding rills. Scientia-Agricultura-Sinica: 2004; 37, (5): 699-703.
9. Zgobicki, W. Anthropogenic changes of the relief and morphological processes in agricultural loess areas (Roztocze Szczebrzeszynskie): Antropogeniczne przekszlcenia rzez by i proceso w rzez botwo rczych na terenach lessowych uzythkowanych rolniczo (Roztocze Szczebrzeszyn?skie). Annales Universitatis Mariae Curie-Sklodowska. Sectio B: 1998(53): 305-321.
10. Hanson, G. J. and Cook, K. R. Apparatus, test procedures, and analytical methods to measure soil erodibility in situ. Applied Engineering in Agriculture : 2004; 20, (4): 455-462.
11. Ionita, I. and Margineanu, R. M. Application of 137Cs for measuring soil erosion/deposition rates in Romania. Acta Geologica Hispanica: 2000; 35, (3-4): 311-319.
12. Blijenberg, H. M. Application of physical modelling of debris flow triggering to field conditions: Limitations posed by boundary conditions. Engineering Geology: 2007; 91, (1): 25-33.
13. Ionita, I. and Margineanu, R. M. Application of ¹³⁷Cs for measuring soil erosion/deposition rates in Romania. Acta Geologica Hispanica. 2000; 35(3-4):311-319. ISSN: 05677505.
14. Capra, A.; Mazzara, L. M., and Scicolone, B. Application of the EGEM model to predict ephemeral gully erosion in Sicily, Italy. Catena. 2005; 59(2):133-146. ISSN: 03418162 (ISSN).
15. Auzet, A. V. ; Boiffin, J.; Papy, F.; Maucorps, J., and Ouvry, J. F. An approach to the assessment of erosion forms and erosion risk on agricultural land in the Northern Paris Basin, France. Boardman, J; Foster, IDL, and Dearing, JA. Soil erosion on agricultural land Proceedings of a workshop sponsored by the British Geomorphological Research Group, Coventry, UK, January 1989. Chichester, UK: John Wiley & Sons

Ltd..: 1990: 383-400.

16. Badger, J. Are we counting all of the erosion? Soil and water conservation news: 1984 Jan; 4, (10): 5.
17. Barrett, Linda R and Lusch, David P. Assessing ephemeral gully erosion using airborne CIR videography. De Souza, Anthony R. Technical Program Abstracts - International Geographical Congress. 1992; 27, 36-37.
18. De Santisteban, L. M.; Casali, J., and Lopez, J. J. Assessing soil erosion rates in cultivated areas of Navarre (Spain). Earth surface processes and landforms: 2006; 31, (4): 487-506.
19. Belyaev, V. R.; Sidorchuk, A. Yu; Golosov, V. N.; Wallbrink, P. J., and Murray, A. S. Assessing the contribution of different processes to soil degradation within an arable catchment of the Stavropol Upland, Southern European Russia. Owens, P N and Collins, A J. Soil erosion and sediment redistribution in river catchments: measurement, modelling and management. Wallingford, UK: CABI.: 2006: 40-50.
20. Lyle Frees, L. Neel J. McVay K. Devlin D. Assessing Tillage Induced Ephemeral Gully Erosion in the Cheney Lake Watershed Using GIS, TIEGEM and the AnnAGNPS Model. Managing Agricultural Landscapes for Environmental Quality: Strengthening the Science Base. Ankeny, 2006.
21. Vandaele, K. Assessment of factors affecting ephemeral gully erosion in cultivated catchments of the Belgian Loam Belt. Farm land erosion in temperate plains environment and hills. Proc. symposium, Saint-Cloud, Paris, 1992: Wicherek S.1993: 125-136.
22. Vandaele, K.; Poesen, J.; Marques De Silva, J. R.; Govers, G., and Desmet, P. Assessment of factors controlling ephemeral gully erosion in Southern Portugal and Central Belgium using aerial photographs. Zeitschrift fur Geomorphologie: 1997; 41, (3): 273-287.
23. Hu, W.; Liu, J.; Cai, Q., and Gao, Z. Assessment of gully erosion in a semi-arid catchment of the Loess Plateau, China using photogrammetric techniques. Gao W. and Shaw D.R. Remote Sensing and Modeling of Ecosystems for Sustainability II. San Diego, CA: 2005; 5884, 1-9.
24. Daba, S.; Rieger, W., and Strauss, P. Assessment of gully erosion in eastern Ethiopia using photogrammetric techniques. Catena: 2003; 50, (2-4): 273-291.
25. Hughes, T. H.; Dillion, A. C.; White, J.; Drummond, S., and Hooks, W. G. Assessment of Practicality of Remote Sensing Techniques for A Study of the Effects of Strip Mining in Alabama. NASA; 1975.
26. Nachtergaele, J. and Poesen, J. Assessment of soil losses by ephemeral gully erosion using high-altitude (stereo) aerial photographs. Earth Surface Processes and Landforms: 1999; 24, (8): 693-706.
27. Govers, G. and Poesen, J. Assessment of the interrill and rill contributions to total soil loss from an upland field plot. Geomorphology: 1988; 1, (4): 343-354.
28. Zhu, Jingcai . Bed scour and head cut processes of concentrated flow erosion. University of Missouri at Columbia, Columbia, MO; 1992.
29. Hunt, S. L.; Hanson, G. J.; Cook, K. R., and Kadavy, K. C. Breach widening observations from earthen embankment tests. Transactions of the American Society of Agricultural Engineers: 2005; 48, (3): 1115-1120.
30. Schmidtchen, G.; Bork, H.-R., and Dotterweich, M. A case of severe gully erosion in Eastern Brandenburg (Germany): Junge Erosionskatastrophen in Ostbrandenburg. Petermanns Geographische Mitteilungen: 2001; 145, (6): 74-82.
31. Heede, B. H. Case Study of a Watershed Rehabilitation Project: Alkali Creek, Colorado. Research paper rm-189, tempe, arizona, june 1977. 18 p, 2 fig, 13 illus, 16 ref, 7 tab.: 1977.
32. Leopold, Luna B; Emmett, William W, and Myrick, Robert M. Channel and hillslope processes in a semiarid area, New Mexico. U. S. Geological Survey Professional Paper, Report: P 0352-G, pp.193-253: 1966.
33. Peterson, J. R.; Flanagan, D. C., and Robinson, K. M. Channel Evolution and Erosion in PAM-treated and Untreated Experimental Waterways. Transactions of the American Society of Agricultural Engineers: 2003; 46, (4): 1023-1031.
34. Torri, D.; Poesen, J.; Borselli, L., and Knapen, A. Channel width-flow discharge relationships for rills and gullies. Geomorphology: 2006; 76, (3-4): 273-279.
35. Vanwalleghem, T.; Van Den Eeckhaut, M.; Poesen, J.; Deckers, J.; Nachtergaele, J.; Van Oost, K., and Slenters, C. Characteristics and controlling factors of old gullies under forest in a temperate humid climate: A case study from the Meerdaal Forest (Central Belgium). Geomorphology: 2003; 56, (1-2): 15-29.

36. Bennett, S. J.; Casali, J.; Robinson, K. M., and Kadavy, K. C. Characteristics of actively eroding ephemeral gullies in an experimental channel. Transactions of the American Society of Agricultural Engineers: 2000; 43, (3): 641-649.

37. Beliaev, V. R. Characteristics of gully formation at the different natural settings. Geomorfologiya: 2002(2): 105-110.

38. Wang, X.; Xu, S.; Li, D., and Wang, D. Characteristics of runoff and sediment yield in gullied-hilly loess areas and soil conservation measures. Qinghua Daxue Xuebao/Journal of Tsinghua University: 2001; 41, (8): 107-109.

39. Bell, D. H.; Glassey, P. J., and Yetton, M. D. Chemical stabilisation of dispersive loessial soils, Banks Peninsula, Canterbury, New Zealand. Proc. 5th International Association of Engineering Geology congress, 1986. Vol. 4: Rimoldi H.V.Balkema; 1990: 2193-2208.

40. Ritchie, J. C. Combining 137Cs and topographic surveys for measuring soil erosion/deposition patterns in a rapidly accreting area. Acta Geologica Hispanica: 2000; 35, (3-4): 207-212.

41. Ritchie, J. C. Comparing erosion and redeposition rates and patterns upslope of a grass hedge determined using 137Cesium and field survey techniques. Stott, D. E.; Mohtar, R. H., and Steinhardt, G. C. Sustaining the global farm: Selected papers from the 10th International Soil Conservation Organization meeting. Purdue University and USDA-ARS National Soil Erosion Research Laboratory; 2000: 1039-1043.

42. Zhu, J. C.; Gantzer, C. J.; Anderson, S. H.; Peyton, R. L. , and Alberts, E. E. Comparison of Concentrated-Flow Detachment Equations for Low Shear Stress. Soil & Tillage Research: 2001 Sep; 61, (3-4): 203-212.

43. Watson, A. and Evans, R. A comparison of estimates of soil erosion made in the field and from photographs. Soil and Tillage Research: 1991; 19, (1): 17-27.

44. Ghidey, F.; Alberts, E. E., and Kramer, L. A. Comparison of measured and WEPP predicted runoff and sediment loss from deep loess soils watershed. Ascough II, J C and Flanagan, D C. Soil erosion research for the 21st century Proceedings of the International Symposium, Honolulu, Hawaii, USA, 3 5 January, 2001. St Joseph, USA: American Society of Agricultural Engineers.: 2001: 131-134.

45. Belyaev, V. R.; Wallbrink, P. J.; Golosov, V. N.; Murray, A. S., and Sidorchuk, A. Yu. A comparison of methods for evaluating soil redistribution in the severely eroded Stavropol region, southern European Russia. Geomorphology: 2005; 65, (3-4): 173-193.

46. Desmet, P. J. J. and Covers, G. Comparison of routing algorithms for digital elevation models and their implications for predicting ephemeral gullies. International Journal of Geographical Information Systems: 1996; 10, (3): 311-331.

47. Rivenbark, B. L. and Jackson, C. R. Concentrated flow breakthroughs moving through silvicultural streamside management zones: Southeastern Piedmont, USA. Journal of the American Water Resources Association: 2004; 40, (4): 1043-1052.

48. Auzet, A. V.; Boiffin, J., and Ludwig, B. Concentrated flow erosion in cultivated catchments: influence of soil surface state. Earth Surface Processes & Landforms: 1995; 20, (8): 759-767.

49. Spomer, R. G. and Hjelmfelt, A. T. Concentrated Flow Erosion on Conventional and Conservation Tilled Watersheds. Transactions of the ASAE: 1986; 29, (1): 124-127, 134.

50. Poesen, J.; De Luna, E.; Franca, A.; Nachtergaele, J., and Govers, G. Concentrated flow erosion rates as affected by rock fragment cover and initial soil moisture content. Catena: 1999; 36, (4): 315-329.

51. Lane, L. J. and Foster, G. R. Concentrated Flow Relationships. Knisel, W. G. Creams: A field-scale model for chemicals, runoff, and erosion from agricultural management systems. 1980.

52. Poesen, J. W. A. Conditions for gully formation in the Belgian loam belt and some ways to control them. Soil erosion protection measures in Europe. Proc. EC workshop. Freising, 1988: Schwertmann U.1991: 39-52.

53. Kramer, L. A. Conservation system effects on seasonal hydrology and sediment loss. ASAE/CSAE SCGR Annual International Meeting, Toronto, Ontario, Canada, 18 21 July, 1999: ASAE Paper No. 99-2039. St Joseph, USA: American Society of Agricultural Engineers (ASAE).: 1999: 15.

54. Reid, L. M. Construction of Sediment Budgets to Assess Erosion in Shinyanga Region, Tanzania. In: research needs and applications to reduce erosion and sedimentation in tropical steeplands. Iahs publication no.192. International association of hydrological sciences, washington, dc. 1990. P 105-114. 1 fig, 2 tab, 15 ref.: 1990.

55. Alstrom, K. and Akerman, A. B. Contemporary soil erosion rates on arable land in southern Sweden. Geografiska Annaler, Series A: 1992; 74 A, (2-3): 101-108.

56. Poesen, J. W.; Vandaele, K., and Van Wesemael, B. Contribution of gully erosion to sediment production on cultivated lands and rangelands. IAHS-AISH Publication: 1996; 236, 251-266.

