Gully geometry: what are we measuring?

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Abstract

Many of the research works on (ephemeral) gully erosion comprise the determination of the geometry of these eroded channels especially their width and depth. This is not a simple task due to uncertainty generated by the wide range of variability of gully cross-section shapes found in the field. However, in the literature, this uncertainty is not recognized so that no criteria in their measurement procedures are indicated. The aim of this work is to make researchers aware of the ambiguity that arises when characterizing the geometry of an ephemeral gully and similar eroded channels. In addition, a measurement protocol is proposed with the ultimate goal of pooling criteria in future works. It is suggested the geometry of a gully could be characterized through its mean equivalent width and mean equivalent depth, which, together with its length, define an "equivalent prismatic gully" (EPG). The latter would facilitate the comparison between each other of different gullies.

1. Introduction

The classic forms of water erosion are caused by non-concentrated or laminar flow and concentrated flow; in the latter, rill and gully erosion has been recognized (Hutchinson and Pritchard, 1976). Rill erosion is produced in the form of numerous channels of a few centimeters in depth, distributed uniformly and randomly over sloping lands (Soil Science Society of America, 2015), and which can easily be obliterated by conventional tillage (Hutchinson and Pritchard, 1976). Also, permanent gullies are distinguished from ephemeral ones (Foster, 1986; Thorne et al., 1986; Casalí et al., 1999). Permanent gullies are erosion channels which are too large to be eliminated by conventional tillage (Soil Science Society of America, 2015). Ephemeral gullies –present in agricultural soils– are, like rills, small enough for it to be possible to eliminate them by traditional tillage (Soil Science Society of America, 2015), hence their being qualified as ephemeral. However, when they form again, and contrary to what is observed in rills, they tend to appear in the same places. This is explained by the fact that the ephemeral gullies are formed in the thalweg which configures the confluence of two opposing slopes, a fact which conditions the trajectory of the runoff. Rills, however, occur entirely on one single slope (Casalí et al., 1999); their formation is, therefore, mainly subjected to the high spatial variability of intrinsic factors of the soil (structural stability, hydraulic conductivity, etc.) and of its tillage.

The objectives of a large number of works on gully erosion have been the estimation of the spatial and/or temporal evolution of a gully or a network of them under different conditions (i.e. climate, land use, etc.) (e.g., Casalí et al, 2006; Gabet and Bookter, 2008; Campo-Bescós et al., 2013). For that purpose, as a first step, a morphological characterization is made of these channels. The most frequent way to do so is by the measurement of their width and depth –and the ratio between both parameters– (e.g., Giménez et al., 2009); and their typology is also studied (for example, whether their cross section presents a general shape like a U or a V). If the measurement of the length of the gully is added to this, it might be possible to arrive at determining their volume (eroded soil).

Consequently, for a precise description of the geometry of a gully, the correct determination of its width is a key factor. This is not always an easy task, especially when faced with cross sections with intricate shapes and diffuse limits. However, in the numerous scientific works on the subject, no uncertainty whatever is expressed on this measurement, and neither are the criteria followed in the procedure specified. We believe that, as a general rule, it is usually assumed that their width is defined by the imaginary line whose ends are located at both points of the two banks, where an abrupt change in slope is manifested. This criterion would be followed both in direct measurements in situ, and in indirect ones taken from digital elevation models and mathematic algorithms ad hoc (e.g., Evans and Lindsay, 2010; Parker et al., 2012; Castillo et al., 2014). This procedure, at first sight reasonable and unquestionable, raises, however, two objections. First, there is the presence of more than one point of slope inflection in one or both banks. Second, although only one visible inflection point is presented on the slope of each bank – with the width of the channel thus being clearly defined – this poses a question. Do the limits of this channel, defined in this way, really correspond to the transversal limits of the erosive process which gave rise to the gully? Only by knowing the topography of the land at moments before the formation of the gully would that question be answered with any certainty.

On the other hand, the width of a gully defines the upper limit of its cross section, therefore conditioning the subsequent determination of the depth of that channel. Furthermore, in this latter measurement (depth of the gully), another important ambiguity is added, i.e. the determination of the lower limit of the cross section (channel bed). This latter limit is usually located –in our belief– at the lowest point of the cross section, which is questionable in beds with a highly irregular cross sectional profile. Even so, nor is the difficulty inherent in measuring a gully depth usually emphasized in the literature.

In short, the lack of any protocol or universal criterion in determining the geometry of gullies would then cause a certain uncertainty at the moment of comparing between each other the experimental results obtained by different researchers; for example, erosion rate values.

In this work it is sought to make the scientific community aware of the –precisely, inadvertent doubts– which are triggered when characterizing the geometry of an ephemeral gully, and for this purpose some examples of real cases will be shown. Also, a measurement protocol is proposed with the ultimate aim of pooling criteria in future works and experimentation. Although they are proposed for ephemeral gullies, these same criteria would equally apply for similar erosion channels.

2. Uncertainties in measuring the width and depth of a gully

Researchers, especially newcomers, when confronted with the measurement of gully geometry, assume that the limits of the erosion channel will present themselves in the field as being clearly defined, and, in fact, this is often true (see Fig. 1.1-1.3). However, on many occasions this is not the case (Fig. 1.4-1.6). It is therefore possible that a clear break in the slope of one of the banks (Fig. 1.6) or in both of them (Fig. 1.5) may not be noticed. Another possible ambiguity –independent or added to the previous one– is that which arises when both banks of the channel are uneven (Fig. 1.4, Fig. 1.6). This means that determining a single height value to trace an imaginary horizontal line between both banks is highly subjective. It is understood that the length of this line would be defining the width of the cross section being measured.

