# Testing the Ephemeral Gully Erosion Model (EGEM) in Mediterranean Environments

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## ABSTRACT

**Few models can predict ephemeral gully erosion rates (e.g. CREAMS, WEPP, EGEM). The Ephemeral Gully Erosion Model (EGEM) was specifically developed to predicted soil loss by ephemeral gully erosion. Although EGEM pretends to have a great potential in predicting soil losses by ephemeral gully erosion, it has never been thoroughly tested.**

**An EGEM-input data set for 86 ephemeral gullies was collected: 46 ephemeral gullies were measured in intensively cultivated land in Southeast Spain and another 40 ephemeral gullies were measured in both intensively cultivated land and in abandoned land in Southeast Portugal. Together with the EGEM-input parameters, the eroded volume for each gully was determined, so that the EGEM performance in predicting ephemeral gully erosion could be tested.**

**A very good relationship between predicted and measured ephemeral gully volumes was found ($R^2 = 0.88$). But as *ephemeral gully length* is an EGEM input parameter, both predicted and measured ephemeral gully volumes have to be divided by this *ephemeral gully length*. The resulting relationship between the predicted and measured ephemeral gully cross-section is not significant ($R^2 = 0.27$). It can therefore be concluded that EGEM is not capable of predicting ephemeral gully erosion for the given Mediterranean areas. A second conclusion is that *ephemeral gully length* is a key parameter in determining the ephemeral gully volume. Regression analysis shows that a very significant relation between *ephemeral gully length* and *ephemeral gully volume* exists ($R^2 = 0.91$). Accurate prediction of ephemeral gully length is therefore crucial.**

## INTRODUCTION

Several researchers have pointed to the importance of ephemeral gully erosion in the loess region of Western Europe (e.g. Evans and Cook, 1987; De Ploey, 1990, Poesen and Govers, 1990, Papy and Douyer, 1991). For the Mediterranean, Poesen et al (1996) showed that ephemeral gully erosion is by far the most important source of sediment production in upland areas.

Despite the importance of ephemeral gully erosion, only few physically based models have been developed to predict soil loss due to ephemeral gullying. CREAMS (Knisel, 1980) simulates ephemeral gully erosion through a procedure that takes into account detachment of soil due to shear of flowing water, sediment transport capacity, and changing channel dimensions. The equations that describe change in channel dimensions are developed by Foster and Lane (1983). The procedures are rather lengthy and need to be applied repetitively when eroded volumes by ephemeral gullying are calculated with CREAMS. The complexity of the Foster and Lane model (1983) led to a desire for an explicit prediction equation. A non-linear regression analysis between the computed values of the Foster and Lane model (1983) and the causative variables was conducted. The resulting regression equations, which represent a simplified erosion procedure based on Foster and Lane (1983), are incorporated in the Ephemeral Gully Erosion Estimator model (EGEE; Watson et al. 1986).EGEE for its part, served as a basis for the erosion component of the Ephemeral Gully Erosion Model (EGEM; Woodward, 1999). As the name of the model suggests EGEM is specifically designed for ephemeral gully erosion modeling.

Although EGEM pretends to have a great potential in predicting soil losses by ephemeral gully erosion, it has never been thoroughly tested. It is therefore the objective of this paper to test the Ephemeral Gully Erosion Model (EGEM) for two typical Mediterranean environments: Guadalentin (Southeast Spain) and Alentejo (Southeast Portugal). Analysis and interpretation of the results, obtained within the framework of desertification research in Southern Europe (Medalus-project), should contribute to a better understanding of the ephemeral gully erosion process in the Mediterranean.
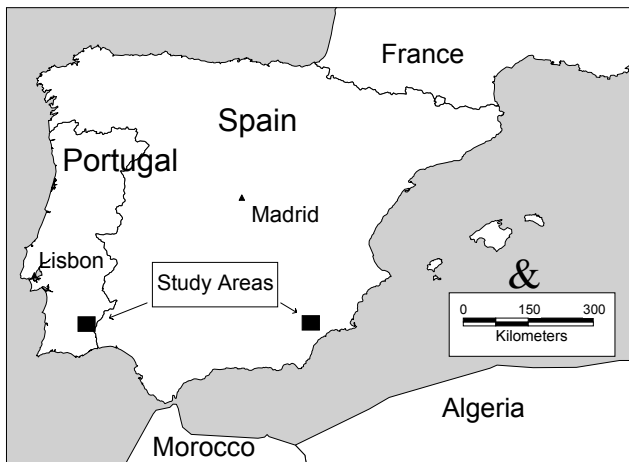
## STUDY AREAS