57. Mathieu, R.; King, C., and Le Bissonnais, Y. Contribution of multi-temporal SPOT data to the mapping of a soil erosion index. The case of the loamy plateaux of northern France. Soil Technology: 1997; 10, (2): 99-110.

58. Shields Jr., F. D.; Dabney, S. M.; Langendoen, E. J., and Temple, D. M. Control of gully erosion using stiff grasses. International Journal of Sediment Research: 2005; 20, (4): 319-332.

59. Dabney, S. M.; Hayes, J. C., and Lemunyon, J. L. Controlling cropland sediment loss with vegetated filter strips and grass hedges. Soil and water conservation society, 7515 northeast ankeny rd, ankeny, ia 50021-9764 (usa). Pp. 36-37. 1995.

60. Storm, D. E.; Barfield, B. J., and Lewis, S. M. Correcting geometrical distortion from photographs for erosion control research. Applied Engineering in Agriculture: 1994; 10, (5): 663-668.

61. Duda, A. M. and Johnson, R. J. Cost-effective targeting of agricultural nonpoint-source pollution controls. Journal of Soil & Water Conservation: 1985; 40, (1): 108-111.

62. Tang, K.; Zhang, K., and Lei, A. Critical slope gradient for compulsory abandonment of farmland on the hilly Loess Plateau. Chinese Science Bulletin: 1998; 43, (5): 409-412.

63. Meyer, L. D.; Dabney, S. M.; Murphree, C. E.; Harmon, W. C., and Grissinger, E. H. Crop production systems to control erosion and reduce runoff. Paper, American Society of Agricultural Engineers. St Joseph, USA: American Society of Agricultural Engineers (ASAE): 1997: (972224): 19.

64. ---. Crop production systems to control erosion and reduce runoff from upland silty soils. Transactions of the American Society of Agricultural Engineers: 1999; 42, (6): 1645-1652.

65. Boardman, J. Current erosion on the South Downs: implication for the past. Bell, M and Boardman, J. Past and present soil erosion: archaeological and geographical perspectives. Oxford, UK: Oxbow Books Ltd..: 1992: 9-19.

66. Jia Ning-feng; Li Xu-lin; Chen Huan-wei; Duan Jian-nan; Li Bao-guo, and Guo Qing-xia. Database Construction for AnnAGNPS Model - Case Study of Zhuanyaogou Watershed in Hilly-gully Loess Plateau. Journal of agro-environment science: 2006 Apr 20; 25, (2): 436-441.

67. Dabney, S. M.; Meyer, L. D.; Harmon, W. C.; Alonso, C. V., and Foster, G. R. Depositional patterns of sediment trapped by grass hedges. Transactions of the American Society of Agricultural Engineers: 1995; 38, (6).

68. Shields Jr., F. D.; Smiley Jr., P. C., and Cooper, C. M. Design and management of edge-of-field water control structures for ecological benefits. Journal of Soil and Water Conservation: 2002; 57, (3): 151-157.

69. Bonta, J. V. and Pierson, F. B. Design, measurement, and sampling with drop-box weirs. Applied Engineering in Agriculture: 2003; 19, (6): 689-700.

70. Wallbrink, P. J.; Murray, A. S.; Olley, J. M., and Olive, L. J. Determining sources and transit times of suspended sediment in the Murrumbidgee River, New South Wales, Australia, using fallout 137Cs and 210Pb. Water Resources Research: 1998; 34, (4): 879-887.

71. Robinson, K. M. and Hanson, G. J. A deterministic headcut advance model. Transactions - American Society of Agricultural Engineers: 1994; 37, (5): 1437-1443.

72. Street, L. and Quinton, J. N. Development of an ephemeral gully erosion model: the role of undercutting in bank failure of small channels. Ascough II, J C and Flanagan, D C. Soil erosion research for the 21st century Proceedings of the International Symposium, Honolulu, Hawaii, USA, 3 5 January, 2001. St Joseph, USA: American Society of Agricultural Engineers.: 2001: 338-341.

73. Yadav, R. C. ; Murthy, J. S. R., and Bhushan, L. S. Development of hydrologically optimal land formation practice for gully erosion susceptible ustifluvent soil. Agricultural water management: 2003; 59, (2): 113-135.

74. Budnik, S V. The development of scarps in erosion rills on slopes. Eurasian Soil Science, vol.34, no.9, pp.1024-1028: 2001 Sep.

75. Jia, Y.-Y.; Zheng, F.-L., and Yang, Q.-K. Distributed water erosion prediction model for small watershed in loess plateau. Shuili Xuebao/Journal of Hydraulic Engineering: 2005; 36, (3): 328-332.

76. Campbell, M. D.; Shakesby, R. A., and Walsh, R. P. D. The distribution of weathering and erosion on an inselberg- pediment system in semi-arid Sudan. International geomorphology 1986. Proc. 1st conference. Vol. 2: Gardiner V.1987: 1249-1270.

77. Dardis, G. F. and Beckedahl, H. R. Drainage evolution in an ephemeral soil pipe-gully system, Transkei, southern Africa. Geomorphological studies in southern Africa: 16 fig. 3000 BR Rotterdam, Netherlands: A. A. Balkema.: 1988: 247-265.

78. Kinner, D. A. and Moody, J. A. Drainage networks after wildfire. International Journal of Sediment Research: 2005; 20, (3): 194-201.

79. Lai HunYeu; Cheng ChiChuan, and Chen YeongKuan. DTM applications in establishing GIS. Quarterly-Journal-of-the-Experimental-Forest-of-National-Taiwan-University: 1997; 11, (2): 15-54.

80. Sidorchouck, A. Yu. Dynamic model of gully erosion . Geomorfologiya: 1998(4): 28-38.

81. Chatterjea, K. Dynamics of fluvial and slope processes in the changing geomorphic environment of Singapore. Earth surface processes and landforms: 1994; 19, (7): 585-607.

82. Olofin, E. A. The dynamics of gully head recession in a savanna environment. Wallings, D. E. ; Yair, A., and Berkowicz, S. Erosion, Transport and Deposition Processes (Proceedings of the Jerusalem Workshop, March-April 1987). Wallingford, UK: IAHS; 1990.

83. Bennett, S J ; Alonso, C V; Prasad, S N; Romkens, M J, and Anonymous. Dynamics of head-cuts in upland concentrated flows. Eos, Transactions, American Geophysical Union, vol.77, no.46, Suppl., pp.253: 1996 Nov 12.

84. Nachtergaele, Jeroen; Poesen, Jean; Govers, Gerard, and Leuven, K. U. Eeen ruimtelijke en temporele analyse van de karakteristieken, het belang en de voorspelling van tijdelijke ravijnen: Ephemeral gullies a spatial and temporal analysis of their characteristics, importance and prediction. BELGEO: 2002(2): 159-182.

85. Boiffin, J.; Ouvry, J. F., and Papy, F. Effect of cropping systems on concentrated flow erosion. Consequences for soil protection measures . Scaife, A. Proceedings Congress of the European Society of Agronomy. Colmar, France: European Society of Agronomy: 1990: 5O 03.

86. Bennett, S. J. and Casali, J. Effect of initial step height on headcut development in upland concentrated flows. Water resources research: 2001 May; 37, (5): 1475-1484.

87. Hadda, M. S. and Sur, H. S. Effect of land modifying measures on erosion, nutrient, water storage and yield of pearl millet fodder. Journal-of-the-Indian-Society-of-Soil-Science: 1987; 35, (3): 480-486.

88. Grayson, R. B. and Moore, I. D. Effect of land-surface configuration on catchment hydrology. Overland-flow-:-hydraulics-and-erosion-mechanics. 1992: 147-175.

89. Kuhnle, R. A.; Bingner, R. L.; Foster, G. R., and Grissinger, E. H. Effect of land use changes on sediment transport in Goodwin Creek. Water Resources Research: 1996; 32, (10): 3189-3196.

90. Bradford, J M; Shainberg, I; Norton, L D, and United States Israel Binational Agricultural Research and Development Fund. Effect of soil properties and water quality on concentrated flow erosion (rills, ephermal gullies and pipes). 1996.

91. Zheng FenLi. Effect of vegetation changes on soil erosion on the Loess Plateau. Pedosphere: 2006; 16, (4): 420-427.

92. ZHENG, F.-L. Effect of Vegetation Changes on Soil Erosion on the Loess Plateau1 1 Project supported by the Chinese Academy of Sciences (No. KZCX3-SW-422) and the National Natural Science Foundation of China (Nos. 9032001 and 40335050). Pedosphere: 2006; 16, (4): 420-427.

93. Fu, B.; Qiu, Y.; Wang, J., and Chen, L. Effect simulations of land use change on the runoff and erosion for a gully catchment of the Loess Plateau, China. Acta Geographica Sinica: 2002; 57, (6): 717-722.

94. Zheng, F.-L. Effects of accelerated soil erosion on soil nutrient loss after deforestation on the Loess Plateau. Pedosphere: 2005; 15, (6): 707-715.

95. Ouvry, J.-F. Effects of agricultural practices on cultivated land susceptibility to concentrated flow erosion. Experience in Pays de Caux, France: Effet des techniques culturales sur la susceptibilite des terrains a l'erosion par ruissellement concentre. Experience du Pays de Caux (France). Cahiers - ORSTOM, Serie Pedologie: 1989; 25, (1-2): 157-169.

96. Gyssels, G.; Poesen, J.; Liu, G.; Van Dessel, W.; Knapen, A., and De Baets, S. Effects of cereal roots on detachment rates of single- and double-drilled topsoils during concentrated flow. European Journal of Soil

Science: 2006; 57, (3): 381-391.

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

98. Zheng, F.; He, X.; Gao, X.; Zhang, C.-E., and Tang, K. Effects of erosion patterns on nutrient loss following deforestation on the Loess Plateau of China. Agriculture, Ecosystems and Environment: 2005; 108, (1): 85-97.

99. Li Zhuo. The effects of forest in controlling gully erosion. Erosion, debris flows and environment in mountain regions. Proc. international symposium, Chengdu, 1992. IAHS; Publication, 209; 1992: 429-437.

100. De Baets, S.; Poesen, J.; Gyssels, G., and Knapen, A. Effects of grass roots on the erodibility of topsoils during concentrated flow. Geomorphology: 2006; 76, (1-2): 54-67.

101. Yu, J.; Lei, T.; Shainberg, I.; Mamedov, A. I., and Levy, G. J. Effects of wetting by spray on concentrated flow erosion and intake rate. Soil Science: 2006; 171, (12): 929-936.

102. Ouvry, J.-F. Effet des techniques culturales sur la susceptibilite des terrains a l'erosion par ruissellement concentre. Experience du Pays de Caux (France): Effects of agricultural practices on cultivated land susceptibility to concentrated flow erosion. Experience in Pays de Caux, France. Cahiers - ORSTOM, Serie Pedologie: 1989; 25, (1-2): 157-169.

103. Knapen, A. and Poesen, J. Enhancing the soil's erosion resistance during concentrated runoff by reducing tillage disturbance. Advances-in-Geoecology: 2006(39): 290-300.

104. Nachtergaele, Jeroen; Poesen, Jean, and Govers, Gerard. Ephemeral gullies; a spatial and temporal analysis of their characteristics, importance and prediction. BELGEO (Leuven), vol.2002, no.2, pp.159-181: de Dapper, Morgan; Ozer, Andre, and Govers, Gerard2002.

105. Nachtergaele, J.; Poesen, J.; Govers, G., and Leuven, K. U. Ephemeral gullies a spatial and temporal analysis of their characteristics, importance and prediction: Eeen ruimtelijke en temporele analyse van de karakteristieken, het belang en de voorspelling van tijdelijke ravijnen. BELGEO: 2002(2): 159-182.

106. Thorne, C. R.; Zevenbergen, L. W.; Grissinger, E. H., and Murphey, J. B. Ephemeral Gullies as Sources of Sediment. Proceedings of the fourth federal interagency sedimentation conference march 24-27, 1986, las vegas, nevada. Volume i, 1986. P 301-309, 6 fig, 10 ref.: 1986.