Field data for this study were collected in two typical intensively cultivated Mediterranean environments. A first field campaign was organized in the Guadalentin basin (Southeast Spain) from 10-17 January 1998. From February 28th until March 6th 1998, a second field campaign was held in the Alentejo (Southeast Portugal) (Fig. 1)

The Guadalentin basin is representative of many Mediterranean semi-arid to arid environments under threat of desertification (Brandt and Thornes, 1996). Soils are shallow, with very stony A/C or $A_p$ horizons (between 50 and 90% rock fragments by mass) over fragmented bedrock

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**Figure 1. Location of the study areas in Southeast Portugal (Alentejo) and Southeast Spain (Guadalentin).**
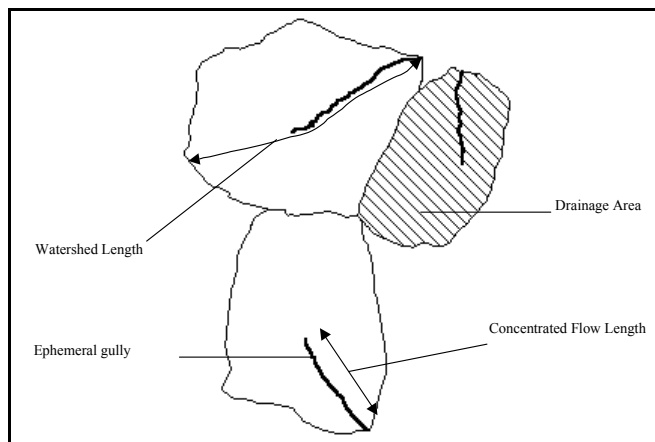


**Figure 2. Three ephemeral gullies and their respective drainage areas. The sketch illustrates how the input parameters *drainage area, watershed length,* and *concentrated flow length* are defined.**

(Puigdefábregas et al., 1996) classified as Eutric, Mollic and Lithic Leptosols (F.A.O., 1994). The area consists of rounded landforms with an altitude of 520 m to 960 m, and moderate to fairly steep slopes. The ephemeral gullies occurred on slopes of 8% - 52% with a mean value of 26.5% ± 10.3. The main land-use in the study area is almond cultivation, which is increasingly replacing the existing scrubland vegetation (matorral) (Poesen et al., 1997). On the other hand unproductive almond groves or other agricultural land are being abandoned and can be found in different stages of regeneration with natural vegetation. 94% of the ephemeral gullies in our survey developed in almond groves, whereas 6% was found in abandoned land. Almond groves are ploughed 3 to 5 times a year to control weeds and conserve water (Poesen et al., 1997; Vandekerckhove et al., 1998). The climate of the Guadalentin basin is mainly semi-arid, with an annual precipitation of 225-483 mm. Most of the rain falls in autumn and spring and rainfall events often show a very erratic spatial distribution (Cabezas, 1996).

The study area in Southeast Portugal is located in the Alentejo region near Mértola. The area is characterized by a network of dry valleys while most valley bottoms are incised by an intermittent stream network. The red shist soils are very shallow with stony topsoils containing on average 30% of rock fragment by mass (Leptosols). Mean annual precipitation is about 550 mm with a maximum between October and March (Vandaele et al., 1996). Around the 1930s the brush and oak vegetation was cleared for winter wheat and barley production (Tomás and Coutinho, 1994). The traditional and most widely spread crop rotation is wheat-fallow (De Lima, 1989), which means that the fields are unprotected during the period with the highest rainfall amounts. Slopes in this study area are gentle, ranging from 3% to 20 % with a mean value of 8.1% ± 4.4.

## METHODS

EGEM consists of two major components: a hydrology component and an erosion component. The model can be used to estimate ephemeral gully erosion for a single storm or for average annual conditions. For average annual estimates the year may be divided into up to three periods representing different soil and cover conditions. For example, (1) time after tillage, (2) crop maturing phase and (3) winter crop or fallow condition. The ephemeral gully erosion for each of these periods is then weighted by the erosivity index (EI) of the rainfall for the associated months of the year. Average annual rainfall is described by the 2-year and 25-year, 24-hour frequency rainfalls. For a single storm erosion estimate, EGEM only uses 24-hour rainfall data (Woodward, 1999). As ephemeral gullies in our study areas are believed to be the result of one single event and as the respective 24-hour rainfall data were available, only EGEM's single storm option is used within this study.