107. Jackson, T. J. and Ritchie, J. C. Ephemeral gully detection using an airborne laser. Paper,-American-Society-of-Agricultural-Engineers. 1987; 87-2575.

108. Laflen, J. M.; Watson, D. A., and Franti, T. G. Ephemeral Gully Erosion. Proceedings of the fourth federal interagency sedimentation conference march 24-27, 1986, las vegas, nevada. Volume i, 1986. P 3-29 to 3-37, 2 tab, 11 ref.: 1986.

109. Capra, A. and Scicolone, B. Ephemeral gully erosion in a wheat-cultivated area in Sicily (Italy). Biosystems Engineering: 2002; 83, (1): 119-126.

110. Valcarcel, M.; Taboada, M. a. T.; Paz, A., and Dafonte, J. Ephemeral gully erosion in northwestern Spain. Catena: 2003 Jan; 50, (2-4): 199-216.

111. Casali, J.; Lopez, J. J., and Giraldez, J. V. Ephemeral gully erosion in southern Navarra (Spain). Catena: 1999; 36, (1-2): 65-84.

112. Grissinger, Earl H; Murphy, Joseph B, and Ding Lianzhen (chairperson). Ephemeral gully erosion in the loess uplands, Goodwin Creek watershed, northern Mississippi, USA. Proceedings of the International Symposium on River Sedimentation. 1989; 4, 51-58.

113. Merkel, W. H.; Woodward, D. E., and Clarke, C. D. Ephemeral gully erosion model (EGEM). Modeling agricultural forest and rangeland hydrology proceedings of the 1988 International Symposium December 12 13 1988 Hyatt Regency Chicago in Illinois Center Chicago Illinois. ASAE Publication, American Society of Agricultural Engineers: 3 fig., 2 tab.; 1988; 07-88, 315-323.

114. Woodward, Donald E; Clarke, C D, and Merkel, William. Ephemeral gully erosion model (EGEM). Fan, Shou-Shan and Kuo, Yung-Huang. Proceedings - Federal Inter-Agency Sedimentation Conference. 1991; 5, PS.9-PS.17.

115. Woodward, Donald E and Gylsson, G Douglas chairperson. Ephemeral gully erosion model (EGEM), next step. Proceedings - Federal Interagency Sedimentation Conference. 2001; 7/2, V23.

116. Torri, D. and Borselli, L. Equation for high-rate gully erosion. Catena: 2003; 50, (2-4): 449-467.

117. Eimberck, M. Erodibility factors for loamy soils: reflexion about the case of Pays de Caux: Facteurs d'erodibilite des sols limoneux: reflexions a partir du cas du Pays de Caux. Cahiers - ORSTOM, Serie Pedologie: 1989; 25, (1-2): 81-94.

118. Foster, G. R. Erosion and Sediment Transport Processes for Agricultural Watersheds. Agricultural nonpoint source pollution: model selection and application. Developments in environmental modeling 10, elsevier, New York. 1986. P 111-122, 29 ref.: 1986.

119. Kirkby, M. J. Erosion by water on hillslopes. Introduction to fluvial processes. London: Methuen; 1971: 98-107.

120. Ranieri, S. B. L.; De Jong Van Lier, Q.; Sparovek, G., and Flanagan, D. C. Erosion database interface (EDI): A computer program for georeferenced application of erosion prediction models. Computers and Geosciences: 2002; 28, (5): 661-668.

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

122. Sneddon, J.; Williams, B. G.; Savage, J. V., and Newman, C. T. Erosion of a gully in duplex soils. Results of a long-term photogrammetric monitoring program. Australian Journal of Soil Research: 1988; 26, (2): 401-408.

123. Brunotte, E. and Sander, H. Erosion of loess-like sediments in northern Namibia (basin of Opuwo) triggered by gullying and the formation of micropediments: Bodenerosion in lossartigen Sedimenten Nordnamibias (Becken von Opuwo) hervorgerufen durch Gullybildung und Mikropedimentation. Zeitschrift fur Geomorphologie: 2000; 44, (2): 249-267.

124. Quine, T. A.; Govers, G.; Walling, D. E.; Zhang, X.; Desmet, P. J. J.; Zhang, Y., and Vandaele, K. Erosion processes and landform evolution on agricultural land - New perspectives from caesium-137 measurements and topographic-based erosion modelling. Earth Surface Processes and Landforms: 1997; 22, (9): 799-816.

125. Dabney, S. M.; Shields Jr., F. D.; Temple, D. M., and Langendoen, E. J. Erosion processes in gullies modified by establishing grass hedges. Transactions of the American Society of Agricultural Engineers: 2004; 47, (5): 1561-1571.

126. Mathys, N; Brochot, S; Meunier, M, and Richard, D. Erosion quantification in the small marly experimental catchments of Draix (Alpes de Haute Provence, France); calibration of the ETC rainfall-runoff-erosion model. Catena (Giessen), vol.50, no.2-4, pp.527-548: Poesen, Jean and Valentin, Christian2003 Jan 1.

127. Watson, D. A.; Laflen, J. M., and Franti, T. G. Estimating ephemeral gully erosion. Papers Presented at the 1986 Summer Meeting, American Society of Agricultural Engineers. San Luis Obispo, CA, USA: 1986.

128. Hessel, R.; Jetten, V., and Guanghui, Z. Estimating Manning's n for steep slopes. Catena: 2003; 54, (1-2): 77-91.

129. Foster, G. R. and Lane, L. J. Estimating Sediment Yield from Rangeland with CREAMS. Proceedings of the workshop on estimating erosion and sediment yield on rangelands, tucson, arizona march 7-9, 1981, agricultural reviews and manuals arm-w-26, june 1982, p 115-119, 14 ref.: 1982.

130. Li, Y; Poesen, J; Yang, JC; Fu, B, and Zhang, JH. Evaluating gully erosion using 137Cs and 210Pb. Soil and tillage research: 2003 Feb; 69, (1-2): 107-115.

131. Ghebreiyessus, Yemane Tedla. Evaluation of concentrated flow erosion and hydraulic shear stress relationships. University of Missouri at Columbia, Columbia, MO; 1990.

132. Ghebreiyessus, Y T; Gantzer, C J, and Alberts, E E. Evaluation of concentrated flow erosion vs. shear stress relationships. Agronomy Abstracts, vol.81, pp.280, Oct 1989: Runge, Edward C. A.1989.

133. Huang, M.; Gallichand, J.; Dang, T., and Shao, M. An evaluation of EPIC soil water and yield components in the gully region of Loess Plateau, China. Journal of Agricultural Science: 2006; 144, (4): 339-348.

134. de Santisteban, L. M.; Casali, J., and Lopez, J. J. Evaluation of rill and ephemeral gully erosion in cultivated areas of Navarre (Spain). International Journal of Sediment Research: 2005; 20, (3): 270-280.

135. Casali, J.; de Santisteban, L. M.; Lopez, J. J.; Giraldez, J. V.; Poesen, J.; Nachtergaele, J.; Goni, M.; Loizu, J., and Campo, M. A. Evaluation of topographic indices for ephemeral-gully erosion assessment. International Journal of Sediment Research: 2005; 20, (4): 295-304.

136. Swanson, M. L.; Kondolf, G. M., and Boison, P. J. An example of rapid gully initiation and extension by subsurface erosion: coastal San Mateo County, California. Geomorphology: 1989; 2, (4): 393-403.

137. Bennett, Sean J and National Sedimentation Laboratory (U.S.). Channel & Watershed Processes Research Unit. An experimental study of headcut growth and development in upland concentrated flows. National Sedimentation Laboratory (U.S.). Channel & Watershed Processes Research Unit; 1999.

138. Stefanovic, J. R. and Bryan, R. B. Experimental study of rill bank collapse. Earth Surface Processes and Landforms: 2007; 32, (2): 180-196.

139. Huang, Y.-L.; Chen, L.-D.; Fu, B.-J., and Wang, Y.-L. Experimental study on ecological water use in a gully catchment of the loess plateau: Effects of climate and land use change. Shuikexue Jinzhan/Advances in Water Science: 2006; 17, (1): 14-19.

140. Bennett, S. J.; Alonso, C. V.; Prasad, S. N., and Romkens, M. J. M. Experiments on headcut growth and migration in concentrated flows typical of upland areas. Water Resources Research: 2000; 36, (7): 1911-1922.

141. De Santisteban, L. M.; Casali, J.; Lopez, J. J.; Giraldez, J. V.; Poesen, J., and Nachtergaele, J. Exploring the role of topography in small channel erosion. Earth Surface Processes and Landforms: 2005; 30, (5): 591-599.

142. Eimberck, M. Facteurs d'erodibilite des sols limoneux: reflexions a partir du cas du Pays de Caux: Erodibility factors for loamy soils: reflexion about the case of Pays de Caux. Cahiers - ORSTOM, Serie Pedologie: 1989; 25, (1-2): 81-94.

143. Bryan, R. B. and Wijdenes, D. O. Field and laboratory experiments on the evolution of microsteps and scour channels on low-angle slopes. Catena Supplement: 1992; 23, 1-29.

144. Ellis, T. W.; Hairsine, P. B., and Seaton, S. P. Field evaluation of a multi-class sediment net deposition model in contour channels. Transactions of the ASABE: 2006; 49, (5): 1341-1350.

145. Kreznor, W. R.; Olson, K. R., and Johnson, D. L. Field evaluation of methods to estimate soil erosion. Soil-Science: 1992; 153, (1): 69-81.

146. Baade, J. Field experiment on the reduction of sediment yield in agricultural drainage areas: Gelandeexperiment sur Verminderung des Schwebstoffaufkommens in landwirtschaftlichen Einzugsgebieten. Heidelberger Geographische Arbeiten: 1994; 95.

147. Wang Zhaoyin; Wai, Onyx W H, and Cui Peng. Field investigation into debris flow mechanism. International Journal of Sediment Research, vol.14, no.4, pp.10-22: 1999.

148. Garland, G. and Humphrey, B. Field measurements of discharge and sediment yield from a soil pipe in the Natal Drakensberg, South Africa. Zeitschrift fur Geomorphologie: 1992; 36, (1): 15-23.

149. Weaver, W.; Sonnevil, R., and Klein, R. Field Methods Used for Monitoring Erosion and Sedimentation Processes in Steeplands of Northwestern California, USA. In: erosion and sedimentation in the pacific rim. Iahs publication no. 165. International association of hydrological sciences, washington, dc. 1987. P 509-510.: 1987.

150. Thorne, Colin R.; Grissinger, Earl H., and Murphey, Joe B. Field study of ephemeral cropland gullies in northern Mississippi. 1984 Winter Meeting - American Society of Agricultural Engineers: Engineering the Future - Capitalizing on the New Technologies. New Orleans, LA, USA: 1984.

151. Williams, A. G.; Les Ternan, J.; Elmes, A.; Del Tanago, M. G., and Blanco, R. A field study of the influence of land management and soil properties on runoff and soil loss in central Spain. Environmental Monitoring and Assessment: 1995; 37, (1-3): 333-345.

152. Boardman, J.; Ligneau, L.; De Roo, A., and Vandaele, K. Flooding of property by runoff from agricultural land in northwestern Europe. Geomorphology: 1994; 10, (1-4): 183-196.

153. Gimenez, R. and Govers, G. Flow Detachment by Concentrated Flow on Smooth and Irregular Beds. Soil Science Society of America Journal: 2002 Sep-2002 Oct 31; 66, (5): 1475-1483.

154. Line, D. E. and Meyer, L. D. Flow velocities of concentrated runoff along cropland furrows. Transactions of the American Society of Agricultural Engineers: 1988; 31, (5): 1435-1439.

155. Li, Z. K. and Hosoyamada, K. Formation, distribution, and characteristics of shallow gullies: investigations in the Loess Plateau, China. Transactions-of-the-Japanese-Society-of-Irrigation,-Drainage-and-Reclamation-Engineering: 1994(173): 93-99.

156. Mccool, D. K. and Williams, J. D. Freeze/thaw effects on rill and gully erosion in the northwestern wheat and range region. International Journal of Sediment Research: 2005; 20, (3): 202-210.

157. Bathurst, J. C. and O'Connell, P. E. Future of distributed modelling: the System Hydrologique Europeen. Hydrological Processes: 1992; 6, (3): 265-277.

158. Baade, J. Gelandeexperiment sur Verminderung des Schwebstoffaufkommens in landwirtschaftlichen Einzugsgebieten: Field experiment on the reduction of sediment yield in agricultural drainage areas. Heidelberger Geographische Arbeiten: 1994; 95, 215.

159. Okon, P. B. and Babalola, O. General and spatial variability of soil under vetiver grass strips . Journal of Sutainable Agriculture: 2005; 27, (3): 93-116.

160. Ezechi, J. I. and Okagbue, C. O. A genetic classification of gullies in eastern Nigeria and its implications on control measures. Journal of African Earth Sciences: 1989; 9, (3-4): 711-718.

161. George, Heidi Wienert and Sidle, Roy C. Geomorphic and pedologic influence on small-scale ephemeral channel dimension in rangelands. Water Resources Bulletin, vol.31, no.6, pp.1051-1062: 1995 Dec.

162. Vandaele, K.; Poesen, J.; Govers, G., and Van Wesemael, B. Geomorphic threshold conditions for ephemeral gully incision. Geomorphology: 1996; 16, (2): 161-173.

163. Billi, P. and Dramis, F. Geomorphological investigation on gully erosion in the Rift Valley and the northern highlands of Ethiopia. Catena: 2003; 50, (2-4): 353-368.

164. Trzcinka, B. W.; Loughran, R. J., and Campbell, B. L. The geomorphology of a field tunnel system: a case study from Australia. Zeitschrift fur Geomorphologie: 1993; 37, (2): 237-247.

165. Blanco-Canqui, H.; Gantzer, C. J.; Anderson, S. H., and Alberts, E. E. Grass barriers for reduced concentrated flow induced soil and nutrient loss. Soil Science Society of America Journal: 2004; 68, (6): 1963-1972.

166. Kramer, L. A. and Alberts, E. E. Grass hedges for erosion control on a small HEL [highly erodible land] watershed. 2000 ASAE Annual International Meeting, Milwaukee, Wisconsin, USA, 9 12 July 2000: ASAE Paper No. 002082. St Joseph, USA: American Society of Agricultural Engineers: 2000: 1-18.

167. Kramer, L. A. and Alberts, E. E. Grass hedges for erosion control on a small hel watershed. 2000 ASAE Annual Intenational Meeting, Technical Papers: Engineering Solutions for a New Century.   Milwaukee, WI.: 2000; 2, 2341-2358. 2000 ASAE Annual International Meeting, Technical Papers: Engineering Solutions for a New Century.

168. Finkel, H. J. Gulley Control. Semiarid soil and water conservation, crc press, inc., Boca raton fl. 1986. P 103-108, 4 fig, 1 ref.: 1986.

169. Taylor, J. C. and Johnson, H. P. Gully bank erosion: Mechanics and simulation by digital computer. Iowa water resources research institute, ames, completion report iswrri-48, september, 1973. 163 p, 20 fig, 2 tab, 34 ref. Owrr a-034-ia(1). 1973.

170. Higgins, C. G.; Hill, B. R., and Lehre, A. K. Gully Development. Higgins, C. G. and Coates, D. R. Ground water geomorphology: the role of subsurface water in earth-surface processes and landforms. Boulder, CO: Geological Society of America; 1990; 252, 139-155.

171. Okagbue, C. O. Gully development and advance in a rain forest of Nigeria. Proc. 5th International Association of Engineering Geology congress, Buenos Aires, 1986. Vol. 3, (Balkema): 1986: 1999-2010.

172. Heede, B. H. Gully Development and Control: The Status of Our Knowledge. Usda for. Serv. Res. Pap. Rm-169 may 1976. 42 p, 36 fig, 81 ref.: 1976.

173. Piest, R. F. and Grissinger, E. H. Gully erosion. Conservation research report - United States, Department of Agriculture. 1980.

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

175. Poesen, J.; Vandaele, K., and Wesemael, B. van. Gully erosion: importance and model implications. Boardman, J and Favis Mortlock, D. Modelling soil erosion by water Proceedings of the NATO Advanced Research Workshop "Global change: modelling soil erosion by water", University of Oxford, Oxford, UK, 11 14 September, 1995: NATO ASI Series. Series I: Global Environmental Change Vol. 55. Berlin, Germany: Springer-Verlag.: 1998: 285-311.

176. Poesen, J. and Govers, G. Gully erosion in the loam belt of Belgium: Typology and control measures. Boardman, J; Foster, IDL, and Dearing, JA. Soil erosion on agricultural land Proceedings of a workshop sponsored by the British Geomorphological Research Group, Coventry, UK, January 1989. Chichester, UK: John Wiley & Sons Ltd..; 1990: 513-530.

177. Ghimire, S. K.; Higaki, D., and Bhattarai, T. P. Gully erosion in the Siwalik Hills, Nepal: Estimation of sediment production from active ephemeral gullies. Earth Surface Processes and Landforms: 2006; 31, (2): 155-165.
178. Gergely, J.; Adam, K., and Sandor, P. Gully erosion in the Tetves catchment: Az arkos erozio vizsgalata a Tetves-patak vizgyujtojen. Foldrajzi Ertesito: 2005; 54, (1-2): 149-165.
179. Lyubimov, B. P. Gully erosion in the valley of Ramenka River (The City of Moscow) in the past and nowadays. Geomorfologiya: 2003(2): 89-100.
180. Veretennikova, M. V. Gully erosion mechanism and dynamics of channel forms. Geomorfologiya: 1998(2): 66-75.
181. Bariss, N. Gully Formation In The Loesses Of Central Nebraska. Rocky Mountain Social Science Journal: 1971; 8, (2): 47-59.
182. Oostwoud Wijdenes, D. J.; Poesen, J.; Vandekerckhove, L.; Nachtergaele, J., and De Baerdemaeker, J. Gully-head morphology and implications for gully development on abandoned fields in a semi-arid environment, Sierra de Gata, southeast Spain. Earth Surface Processes and Landforms: 1999; 24, (7): 585-603.
183. Robinson, K. M. and Hanson, G. J. Gully headcut advance. Transactions of the American Society of Agricultural Engineers: 1996; 39, (1): 33-38.
184. Croke, J. and Mockler, S. Gully initiation and road-to-stream linkage in a forested catchment southeastern Australia. Earth Surface Processes and Landforms: 2001; 26, (2): 205-217.
185. Hancock, G. R. and Evans, K. G. Gully position, characteristics and geomorphic thresholds in an undisturbed catchment in northern Australia. Hydrological Processes: 2006; 20, (14): 2935-2951.
186. Abt, S. R.; Pauley, C. J.; Hogan, S. A., and Johnson, T. L. Gully potential in soil-covered uranium waste impoundments. Journal of Energy Engineering - ASCE: 1994; 120, (2): 51-66.
187. Bull, L. J. and Kirkby, M. J. Gully processes and modelling. Progress in Physical Geography: 1997; 21, (3): 354-374.
188. Blong, R. J. Gully sidewall development in New South Wales, Australia. Soil erosion and conservation: El-Swaify S.A.Soil Conservation Society of America; 1985: 574-584.
189. Poesen, J. Gully typology and gully control measures in the European loess belt. Farm land erosion in temperate plains environment and hills. Proc. symposium, Saint-Cloud, Paris, 1992: Wicherek S.1993: 221-239.
190. Pederson, J. L.; Petersen, P. A., and Dierker, J. L. Gullying and erosion control at archaeological sites in Grand Canyon, Arizona. Earth-Surface-Processes-and-Landforms: 2006; 31, (4): 507-525.
191. Veretennikova, M. V. Gylly erosion mechanism and dynamics of channel forms. Geomorfologiya: 1998(2): 66-75.
192. Temple, D. M. and Hanson, G. J. Headcut development in vegetated earth spillways. Applied Engineering in Agriculture: 1994; 10, (5): 677-682.
193. Robinson, K. M.; Bennett, S. J., and Casali, J. Headcut dynamics and ephemeral gully erosion. ASAE Annual International Meeting, Orlando, Florida, USA, 12 16 July, 1998: ASAE Paper no. 982125. St Joseph, USA: American Society of Agricultural Engineers (ASAE).: 1998: 14.
194. Kemper, D.; Dabney, S.; Kramer, L.; Dominick, D., and Keep, T. Hedging Against Erosion. Journal of soil and water conservation jswca3, vol. 47, no. 4, p 284-288, july/august 1992. 3 ref.: 1992.
195. Ionita, I. Hydraulic efficiency of the discontinuous gullies. Catena: 2003; 50, (2-4): 369-379.
196. Temple, Darrel; Dabney, Seth M, and Gylsson, G Douglas chairperson. Hydraulic performance testing of stiff grass hedges. Proceedings - Federal Interagency Sedimentation Conference, vol.7, Volume 2, pp.XI118-XI124: 2001.
197. Prasad, S. N. and Singh, V. P. Hydrodynamic Model of Sediment Transport in Rill Flows. Recent developments in the explanation and prediction of erosion and sediment yield iahs publication no. 137, 1982. Proceedings of a symposium at the first scientific general assembly of the iahs, july 19-30, 1982, exeter, england. P 293-301, 1 fig, 10 ref. Nsf-cee-81-19878.: 1982.
198. Ascough, J. C. II; Nearing, M. A.; Flanagan, D. C., and Livingston, S. J. Hydrologic and erosion calculations in the Water Erosion Prediction Project (WEPP) watershed model. Paper-American-Society-of-Agricultural-

Engineers: 1994(942037): 11.

199. Elsenbeer, H.; West, A., and Bonell, M. Hydrologic pathways and stormflow hydrochemistry at South Creek, northeast Queensland. Journal of Hydrology: 1994; 162, (1-2): 1-21.

200. Ludwig, B.; Boiffin, J.; Chadoeuf, J., and Auzet, A. V. Hydrological Structure and Erosion Damage Caused by Concentrated Flow in Cultivated Catchments. Catena: 1995 Jun; 25, (1-4): 227-252.

201. Ewing, L. K. Hydrology and Sedimentology Modelling on Illinois Agricultural Watersheds. Available from national technical information service, springfield va 22161 as pb90-173782/as. Price codes: a03 in paper copy, a01 in microfiche. Illinois water resources center, urbana-champaign , wrc research report no. 211, uilu-wrc-89-211. January 1989. 22p, 6 fig, 5 tab, 12 ref. Usgs project g-1420-04.: 1989.

202. Storm, Daniel E; Barfield, Billy J, and Ormsbee, Lindell E. Hydrology and sedimentology of dynamic rill networks; Volume I, Erosion model for dynamic rill networks, Part A, Introduction and overview, Part B, Erosion and model development. University of Kentucky; 1990.

203. Ormsbee, Lindell E; Blandford, George E; Montgomery, John S; Terrell, Laura B; Barfield, Billy J, and Storm, Daniel E. Hydrology and sedimentology of dynamic rill networks; Volume II, Erosion model for dynamic rill networks. 1990.

204. DeJolsvay, Dianne J; Data, Bithin; Tayfur, Gokmen; Kavvas, M L; Barfield, Billy J, and Storm, Daniel E. Hydrology and sedimentology of dynamic rill networks; Volume III, Simulation of random rill network geometries on agricultural soils. University of Kentucky; 1990.

205. Vanacker, V.; Govers, G.; Poesen, J.; Deckers, J.; Dercon, G., and Loaiza, G. The impact of environmental change on the intensity and spatial pattern of water erosion in a semi-arid mountainous Andean environment. Catena: 2003; 51, (3-4): 329-347.

206. Gyssels, G.; Poesen, J.; Bochet, E., and Li, Y. Impact of plant roots on the resistance of soils to erosion by water: A review. Progress in Physical Geography: 2005; 29, (2): 189-217.

207. Nyssen, J.; Poesen, J.; Moeyersons, J.; Luyten, E.; Veyret-Picot, M.; Deckers, J.; Haile, M., and Govers, G. Impact of road building on gully erosion risk: A case study from the Northern Ethiopian Highlands. Earth Surface Processes and Landforms: 2002; 27, (12): 1267-1283.

208. Gyssels, G.; Poesen, J.; Nachtergaele, J., and Govers, G. The impact of sowing density of small grains on rill and ephemeral gully erosion in concentrated flow zones. Soil and Tillage Research: 2002; 64, (3-4): 189-201.