Table 1 summarizes all EGEM input parameters and the way they were collected. Fig 2 visualizes how the input parameters *drainage area, watershed length* and *concentrated flow length* are defined. For most parameters a mean and standard deviation is given (Table 1). These figures clearly illustrate differences between the two study areas. Ephemeral gullies in the Guadalentin were much smaller than these from the Alentejo. Consequently they had also smaller drainage areas, but developed on steeper slopes. These differences are masked by rain depth, as the event that caused ephemeral gullies in the Guadalentin had only 2/3 of the rain depth of the event that caused ephemeral gullies to develop in the Alentejo. All other input parameters are very similar for the Guadalentin and for the Alentejo.

Together with the EGEM input parameters, also depth, width and length of the ephemeral gullies were measured. Each ephemeral gully was divided in as many segments as there were significant (i.e. observable by eye) changes in gully channel morphology along the longitudinal profile. For each segment, length was measured by means of differential GPS, while depth and width were measured with a folding rule. This depth and width were then stored as attributes for that segment, so that numerical and graphical information for each ephemeral gully was directly linked to each other. Given depth, width, and length of each gully segment, total

**Table 1. An overview of the EGEM-input parameters and the way they are collected, for both the Alentejo and the Guadalentin study area.**

| Parameter | Data collection method | Guadalentin | | Alentejo | |
|---|---|---|---|---|---|
| | | Mean | Standard deviation | Mean | Standard deviation |
| **Drainage Area (m²)** | GPS | 996 | 2479 | 12 280 | 12 122 |
| **Watershed length (m)** | Mapinfo analysis | 59.6 | 41.0 | 157.9 | 105.5 |
| **Concentrated flow length (m)** | GPS | 22.1 | 18.1 | 86.1 | 78.1 |
| **Watershed slope (%)** | Clinometer | 27.5 | 8.6 | 12.5 | 4.0 |
| **Concentrated flow slope (%)** | Clinometer | 30.2 | 10.3 | 9.8 | 4.5 |
| **Curve number** | Field observation | 87.7 | 1.4 | 85.7 | 1.6 |
| **Soil class** | Soil sample / granulometric analysis | Sandy Loam: 72%, Loamy sand: 15%, Loam: 13% | | Sandy Loam: 55%, Loamy sand: 2.5%, Loam: 42.5% | |
| **Channel erodibility factor (s⁻¹)** | Auto generated † | 0.27 | 0.01 | 0.23 | 0.09 |
| **Critical shear stress (kg/m²)** | Auto generated † | 0.101 | 0.015 | 0.242 | 0.308 |
| **Maximum gully depth (m)** | Field measurement | 0.265 | 0.090 | 0.280 | 0.141 |
| **Bulk density (kg/m³)** | Soil sample | 1373 | 175 | 1400 | 146 |
| **Particle diameter (mm)** | Auto generated † | 0.14 | 0.05 | 0.10 | 0.05 |
| **Particle specific gravity (kg/m³)** | Auto generated † | 2.62 | | 2.62 | |
| **Manning n** | Auto generated † | 0.03 | | 0.03 | |
| **Rain distribution type** | Rainstorm distribution analysis | II | | II | |
| **24 hour rainfall depth (mm)** | Rain gauge | 48.6 | | 74 | |
| **Tillage practice** | Field observation | Total area tilled: 100% | | No-till: 7% Total area tilled 97% | |

† As soon as *soil class* and *tillage practice* are filled in EGEM defines values for this parameter

ephemeral gully volume for each ephemeral gully could easily be calculated by summing up the volumes of the respective segments.

## RESULTS AND DISCUSSION

The most direct way to present EGEM 's performance is confronting the predicted ephemeral gully volumes with the ephemeral gully volumes measured in the field. Combining the data from the Alentejo study area and the Guadalentin study area yielded detailed information on 86 ephemeral gullies. Fig 3 shows a significant relation ($R^2$ = 0.88) between measured and predicted ephemeral gully volumes. Moreover, the trend line is lying close and almost parallel to the line of perfect agreement.