209. Istanbulluoglu, E.; Bras, R. L.; Flores-Cervantes, H., and Tucker, G. E. Implications of bank failures and fluvial erosion for gully development: Field observations and modeling. Journal of Geophysical Research F: Earth Surface: 2005; 110, (1).

210. Piccarreta, M.; Capolongo, D.; Boenzi, F., and Bentivenga, M. Implications of decadal changes in precipitation and land use policy to soil erosion in Basilicata, Italy. Catena: 2006; 65, (2): 138-151.

211. Gyssels, G. and Poesen, J. The importance of plant root characteristics in controlling concentrated flow erosion rates. Earth Surface Processes and Landforms: 2003; 28, (4): 371-384.

212. Desmet, P. J. J.; Poesen, J.; Govers, G., and Vandaele, K. Importance of slope gradient and contributing area for optimal prediction of the initiation and trajectory of ephemeral gullies. Catena: 1999; 37, (3-4): 377-392.

213. Burt, T. P. Infiltration for soil erosion models: some temporal and spatial complications. Boardman, J and Favis Mortlock, D. Modelling soil erosion by water Proceedings of the NATO Advanced Research Workshop "Global change: modelling soil erosion by water", University of Oxford, Oxford, UK, 11 14 September, 1995: NATO ASI Series. Series I: Global Environmental Change Vol. 55. Berlin, Germany: Springer-Verlag.: 1998: 213-224.

214. Boiffin, J.; Papy, F., and Eimberck, M. Influence of cropping systems on concentrated flow erosion risk. I. Analysis of the conditions for initiating erosion [Influence des systemes de culture sur les risques d'erosion par ruissellement concentre. I. Analyse des conditions de declenchement de l'erosion. Agronomie: 1988; 8, (8): 663-673.

215. Papy, F.; Boiffin, J., and Douyer, C. Influence of cropping systems on the risk of concentrated flow erosion. II. Evaluation of control possibilities within farms [Influence des systemes de culture sur les risques d'erosion par ruissellement concentre. II. Evaluation des possibilites de maitrise du phenomene dans les exploitations

agricoles. Agronomie: 1988; 8, (9): 745-756.

216. Rockwell, D. L. The influence of ground water on surface flow erosion processes during a rainstorm. Earth Surface Processes and Landforms: 2002; 27, (5): 495-514.
217. Shvebs, G. I. Influence of relief on surface soil erosion (Vliyaniye rel'yefa na poverkhnostnyy smyv pochv). In: sbornik rabot po gidrologii, no 9; gosudarstvennyy gidrologicheskiy institut, leningrad, gidrometeoizdat, p 83-105, 1970. 5 fig, 3 tab, 36 ref.: 1970.
218. Bryan, R. B.; Hawke, R. M., and Rockwell, D. L. The influence of subsurface moisture on rill system evolution. Earth Surface Processes and Landforms: 1998; 23, (9): 773-789.
219. Dabney, S. M.; Moore, M. T., and Locke, M. A. Integrated management of in-field, edge-of-field, and after-field buffers. Journal of the American Water Resources Association: 2006; 42, (1): 15-24.
220. Van Den Elsen, E.; Xie, Y.; Liu, B.; Stolte, J.; Wu, Y.; Trouwborst, K., and Ritsema, C. J. Intensive water content and discharge measurement system in a hillslope gully in China. Catena: 2003; 54, (1-2): 93-115.
221. Meyer, L. D. Interrill Erosion Rates and Sediment Characteristics. Soil erosion and conservation. Soil conservation society of america, ankeny, iowa. 1985. P 167-177, 1 fig, 3 tab, 18 ref.: 1985.
222. Smith, L. M. United States. Soil Conservation Service. U. S. Army Engineer Waterways Experiment Station. Investigation of Ephemeral Gullies in Loessial Soils in Mississippi. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station; 1993.
223. Bennett, SJ and Alonso, CV. Kinematics of flow within headcut scour holes on hillslopes. Water resources research: 2005 Sep; 41, (9): W09418.
224. Bryan, R. B. Knickpoint evolution in rillwash. Catena,-Supplement: 1990(17): 111-132.
225. van Zyl, Albert J. A knowledge gap analysis on multi-scale predictive ability for agriculturally derived sediments under South African conditions. Water Science and Technology: 2007; 55, (3): 107-114.
226. Dos Reis Castro, N. M.; Auzet, A.-V.; Chevallier, P., and Leprun, J.-C. Land use change effects on runoff and erosion from plot to catchment scale on the basaltic plateau of Southern Brazil. Hydrological Processes: John Wiley & Sons Ltd; 1999; 13, (11): 1621-1628.
227. Dabney, S. M.; Liu, Z.; Lane, M.; Douglas, J.; Zhu, J., and Flanagan, D. C. Landscape benching from tillage erosion between grass hedges. Soil and Tillage Research: 1999; 51, (3-4): 219-231.
228. Laffan, M. D. and Cutler, E. J. B. Landscapes, soils, and erosion of a catchment in the Wither Hills, Marlborough. 2. Mechanism of tunnel-gully erosion in Wither hill soils from loessial drift and comparison with other loessial soils in the South Island. New-Zealand-Journal-of-Science: 1977; 20, (3): 279-289.
229. Kerenyi, A. Loess erosion on the Tokaj Big-Hill. Quaternary International: 1994; 24, 47-52.
230. Wang Jingming. Loessic gully network and neotectonic stress fields. Scientia Geographica Sinica: 1987; 7, (2): 139-146.
231. Govers, G.; Everaert, W.; Poesen, J.; Rauws, G.; De Ploey, J., and Lautridou, J. P. A long flume study of the dynamic factors affecting the resistance of a loamy soil to concentrated flow erosion. Earth Surface Processes & Landforms: 1990; 15, (4): 313-328.
232. Gimenez, R.; Planchon, O.; Silvera, N., and Govers, G. Longitudinal velocity patterns and bed morphology interaction in a rill. Earth Surface Processes and Landforms: 2004; 29, (1): 105-114.
233. Kerenyi, A. and Kocsis-Hodosi, E. Loszpusztulasi formak es folyamatok kvantitativ vizsgalata szoloteruleten: Quantitative investigation of erosion forms and processes on loess in a vineyard. Foldrajzi Ertesito: 1990; 39, (1-4): 29-54.
234. Clarke, Charles D. Major sedimentation activities in the Soil Conservation Service. Chang Howard H. and Hill Joseph C. Hydraulic Engineering - Proceedings of the 1990 National Conference. Publ by ASCE; 1990: 1066-1069.
235. Fiener, P. and Auerswald, K. Measurement and modeling of concentrated runoff in grassed waterways. Journal of Hydrology: 2005; 301, (1-4): 198-215.
236. Thomas, A. W. and Welch, R. Measurement of ephemeral gully erosion. Transactions of the American Society of Agricultural Engineers: 1988; 31, (6): 1723-1728.
237. Ritchie, J. C.; Menenti, M., and Weltz, M. A. Measurements of land surface features using an airborne laser altimeter: The HAPEX-Sahel experiment. International Journal of Remote Sensing: 1996; 17, (18): 3705-

3724.
238. Comis, DL. Measuring ephemeral cropland gullies. Soil and water conservation news: 1984 Aug; 5, (5): 10.
239. Thomas, AW and Welch, R. Measuring ephemeral gully erosion with aerial photogrammetry. American Society of Agricultural Engineers Microfiche collection: 1987: 1987 (Fiche No 87-2576).
240. Hancock, G. R.; Evans, K. G.; Willgoose, G. R.; Moliere, D. R.; Saynor, M. J., and Loch, R. J. Medium-term erosion simulation of an abandoned mine site using the SIBERIA landscape evolution model. Australian Journal of Soil Research: 2000; 38, (2): 249-263.
241. Nachtergaele, J.; Poesen, J.; Oostwoud Wijdenes, D., and Vandekerckhove, L. Medium-term evolution of a gully developed in a loess-derived soil. Geomorphology: 2002; 46, (3-4): 223-239.
242. Woodward, D. E. Method to predict cropland ephemeral gully erosion. Catena: 1999; 37, (3-4): 393-399.
243. Bradford, J. M. and Blanchar, R. W. Mineralogy and water quality parameters in rill erosion of clay-sand mixtures. Soil Science Society of America Journal: Soil Science Soc of America; 1999; 63, (5): 1300-1307.
244. Foster, G. R. Modeling ephemeral gully erosion for conservation planning. International Journal of Sediment Research: 2005; 20, (3): 157-175.
245. Bennett, S. J. and Alonso, C. V. Modeling headcut development and migration in upland concentrated flows. International Journal of Sediment Research: 2005; 20, (4): 281-294.
246. Foster, G. R. Modeling Soil Erosion and Sediment Yield. Soil erosion research methods. Winrock international, arlington virginia. 1988. P 97-117. 2 fig, 2 tab, 53 ref.: 1988.
247. Souchere, V.; Cerdan, O.; Ludwig, B.; Le Bissonnais, Y.; Couturier, A., and Papy, F. Modelling ephemeral gully erosion in small cultivated catchments. Catena: 2003 Jan; 50, (2-4): 489-505.
248. Kirkby, M. and Bracken, L. Modelling hillslope connectivity and channel interactions in semiarid areas: Implications for hillslope restoration following land abandonment. IAHS-AISH Publication: 2005; 299, 3-15.
249. Deletic, A.; Ashley, R., and Rest, D. Modelling input of fine granular sediment into drainage systems via gully-pots. Water Research: Elsevier Science Ltd; 2000; 34, (15): 3836-3844.
250. Hessel, R. Modelling soil erosion in a small catchment on the Chinese Loess Plateau applying LISEM to extreme conditions. Nederlandse Geografische Studies: 2002(307): 316.
251. Boardman, J. Modelling soil erosion in real landscapes: a Western European perspective. Boardman, J and Favis Mortlock, D. Modelling soil erosion by water Proceedings of the NATO Advanced Research Workshop "Global change: modelling soil erosion by water", University of Oxford, Oxford, UK, 11 14 September, 1995: NATO ASI Series. Series I: Global Environmental Change Vol. 55. Berlin, Germany: Springer-Verlag.: 1998: 17-29.
252. Dunn, G. H. and Dabney, S. M. Modulus of elasticity and moment of inertia of grass hedge stems. Transactions of the American Society of Agricultural Engineers: 1996; 39, (3): 947-952.
253. Cheng, H.; Zou, X.; Wu, Y.; Zhang, C.; Zheng, Q., and Jiang, Z. Morphology parameters of ephemeral gully in characteristics hillslopes on the Loess Plateau of China. Soil and Tillage Research: 2007; 94, (1): 4-14.
254. Ritchie, J. C.; Kemper, W. D., and Englert, J. M. Narrow stiff grass hedges for erosion control. Human impact on erosion and sedimentation. Proc. international symposium, Rabat, Morocco, 1997: 1997; 245, 195-203.
255. Viero, A. C.; dos Castro, N. M. R.; Goldenfum, J. A., and Risso, A. Natural and anthropogenic factors controlling gully erosion in the basaltic upland of southern brazil. International Journal of Sediment Research: 2005; 20, (3): 211-223.
256. Davidson, DA and Harrison, DJ. The nature, causes and implications of water erosion on arable land in Scotland. Soil use and management: 1995 Jun; 11, (2): 63-68.
257. Soler, M. R.; Infante, C.; Buenestado, P., and Mahrt, L. Observations of nocturnal drainage flow in a shallow gully. Boundary-Layer-Meteorology: 2002; 105, (2): 253-273.
258. Kirkby, M. J.; Bull, L. J.; Poesen, J.; Nachtergaele, J., and Vandekerckhove, L. Observed and modelled distributions of channel and gully heads - With examples from SE Spain and Belgium. Catena: 2003; 50, (2-4): 415-434.
259. Martinez Casasnovas, J. A.; Concepcion Ramos, M., and Ribes Dasi, M. On-site effects of concentrated flow erosion in vineyard fields: some economic implications. Catena: 2005; 60, (2): 129-146.

260. Pal, D; Prasad, S N, and Roemkens, M J M. Optimal mode of sediment transport by shallow flows in upland areas. International Journal of Sediment Research, vol.15, no.2, pp.260-267 : Roemkens, M J M and Fan, Shoushan2000.

261. Burkard, M. B. and Kostaschuk, R. A. Patterns and controls of gully growth along the shoreline of lake huron. Earth Surface Processes and Landforms: 1997; 22, (10): 901-911.

262. Nazarov, N. N. The peculiarities of contemporary interpretation of the term "gully". Geomorfologiya: 1997(4): 43-50.

263. Blanco-Canqui, H.; Gantzer, C. J., and Anderson, S. H. Performance of Grass Barriers and Filter Strips Under Interrill and Concentrated Flow. Journal of Environmental Quality: 2006 Nov-2006 Dec 31; 35, (6): 1969-1974.

264. Thomas, A. W.; Welch, R.; Fung, S. S., and Jordan, T. R. Photogrammetric Measurement of Ephemeral Gully Erosion. Washington, D.C.: U.S. Department of Agriculture, Agricultural Research Service; 1995 May.

265. Welch, R.; Jordan, T. R.; Thomas, A. W., and Ellis, J. W. Photogrammetric Techniques for Monitoring Soil Erosion. Photogrammetry - soil erosion investigations 1983 research report no. Irc 09083, september, 1983. 22 p, 6 fig, tab 1, 5 ref.: 1983.

266. Welch, R.; Jordan, T. R.; Fung, S. S., and Thomas, A. W. Photogrammetry: a revolutionary solution to the assessment of ephemeral gully erosion. Technical Papers of the American Society of Photogrammetry, Annual Meeting. Washington, DC, USA: 1985; 2, 873-874. Technical Papers, 51st Annual Meeting, 1985 ASP-ACSM Convention: Theodolite to Satellite.

267. Grayson, R. B.; Moore, I. D., and McMahon, T. A. Physically based hydrologic modeling. 1. A terrain-based model for investigating purposes. Water-Resources-Research: 1992; 28, (10): 2639-2658.

268. Bathurst, J. C.; Gonzalez, E., and Salgado, R. Physically based modelling of gully erosion and sediment yield at the basin scale. Hydrology in a changing environment volume iii. Pp. 253-260. 1998.: Whater, H. and Kirby, C. (eds)1998.

269. Xu Jiongxin . Physico-geographical factors in the formation of hyperconcentrated flows in the Loess Plateau, China. Acta Geographica Sinica, vol.54, no.4, pp.318-326: 1999 Jul.

270. Nwankwor, G. I.; Dike, C. E., and Iwuagwu, C. J. Piping, quick conditions and liquefaction as factors of gully erosion: A case study of Okwudor - Amucha gully complex, Imo State, Nigeria. Journal of Mining and Geology: 1998; 34, (2): 225-230.

271. Hagerty, D. J. Piping/sapping erosion. II: identification-diagnosis. Journal of Hydraulic Engineering: 1991; 117, (8): 1009-1025.

272. Brookman, G. T.; Ripp, J. A.; Katz, P. B.; Middlesworth, B. C., and Martin, D. K. Planning Study to Model and Monitor Coal Pile Run-Off. Available from the national technical information service, springfield va 22161 as pb81-152530, price codes: a10 in paper copy, a01 in microfiche. Environmental protection agency project summary epa-600/s7-81-016, july 1981. 5 p, 3 fig, 1 tab.: 1981.

273. Johnson, H. P. and Moldenhauer, W. C. Pollution by sediment: Sources and the detachment and transport processes. Agricultural practices and water quality, iowa state university press, ames, iowa, 1970, chapter 1, p 3-20. 2 tab, 2 fig, 59 ref.: 1970.

274. Alonso, C. V.; Bennett, S. J., and Stein, O. R. Predicting head cut erosion and migration in concentrated flows typical of upland areas. Water Resources Research: 2002; 38, (12): 391-3915.

275. Franti, T. G.; Laflen, J. M., and Watson, D. A. Predicting soil detachment from high-discharge concentrated flow. Transactions of the American Society of Agricultural Engineers: 1999; 42, (2): 329-335.

276. Line, D. E. and Meyer, L. D. Predicting the effect of diversions on soil loss using CREAMS. Optimum erosion control at least cost Proceedings of the National Symposium on Conservation Systems, December 14 15, 1987, Chicago, IL, USA: 2 fig., 4 tab. ASAE Publication 08-87. St. Joseph, MI, USA: American Society of Agricultural Engineers.: 1987: 276-284.

277. Nachtergaele, J.; Poesen, J.; Sidorchuk, A., and Torri, D. Prediction of concentrated flow width in ephemeral gully channels. Hydrological Processes: 2002; 16, (10): 1935-1953.

278. Thorne, C. R. and Zevenbergen, L. W. Prediction of ephemeral gully erosion on cropland in the south-eastern United States. Boardman, J; Foster, IDL, and Dearing, JA. Soil erosion on agricultural land Proceedings of a workshop sponsored by the British Geomorphological Research Group, Coventry, UK, January 1989.

Chichester, UK: John Wiley & Sons Ltd..: 1990: 447-470.

279. Wang, Yangmin. Prediction of ephemeral gully formation and erosion on hillslopes. University of Minnesota; 1992.

280. Yadav, R. C. and Bhushan, L. S. Prefabricated drop spillways for outlets of reclaimed gullied lands. Agricultural Water Management: 1994; 26, (4): 227-237.

281. Liu, T.; Wang, X., and Cui, P. Preliminary study on 1D numerical experiment of water debris flow in gully. Journal of Sichuan University (Engineering Science Ed.): 2005; 37, (SUPPL.): 143-147.

282. . Present and prospective technology for predicting sediment yields and sources. Sediment-Yield Workshop, Proc, Pap, USDA Sediment Lab, Oxford, Miss. U.S. Dep of Agric, Agric Res Serv (ARS-S-40), Jun 1975; 1976.

283. Casali, J.; Lopez, J. J., and Giraldez, J. V. A process-based model for channel degradation: Application to ephemeral gully erosion. Catena: 2003; 50, (2-4): 435-447.

284. Foster, G. R. Process-based modelling of soil erosion by water on agricultural land. Boardman, J; Foster, IDL, and Dearing, JA. Soil erosion on agricultural land Proceedings of a workshop sponsored by the British Geomorphological Research Group, Coventry, UK, January 1989. Chichester, UK: John Wiley & Sons Ltd..; 1990: 429-445.

285. Casali, Javier; Bennett, Sean J, and Robinson, Kerry M. Processes of ephemeral gully erosion. International Journal of Sediment Research, vol.15, no.1, pp.31-41: Romkens, M J M and Fan, Shoushan2000.

286. Thomas, A. W.; Welch, R., and Jordan, T. R. Quantifying concentrated-flow erosion on cropland with aerial photogrammetry. Journal-of-Soil-and-Water-Conservation: 1986; 41, (4): 249-252.

287. Kerenyi, A. and Kocsis-Hodosi, E. Quantitative investigation of erosion forms and processes on loess in a vineyard: Loszpusztulasi formak es folyamatok kvantitativ vizsgalata szoloteruleten. Foldrajzi Ertesito: 1990; 39, (1-4): 29-54.

288. Vanwalleghem, T.; Bork, H. R.; Poesen, J.; Schmidtchen, G.; Dotterweich, M.; Nachtergaele, J.; Bork, H.; Deckers, J.; Brusch, B.; Bungeneers, J., and De Bie, M. Rapid development and infilling of a buried gully under cropland, central Belgium. Catena: 2005; 63, (2-3): 221-243.

289. Grissinger, E. H. Reclamation of gullies and channel erosion. Agassi, M. Soil erosion, conservation and rehabilitation. New York, USA: Marcel Dekker Inc..; 1996: 301-313.

290. Heede, Burchard H. Rehabilitation of disturbed watersheds through vegetation treatment and physical structures. Interior West Watershed Management, Proceedings of a Symposium.; Spokane, WA, USA; Code 413. Wash State Univ, Coop Ext; 1981: 257-268.

291. Knapen, A.; Poesen, J.; Govers, G.; Gyssels, G., and Nachtergaele, J. Resistance of soils to concentrated flow erosion: A review. Earth-Science Reviews: 2007; 80, (1-2): 75-109.

292. King, Norman J. Restoration of gullied valley floors in arid and semiarid regions. Proc 23rd int geol congr, vol 12, p 187-195, 1968. 9 p, 2 fig, 16 ref. 1968.

293. Grissinger, E. H. Rill and gullies erosion. Agassi, M. Soil erosion, conservation and rehabilitation. New York, USA: Marcel Dekker Inc..: 1996: 153-167.

294. Oygarden, L. Rill and gully development during an extreme winter runoff event in Norway. Catena: 2003; 50, (2-4): 217-242.

295. Berael, C.; Poesen, J., and van Wesemael, B. Rill and gully erosion in relation to rock fragment cover and surface slope along a hillslope in south eastern Spain. Fantechi, R; Peter, D; Balabanis, P, and Rubio, J L. Desertification in a European context: physical and socio economic aspects Proceedings of the European School of Climatology and Natural Hazards Course, El Campello, Pueblo Acantilado, Alicante, Spain, 6 13 October 1993. Luxembourg: Office for Official Publications of the European Community.: 1995: 371-375.

296. Slattery, M. C.; Burt, T. P., and Boardman, J. Rill erosion along the thalweg of a hillslope hollow: a case study from the Cotswold Hills, central England. Earth Surface Processes & Landforms: 1994; 19, (4): 377-385.

297. Auzet, A. V.; Boiffin, J.; Papy, F.; Ludwig, B., and Maucorps, J. Rill Erosion as a Function of the Characteristics of Cultivated Catchments in the North of France. Catena, vol. 20, no. 1/2, p 41-62, february/april 1993. 9 fig, 11 tab, 41 ref.: 1993.

298. Cerdan, O.; Le Bissonnais, Y.; Couturier, A.; Bourennane, H., and Souchere, V. Rill erosion on cultivated hillslopes during two extreme rainfall events in Normandy, France. Soil and Tillage Research: 2002; 67,

(1): 99-108.

299. Zheng Fenli and Tang Keli. Rill erosion process on steep slope land of the Loess Plateau. International Journal of Sediment Research, vol.12, no.1, pp.52-59: 1997 Apr.

300. Montolar Sparovek, R. B.; Vidal Torrado, P., and Sparovek, G. Rill, interrill and gully erosion in an intensively cultivated watershed of Piracicaba [Erosao em sulcos, entressulcos e vocorocas em uma microbacia de Piracicaba (SP) intensivamente cultivada. Scientia-Agricola: 1999; 56, (4): 859-865.

301. Huang, C; Bradford, J M, and Anonymous. Rill network development under simulated rain; a microscale approach. Eos, Transactions, American Geophysical Union, vol.71, no.43, pp.1345 : 1990 Oct 23.

302. Beckedahl, H. R. and Dardis, G. F. The role of artificial drainage in the development of soil pipes and gullies: Some examples from Transkei, southern Africa. Geomorphological studies in southern Africa. 3000 BR Rotterdam, Netherlands: A. A. Balkema.; 1988: 229-245.

303. Larson, W. E.; Lindstrom, M. J., and Schumacher, T. E. The role of severe storms in soil erosion: A problem needing consideration. Journal of soil and water conservation: 1997 Apr; 52, (2): 90-95.

304. Walker, R. D. Role of silt in water pollution. Amer water works ass j, vol 58, no 11, pp 1483-1488, nov 1966. 6 p, 2 tab, 1 fig, 6 ref.: 1966.

305. Helming, K.; Romkens, M. J. M., and Prasad, S. N. Roughness and sealing effect on soil loss and infiltration on a low slope. Advances in Geoecology. 1998: (31): 589-595.

306. van Dijk, A. I. J. M.; Bruijnzeel, L. A.; Vertessy, R. A., and Ruijter, J. Runoff and sediment generation on bench-terraced hillsides: Measurements and up-scaling of a field-based model. Hydrological Processes: 2005; 19, (8): 1667-1685.

307. Wijdenes, D. J. O. and Gerits, J. Runoff and sediment transport on intensively gullied, low-angled slopes in Baringo District. Soil erosion, land degradation and social transition: Bryan R.B.Catena; Advances in Geoecology, 27; 1994: 121-141.