The performance of EGEM as presented above has to be put into perspective. The input parameters used for testing EGEM are optimal figures, most accurately assessed in the field. What has been tested therefore, is in fact the potential performance of EGEM. For the ephemeral gullies to be predicted by EGEM in this study, input parameters such as *Drainage area*, *Watershed length*, *Concentrated flow length*, *Watershed slope*, *Concentrated flow slope*, *Curve number*, *Maximum depth* and *Bulk density*, have been measured in the field at the time that the ephemeral gullies were present. It is evident that whenever the EGEM will be used for prediction of ephemeral gully erosion rates quality of input data will be worse, and therefore prediction will be worse too.

Another significant remark is that *ephemeral gully length* is amongst the input parameters. EGEM uses this parameter to multiply it with the predicted mean ephemeral gully cross-section, in order to obtain ephemeral gully volumes. To have an idea of the real performance of EGEM, both predicted and measured erosion volumes should be divided by this *ephemeral gully length*. Fig 4 shows that the relationship between predicted and measured mean cross-sections is rather poor ($R^2$ = 0.27). This strongly contrasts with the relationships found between predicted and measured
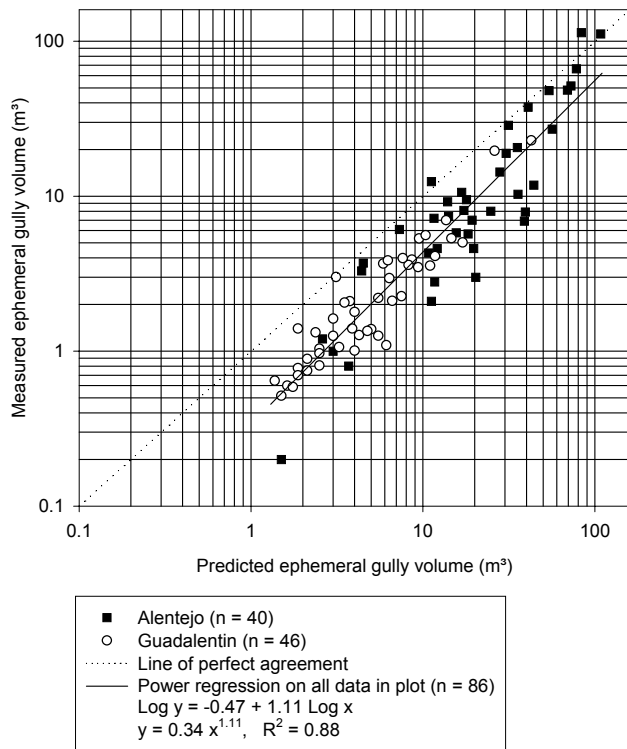
Figure 3. Predicted versus measured ephemeral gully volume on a double logarithmic scale for two Mediterranean areas: Alentejo (Southeast Portugal) and Guadalentin (Southeast Spain). N = 86. Ephemeral gully volumes are predicted by EGEM.
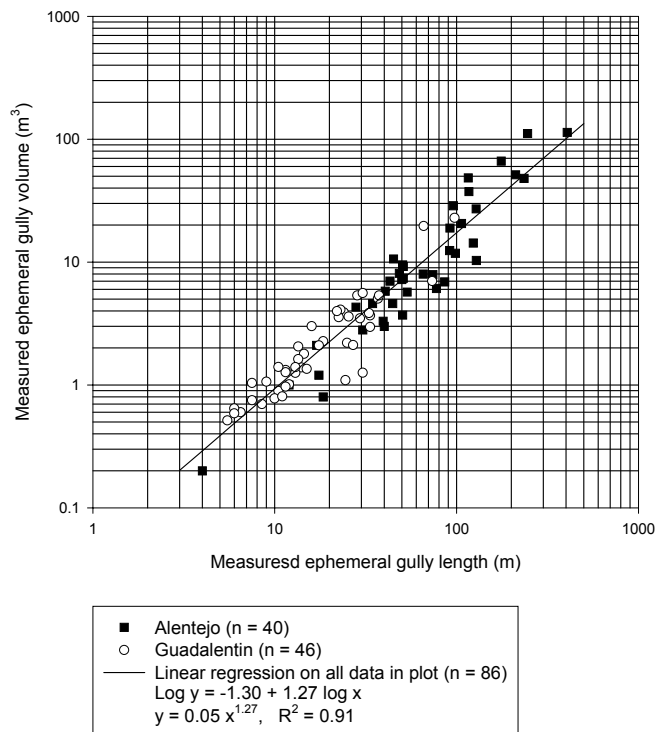