308. Croke, J.; Hairsine, P., and Fogarty, P. Runoff generation and re-distribution in logged eucalyptus forests, south-eastern Australia. Journal of hydrology (amsterdam): 1999 Mar 8; 216, (1-2): 56-77.

309. Peugeot, C.; Esteves, M.; Galle, S.; Rajot, J. L., and Vandervaere, J. P. Runoff generation processes: Results and analysis of field data collected at the East Central Supersite of the HAPEX-Sahel experiment. Journal of Hydrology: 1997; 188-189, (1-4): 179-202.

310. Lewis, L. A.; Verstraeten, G., and Zhu, H. RUSLE applied in a GIS framework: Calculating the LS factor and deriving homogeneous patches for estimating soil loss. International Journal of Geographical Information Science: 2005; 19, (7): 809-829.

311. Robinson, Kerry M.; Hanson, Gregory J., and Cook, Kevin R. Scour below an overfall: Part I. Investigation. Transactions of the American Society of Agricultural Engineers: 2002; 45, (4): 949-956.

312. Riley, Steve J. Sediment depletion in rills and gullies and its impact on the stability of engineered landforms, Ranger uranium mine, Northern Territory, Australia. Technical Program Abstracts - International Geographical Congress, vol.27, pp.533: De Souza, Anthony R.1992.

313. Alberts, E. E.; Kramer, L. A., and Ghidey, F. Sediment deposition within a watershed with stiff-stemmed grass hedges. Ascough II, J C and Flanagan, D C. Soil erosion research for the 21st century Proceedings of the International Symposium, Honolulu, Hawaii, USA, 3 5 January, 2001. St Joseph, USA: American Society of Agricultural Engineers: 2001: 167-170.

314. Brake, D.; Molnau, M., and King, J. G. Sediment transport distances and culvert spacings on logging roads within the Oregon coast mountain range. ASAE Annual International Meeting, Minneapolis, Minnesota, USA, 10-14 August, 1997. American-Society-of-Agricultural-Engineers; 1997; 975018, 12.

315. Meyer, L. D.; Dabney, S. M., and Harmon, W. C. Sediment-trapping effectiveness of stiff-grass hedges. Transactions of the American Society of Agricultural Engineers: 1995; 38, (3): 809-815.

316. Ward, Jason M. and Jackson, C. Rhett. Sediment trapping within forestry streamside management zones: Georgia Piedmont, USA. Journal of the American Water Resources Association: 2004; 40, (6): 1421-1431.

317. Baade, J.; Barsch, D.; Mausbacher, R., and Schukraft, G. Sediment yield and sediment retention in a small loess-covered catchment in SW-Germany. Zeitschrift fur Geomorphologie, Supplementband: 1993; 92, 217-230.

318. Welch, N. H. Sediment Yield from a Gully. Proceedings of the fourth federal interagency sedimentation

conference march 24-27, 1986, las vegas, nevada. Volume i, 1986. P 291-300, 3 fig, 3 tab, 6 ref.: 1986.

319. Sartz, R. S. Sediment Yield from Steep Lands in the Driftless Area. Proceedings of the third federal inter-agency sedimentation conference 1976; denver, colorado, march 22-25, 1976. Water resources council, washington, d.c., Sedimentation committee, p 1-123 - 1-131, 1976. 4 fig, 4 tab, 8 ref.: 1976.
320. Alonso, C. V.; Bingner, R. L., and Kuhnle, R. A. Sediment yield from watersheds with eroding channels. Espey William H. and Combs Phil G. International Water Resources Engineering Conference - Proceedings. San Antonio, TX, USA: 1995; 2, 1183-1187. Proceedings of the 1st International Conference on Water Resources. Part 1 (of 2).
321. Huang, C.-H. and Laflen, J. M. Seepage and soil erosion for a clay loam soil. Soil Science Society of America Journal: 1996; 60, (2): 408-416.
322. Gang Hu; Yongqiu Wu; Baoyuan Liu; Zhangtao Yu; Zhimin You; and, and Yongguang Zhang. Short-term Gully Retreat Rates Over Rolling Hill Areas in Black Soil of Northeast China. 2007; 71, 321-329.
323. Gordon, L. M.; Bennett, S. J.; Bingner, R. L.; Theurer, F. D.; and, and Alonso, C. V. Simulating Ephemeral Gully Erosion in AnnAGNPS. 2007; 50, (3): 857-866.
324. Sangodoyin, A. Y. and Nwosu, E. O. Slope, antecedent moisture and rill influences on soil erosion in Southeastern Nigeria. Discovery and Innovation: 1997; 9, (3-4): 205-212.
325. Teixeira De Oliveira, M. A. Slope geometry and gully erosion development: Bananal, Sao Paulo, Brazil. Zeitschrift fur Geomorphologie: 1990; 34, (4): 423-434.
326. Bursik, M; Martinez Hackert, B; Delgado, H, and Gonzalez Huesca, A. A smoothed-particle hydrodynamic automaton of landform degradation by overland flow. Geomorphology, vol.53, no.1-2, pp.25-44: Shroder, John F Jr and Bishop, Michael P2003 Jul 1.
327. Strunk, H. Soil degradation and overland flow as causes of gully erosion on mountain pastures and in forests. Catena: 2003; 50, (2-4): 185-198.
328. Nagasaka, Akiko; Yanai, S.; Sato, H., and Hasegawa, S. Soil erosion and gully growth associated with cultivation in southwestern Hokkaido, Japan. Ecological Engineering: 2005; 24, (5 SPEC. ISS.): 503-508.
329. Sang-Arun, J.; Mihara, M.; Horaguchi, Y., and Yamaji, E. Soil erosion and participatory remediation strategy for bench terraces in northern Thailand. Catena: 2006; 65, (3): 258-264.
330. Piest, Robert F.; Bradford, Joe M., and Wyatt, George M. Soil erosion and sediment transport from gullies. ASCE J Hydraul Div: 1975; 101, (1): 65-80.
331. Ghebreiyessus, Y T; Gantzer, C J; Alberts, E E, and Lentz, R W. Soil erosion by concentrated flow; shear stress and bulk density. Transactions of the ASAE: 1994 Dec; 37, (6): 1791-1797.
332. Martinez-Casasnovas, J. A.; Ramos, M. C., and Ribes-Dasi, M. Soil erosion caused by extreme rainfall events: Mapping and quantification in agricultural plots from very detailed digital elevation models. Geoderma: 2002; 105, (1-2): 125-140.
333. Finkel, H. J. Soil Erosion Process. Semiarid soil and water conservation, crc press, inc., Boca raton fl. 1986. P 27-37, 3 fig, 3 tab, 12 ref.: 1986.
334. Govers, G.; Poesen, J., and Goossens, D. Soil erosion - processes, damages and countermeasures. Schj<o>nning, P; Elmholt, S, and Christensen, B T. Managing soil quality: challenges in modern agriculture. Wallingford, UK: CABI Publishing.: 2004: 199-217.
335. Schwertmann, U.; Rickson, R. J., and Auerswald, K. Soil erosion protection measures in Europe. Proceedings of the European Community workshop, Freising, Germany, May 1988. Soil erosion protection measures in Europe. Proceedings of the European Community workshop, Freising, Germany, May 1988: Catena Verlag, D-3302 Cremlingen-Destedt; Soil Technology Series, 1; 1991.
336. Romkens, M. J. M.; Helming, K., and Prasad, S. N. Soil erosion under different rainfall intensities, surface roughness, and soil water regimes. Catena: 2002; 46, (2-3): 103-123.
337. Esteves, M.; Descroix, L.; Mathys, N., and Lapetite, J. M. Soil hydraulic properties in a marly gully catchment (Draix, France). Catena: 2005; 63, (2-3): 282-298.
338. Lentz, R. D.; Dowdy, R. H., and Rust, R. H. Soil property patterns and topographic parameters associated with ephemeral gully erosion. Journal of Soil & Water Conservation: 1993; 48, (4): 354-360.
339. Govers, G.; Takken, I., and Helming, K. Soil roughness and overland flow. Agronomie: 2000; 20, (2): 131-146.

340. Castro, L. G.; Libardi, P. L., and Lier, Q. de J van. Soil water dynamics in a Brazilian infiltration terrace under different management practices. Advances-in-Geoecology: 2002(35): 191-198.

341. Vandaele, K. and Poesen, J. Spatial and temporal patterns of soil erosion rates in an agricultural catchment, central Belgium. Catena : Poesen, J.; Govers, G., and Goossens, D. (eds)1995; 25, (1-4): 213-226.

342. Nachtergaele, J. and Poesen, J. Spatial and temporal variations in resistance of loess-derived soils to ephemeral gully erosion. European Journal of Soil Science: 2002; 53, (3): 449-463.

343. Zucca, C.; Canu, A., and Della Peruta, R. Spatial distribution and morphological features of gullies in an agropastoral area in Sardinia, Italy. International Journal of Sediment Research: 2006; 21, (2): 132-144.

344. Takken, I.; Beuselinck, L.; Nachtergaele, J.; Govers, G.; Poesen, J., and Degraer, G. Spatial evaluation of a physically-based distributed erosion model (LISEM). Catena: 1999; 37, (3-4): 431-447.

345. Martinez-Casasnovas, J. A. A spatial information technology approach for the mapping and quantification of gully erosion. Catena: 2003 Jan; 50, (2-4): 293-308.

346. Jetten, V.; Poesen, J.; Nachtergaele, J., and Vlag, D. van de. Spatial modelling of ephemeral gully incision: a combined empirical and physical approach. Owens, P N and Collins, A J. Soil erosion and sediment redistribution in river catchments: measurement, modelling and management. Wallingford, UK: CABI: 2006: 195-206.

347. Moody, J. A. and Kinner, D. A. Spatial structures of stream and hillslope drainage networks following gully erosion after wildfire. Earth Surface Processes and Landforms: 2006; 31, (3): 319-337.

348. Heede, B. H. Stages of development of gullies in the West. Present and Prospective Technology for Predicting Sediment Yields and Sources. Proceedings, Sediment-Yield Workshorp, Oxford, Mississippi, November 1972. Agricultural-Research-Service,-U.S.-Department-of-Agriculture; 1975; ARS-S-40.

349. ---. Stages of development of gullies in western United States of America. Zeitschrift fur geomorphologie: 1974; 18, (3): 260-271.

350. United States. Soil Conservation Service. State of Colorado, Yampa River Basin study. United States. Soil Conservation Service.; 1990.

351. Haraguchi, N.; Takagi, A., and Nakano, M. Stochastic Simulation of Gully Networks on Eroded Land. Soil erosion and conservation. Ankeny, IA: Soil conservation society of america; 1985: 178-187.

352. Ohmori, H.; Speight, J. G., and Takeuchi, K. Stratigraphic background of gully development of the Pekina catchment in the Mt. Lofty Ranges, South Australia. Geographical Reports - Tokyo Metropolitan University: 1986; 21, 65-84.

353. Calver, A. Stream Head Migration: An Indicator of Runoff Processes on Chalklands. Catena, vol. 17, no. 4/5, p 399-408, august/october 1990. 3 fig, 11 ref.: 1990.

354. Beavis, S. G. Structural controls on the orientation of erosion gullies in mid-western New South Wales, Australia. Geomorphology: 2000; 33, (1-2): 59-72.

355. Zhang, K. L.; Tang, K. L., and Wang, B. K. A study of characteristic values of shallow gully erosion formation on sloping farmland on the loess plateau. Acta-Conservationis-Soli-et-Aquae-Sinica: 1991; 5, (2): 8-13.

356. Cheng, H.; Wu, Y.; Zou, X.; Si, H.; Zhao, Y.; Liu, D., and Yue, X. Study of ephemeral gully erosion in a small upland catchment on the Inner-Mongolian Plateau. Soil and Tillage Research: 2006; 90, (1-2): 184-193.

357. Liu, G.; Xu, M., and Ritsema, C. A study of soil surface characteristics in a small watershed in the hilly, gullied area on the Chinese Loess Plateau. Catena: 2003; 54, (1-2): 31-44.

358. Zhang XiaoMing; Wei TianXing, and Zhang XuePei. Study on function of vegetation's preventing soil erosion in small watershed of the Loess area. Chinese-Forestry-Science-and-Technology: 2003; 2, (4): 71-78.