Figure 5. Measured ephemeral gully length versus measured ephemeral gully volume on a double logarithmic scale for two Mediterranean areas: Alentejo (Southeast Portugal) and Guadalentin (Southeast Spain).
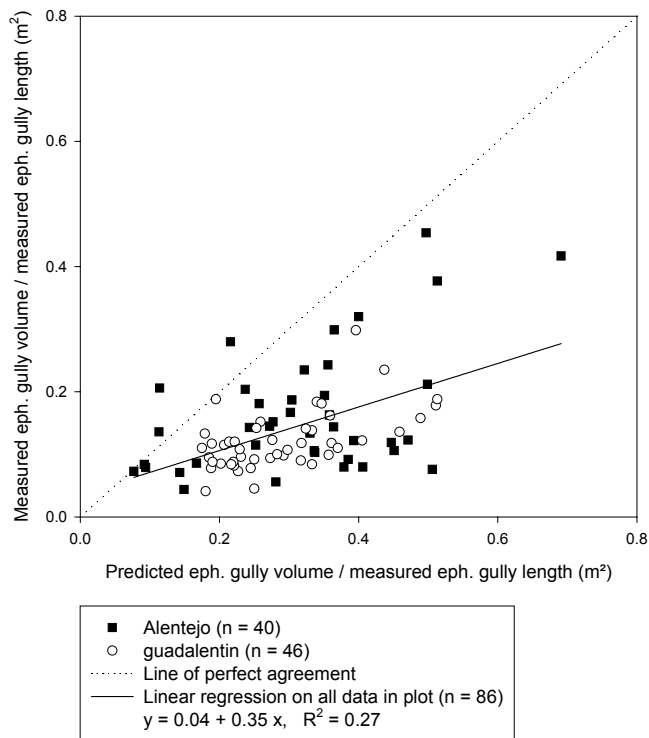
ephemeral gully volumes (Fig 3). Therefore it can be concluded that for the ephemeral gullies found in our study areas, EGEM is not capable of predicting mean ephemeral gully cross-sections well. The fact that EGEM predicts total ephemeral gully volumes in a satisfactory way, is entirely due to the strong relationship that exists between the *ephemeral gully length*, which is an EGEM input parameter, and the *total ephemeral gully erosion volume* ($R^2 = 0.91$; Fig. 5).

EGEM is not capable of predicting ephemeral gully erosion in the Alentejo and the Guadalentin. Reasons for EGEM's inability could be the underlying theory of Foster and Lane (1983) which may not be adapted to describe the ephemeral gully erosion process in the Mediterranean areas. Also the regression equations (Watson et al., 1986) which in fact replace Foster and Lane's theory (1983) within the EGEM model, may be inappropriate for the Mediterranean situation. Further sources of uncertainty are input parameters such as *channel erodibility* and *critical shear stress*, which are auto-generated by the model, and may therefore not be representative for the situation in our study areas. Uncertainty may also be related to data collection. While most of the input parameters have been assessed very accurately, there is a great source of uncertainty on the rainfall data. However these data have been obtained from rain gauges in the respective study areas. The erratic spatial distribution of rain in these semi-arid environments (Cabezas, 1996), makes it very hard to determine local rain depth. Finally, there are some factors controlling ephemeral gully erosion that are not incorporated in EGEM: examples



Figure 4: Predicted versus measured mean ephemeral gully cross-sections for two Mediterranean areas: Alentejo (Southeast Portugal) and Guadalentin (Southeast Spain). Ephemeral gully cross-sections are predicted by EGEM.

are: land use at the place of gully formation and stoniness. The first factor can be taken into account via the *curve number*, but there is no way to incorporate the effect of land use in the *channel erodibility* value and the *critical shear stress*. Also the presence of rock fragments will have a significant influence on gully formation, which is at present not taken into account in the *channel erodibility* and *critical shear stress*.

## CONCLUSIONS

A first conclusion of this study is that despite the optimal conditions under which input data have been obtained, EGEM is not capable of predicting ephemeral gully cross-sections for the two considered Mediterranean study areas.

A second important conclusion that results from testing EGEM is that *ephemeral gully length* is a key parameter in determining ephemeral gully erosion. Further research should therefore focus on this gully parameter. Given the problems with physically based erosion equations, determining ephemeral gully length from simple topographical thresholds may be an interesting alternative.

## ACKNOWLEDGEMENTS

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