359. Heede, B. H. Submerged Burlap Strips Aided Rehabilitation of Disturbed Semiarid Sites in Colorado and New Mexico. Usda forest service research note rm-302, december 1975. 8 p., 8 fig., 1 tab., 2 ref.: 1975.

360. Terajima, T. Subsurface water discharge and sediment yield relevant to pipe flow in a forested O-order basin, Hokkaido, northern Japan. Chikei: 2002; 23, (4): 511-535.

361. Zaslavsky, D. and Sinai, G. Surface hydrology: V-In-surface transient flow. Journal-of-the-Hydraulics-Division,-ASCE: 1981; 107, (HY1): 65-93.

362. Elsenbeer, H. and Cassel, D. K. Surficial processes in the rainforest of western Amazonia . Ziemer R.R. Research needs and applications to reduce erosion and sedimentation in tropical steeplands. Proc.

symposium, Suva, 1990. 1990: 289-297.

363. Nistor, C. J. and Church, M. Suspended sediment transport regime in a debris-flow gully on Vancouver Island, British Columbia. Hydrological Processes: 2005; 19, (4): 861-885.

364. Valcarcel Armesto, M.; Dafonte Dafonte, J.; Cacheiro Pose, M., and Paz Gonzalez, A. Taking into account the effect of tillage on runoff direction and its importance for erosion modelling. Rubio, J L; Morgan, R P C; Asins, S, and Andreu, V. Man and soil at the Third Millennium Proceedings International Congress of the European Society for Soil Conservation, Valencia, Spain, 28 March 1 April, 2000 Volume 2. Logrona, Spain: GEOFORMA Edicions, S.L..; 2002: 1207-1218.

365. Yan, Y.; Zhang, S.; Li, X., and Yue, S. Temporal and spatial variation of erosion gullies in Kebai black soil region of Heilongjiang during the past 50 years. Acta Geographica Sinica: 2005; 60, (6): 1015-1020.

366. Speidel, D. R. Terraces technology obsolete or will terraces still have a future? Campbell, K L; Graham, W D, and Bottcher, A B. Environmentally sound agriculture: proceedings of the second conference, Orlando, Florida, USA, 20 22 April 1994: ASAE publication 04-94. St Joseph, USA: American Society of Agricultural Engineers (ASAE).: 1994: 155-159.

367. Nachtergaele, J.; Poesen, J.; Vandekerckhove, L.; Oostwoud Wijdenes, D., and Roxo, M. Testing the ephemeral gully erosion model (EGEM) for two mediterranean environments. Earth Surface Processes and Landforms: 2001; 26, (1): 17-30.

368. Hu, S.-X. and Jin, C.-X. Theoretical analysis and experimental study on the critical slope of erosion. Acta Geographica Sinica: 1999; 54, (4): 347-356.

369. Vandekerckhove, L; Poesen, J; Wijdenes, D Oostwoud, and de Figueiredo, T. Thresholds for ephemeral gully initiation in intensively cultivated areas in the Mediterranean. Supplementi di Geografia Fisica e Dinamica Quaternaria (Testo Stampato), vol.3, Part 1, pp.388: Federici, Paolo Roberto1997.

370. Vandekerckhove, L.; Poesen, J.; Oostwoud Wijdenes, D.; Nachtergaele, J.; Kosmas, C.; Roxo, M. J., and De Figueiredo, T. Thresholds for gully initiation and sedimentation in Mediterranean Europe. Earth Surface Processes and Landforms: 2000; 25, (11): 1201-1220.

371. DeCoursey, D. G.; Chameides, W. L.; McQuigg, J.; Frere, M. H., and Nicks, A. D. Thunderstorm in Agriculture and in Forest Management. Thunderstorms: a social, scientific, and technological documentary vol i, the thunderstorm in human affairs, noaa, september, 1981, p 85-112, 21 fig, 1 tab, 54 ref.: 1981.

372. Schmitt, A. ; Rodzik, J.; Zgobicki, W.; Russok, C.; Dotterweich, M., and Bork, H.-R. Time and scale of gully erosion in the Jedliczny Dol gully system, south-east Poland. Catena: 2006; 68, (2-3): 124-132.

373. Burch, G. J.; Mackenzie, D. H., and Moore, I. D. Topographic and soil management effects on ephemeral gully erosion and distribution of water in surface soil. Conference and Workshop Series Queensland Department of Primary Industries: 2 fig., 1 tab. Proceedings National Workshop, Toowoomba, Queensland, 7-10 Sep. 1987. Edited by K. J. Coughlan and P. N. Truong. 1987: (qc87006): 174-177.

374. Moore, I. D.; Burch, G. J., and Mackenzie, D. H. Topographic effects on the distribution of surface soil water and the location of ephemeral gullies. Transactions of the American Society of Agricultural Engineers: 1988; 31, (4): 1098-1107.

375. Bingner, R. L. and Theurer, F. D. Topographic factors for RUSLE in the continuous-simulation watershed model for predicting agricultural, non-point source pollutants (AnnAGNPS). Ascough, J C II and Flanagan, D C. Soil erosion research for the 21st century Proceedings of the International Symposium, Honolulu, Hawaii, USA, 3 5 January, 2001. St Joseph, USA: American Society of Agricultural Engineers: 2001: 619-622.

376. Vandekerckhove, L.; Poesen, J.; Oostwoud Wijdenes, D., and De Figueiredo, T. Topographical thresholds for ephemeral gully initiation in intensively cultivated areas of the Mediterranean. Catena: 1998; 33, (3-4): 271-292.

377. Barthes, B. and Roose, E. Topsoil aggregate stability, an indicator of soil susceptibility to runoff and erosion: validation at several scales [La stabilite de l'agregation, un indicateur de la sensibilite des sols au ruissellement et a l'erosion : validation a plusieurs echelles. Cahiers-Agricultures: 2001; 10, (3): 185-193.

378. De Oliveira, M. A. T. Towards the integration of subsurface flow and overland flow in gully head extension: Issues from a conceptual model for gully rosion evolution. South African Geographical Journal: 1997; 79, (2): 120-128.

379. de Oliveira, M A T. Towards the integration of subsurface flow and overland flow in gully head extension; issues from a conceptual model for gully erosion evolution. South African Geographical Journal, vol.79, no.2, pp.120-128: 1997 Sep.
380. Poesen, J. Transport of rock fragments by rill flow - a field study. Catena Supplement: 1987; 8, 35-54.
381. Zhu, T. X.; Luk, S. H., and Cai, Q. G. Tunnel erosion and sediment production in the hilly loess region, North China. Journal of Hydrology: 2002; 257, (1-4): 78-90.
382. Bennett, S. J. and Alonso, C. V. Turbulent flow and bed pressure within headcut scour holes due to plane reattached jets. Journal of Hydraulic Research: 2006; 44, (4): 510-521.
383. Desmet, P. J. J. and Govers, G. Two-dimensional modelling of the within-field variation in rill and gully geometry and location related to topography. Catena: 1997; 29, (3-4): 283-306.
384. Domingues, E. N.; Rossi, M.; Mattos, I. F. A.; Abe, K., and Kitada, M. Typology and distribution of erosion processes in a microwatershed of the ribeirao Agua da Cachoeira from Paraguacu Paulista, Sao Paulo State, Brazil [Tipologia e distribuicao dos processos erosivos na microbacia do ribeirao Agua da Cachoeira, em Paraguacu Paulista, SP. Revista-Brasileira-de-Ciencia-do-Solo: 1998; 22, (1): 141-149.
385. Foster, G. R. Understanding ephemeral gully erosion. Soil Conservation: An Assessment of the National Resources Inventory, Volume II. Washington, DC: National Academy of Sciences; 1986.
386. Yang, C. T. A unified approach for erosion and sediment transport studies. Ascough, J C and Flanagan, D C. Soil erosion research for the 21st century Proceedings of the International Symposium, Honolulu, Hawaii, USA, 3 5 January, 2001. St Joseph, USA: American Society of Agricultural Engineers; 2001: 572-574.
387. Brazier, R. E.; Parsons, A. J.; Wainwright, J.; Powell, D. M., and Schlesinger, W. H. Upscaling understanding of nitrogen dynamics associated with overland flow in a semi-arid environment. Biogeochemistry: 2007; 82, (3): 265-278.
388. Lane, L. J.; Schertz, D. L.; Alberts, E. E.; Laflen, J. M., and Lopes, V. L. The U.S. National Project to Develop Improved Erosion Prediction Technology to Replace the USLE. In: sediment budgets. Iahs publication no. 174. International association of hydrological sciences, washington, dc. 1988. P 473-481, 25 ref.: 1988.
389. Gilley, J. E.; Lane, L. J.; Laflen, J. M.; Nicks, A. D., and Rawls, W. J. USDA-water erosion prediction project: new generation erosion prediction technology. ASAE Publication, American Society of Agricultural Engineers. 1988: (07-88): 260-263.
390. Garen, D.; Woodward, D., and Geter, F. A user agency's view of hydrologic, soil erosion and water quality modelling. Catena: 1999; 37, (3-4): 277-289.
391. Ludwig, B.; Daroussin, J.; King, D., and Souchere, V. Using GIS to predict concentrated flow erosion in cultivated catchments. Kovar K. and Nachtnebel H.P. Application of geographic information systems in hydrology and water resources management. Proc. HydroGIS'96 Conference, Vienna, 1996. IAHS; Publication, 235; 1996; 235, 429-436.
392. Line, D. E. and Meyer, L. D. Using the CREAMS model to estimate the effect of diversions on soil loss. Transactions-of-the-ASAE,-American-Society-of-Agricultural-Engineers: 1988; 31, (5): 1430-1434.
393. Nachtergaele, J.; Poesen, J.; Steegen, A.; Takken, I.; Beuselinck, L.; Vandekerchove, L., and Govers, G. The value of a physically based model versus an empirical approach in the prediction of ephemeral gully erosion for loess-derived soils. Geomorphology: 2001; 40, (3-4): 237-252.
394. Faulkner, H.; Alexander, R.; Teeuw, R., and Zukowskyj, P. Variations in soil dispersivity across a gully head displaying shallow sub-surface pipes, and the role of shallow pipes in rill initiation. Earth Surface Processes and Landforms: 2004; 29, (9): 1143-1160.
395. Rey, F.; Isselin-Nondedeu, F., and Bedecarrats, A. Vegetation Dynamics on Sediment Deposits Upstream of Bioengineering Works in Mountainous Marly Gullies in a Mediterranean Climate (Southern Alps, France). Plant and soil: 2005 Dec; 278, (1-2): 149-158.
396. Robinson, K. M.; Cook, K. R., and Hanson, G. J. Velocity field measurements at an overfall. Transactions of the American Society of Agricultural Engineers: ASAE; 2000; 43, (3): 665-670.
397. Cooper, C. M.; Smiley Jr., P. C.; Wigginton, J. D.; Knight, S. S., and Kallies, K. W. Vertebrate use of habitats created by installation of field-scale erosion control structures. Journal of Freshwater Ecology: 1997; 12, (2): 199-207.
398. Sanders, D. W. Water Erosion Control. Climatic change: 1986 Aug-1986 Oct 31; 9, (1/2): 187-194.

399. Miller, N. and Lee, O. Water erosion prediction project: operational computer program. National Water Conference: Proceedings of the Specialty Conference; Newark, DE, USA; 17 July 1989 through 20 July 1989. New York: American Society of Civil Engineers; 1989.

400. Maul, J. D. and Cooper, C. M. Water quality of seasonally flooded agricultural fields in Mississippi, USA. Agriculture, Ecosystems and Environment: 2000; 81, (3): 171-178.

401. Laflen, J. M.; Elliot, W. J.; Simanton, J. R.; Holzhey, C. S., and Kohl, K. D. WEPP: soil erodibility experiments for rangeland and cropland soils. Journal of Soil & Water Conservation: 1991; 46, (1): 39-44.

402. Ascough II, J. C.; Baffaut, C.; Nearing, M. A., and Liu, B. Y. The WEPP watershed model: I. Hydrology and erosion. Transactions of the American Society of Agricultural Engineers: 1997; 40, (4): 921-933.

403. Lubimov, B. P. Zonal features of gully erosion. Geomorfologiya: 1998; 1, 68-72.