In another sense, when defining the depth of a gully, the lower limit of the cross section is usually well defined by the lowest point of the bed (see Fig. 1.2). However, what usually happens is that the location of this limit is also controversial as can be seen in the cross sections in Figures 1.1. and 1.3., where it is precisely not clear if this limit would really be represented by the lower height of the bed.

An incorrect determination of the width and/or depth of a certain gully may cause (important) errors in the determination of its volume; i.e. in the estimation of the eroded soil (Fig. 2 and Fig. 3). The magnitude of this potential experimental error would be less obvious, and even underestimated, if we analyze the cross sections individually (Fig. 2). However, an overall review of all the sections conforming the gully being studied would give a better assessment of this measurement error. Fig. 3 aims to illustrate the effect that the criterion followed to determine the cross section width exerts on the computed volume of a gully reach. A real gully reach was selected and three cross sections were used for calculating the volume of the reach (P1, P2 and P3) (Fig. 3a), the distance between cross sections being known. First, the eroded volume was calculated considering a possible criterion for defining the gully cross sections width (in blue, Fig. 3b). Then, the eroded soil was calculated again but considering another possible criterion for defining the gully cross sections widths (in red, Fig. 3b). The difference in the calculated volume for both situations is remarkable, increasing by 96% from option b to option c. Figure 3 is just one example illustrating: i) the great differences in volumes that can be obtained in fixing the gully widths arbitrarily; ii) the error that can be generated and; iii) the necessity of establishing rigorous and objective criteria and protocols. The purpose of figure 3 is similar to figure 2, the latter depicting the effect of the uncertainty in the determination of width in a single cross-section of a gully.

3. Topographic definition of gully width, equivalent prismatic gully (EPG)

Let`s suppose that we have a detailed digital elevation model (DEM) of a gully whose geometry we wish to determine (Fig. 4a). Similarly, we would also have a DEM, not more than one year old, of the same area, but before the gully in question would have formed. Remember that the cycle of the formation and obliteration of an ephemeral gully is conditioned by the periodicity (usually one year) of the agricultural tillage responsible for it. We shall call the DEM prior to the appearance of the gully $DEM_{year\ n}$, whereas that of the following year –that is, with the gully now present– $DEM_{year\ n+1}$ (Fig. 4a).

Let`s imagine now that, at any point x along the longitudinal axis of length L of the gully, we draw a vertical plane P_x, perpendicular to that axis (Fig. 4b). If in this plane P_x we substract the $DEM_{year\ n+1}$ from the $DEM_{year\ n}$, we should obtain the eroded area or cross section of the gully (Fig. 4b). Now, the imaginary line which arises from joining the two points of the intersection of both DEMs would define, in turn, the width of the gully in that section (P_x) (Fig. 4b). In the case of both points being uneven, a horizontal projection of the line should be considered. This same operation could be repeated in a multitude of other points xi along the channel, thus obtaining the width value of each new section (W_i). Finally, the average of the values W_i would define the mean equivalent width of the whole gully, W_{me}. Those widths, determined thus, would undoubtedly be the true transversal limit of the erosion process which caused the gully in question.

If we now carry out the substraction of both DEMs but on their entire surface, we should obtain the volume V of the gully (Fig. 4a).

Also, knowing V and W_{me}, we could, in turn, determine a mean equivalent depth D_{me} expressed as:

$$D_{me} = V / (W_{me}\ L) \tag{1}$$

This depth value would be more representative of the whole gully than that resulting from considering the minimum height of the bed as being the lower limit of the cross section (see above).

Finally, the gully could be represented as a rectangular-based prism ($W_{me}\ D_{me}$) of a length L, which we would call “equivalent prismatic gully” (EPG) (Fig. 4c and Fig. 5). This sort of normalization of the complex geometry of a certain gully –by means of its respective EPGs– would permit, for example, a quick visual comparison of the individuals of a varied population(s) of gullies (Fig. 5). It would thus be an interesting tool for incorporating into simulation models (e.g., AnnAGNPS, Gordon et al., 2007).

In effect, we believe that the concept of equivalent prismatic gully shows several benefits and applications. Probably the principal one is that it permits the determination of the most important characteristics of a complete gully (V, L, W_{me} and D_{me}), using objective and repeatable criteria. Otherwise, there is the risk of assigning information from specific cross sections or reaches to the whole gully. Besides, the gully properties (V, L, W_{me} and D_{me}), as defined here, can be incorporated into statistical analyses or similar studies in which many gullies are involved, using a common language, repeatable and comparable among different researchers. Furthermore, by using the concept of an equivalent prismatic gully, sets of complete gullies can easily be graphically represented, which enables a quick and explanatory visual comparison.

The width of a gully cross section, as defined in this paper, depends on the DEMs pixel size and it depends on the type and size of the studied channel. Hengl (2006) concluded that, to prevent the loss of relevant information, the maximum pixel size must be the average of the minimum distances between sampling points. In the same way, Garbrecht and Martz (1994) fixed the pixel size to the size of the minimum distinguishable object. Additionally, the new methodologies available (terrestrial or aerial LIDAR, 3D photo-reconstruction, etc.), provide a very detailed information, which may be more than enough, in our opinion, for the purposes of these studies. However, these thresholds should be explored in future researches.

4. Conclusions

In order to progress in gully erosion research, clear criteria to define and determine the key morphological characteristics of gullies and their related properties (such as volumes) are needed. In this paper, a new proposal for advancing towards that goal has been submitted. Thus, starting from a precise definition of the width of each gully cross section, the mean equivalent gully width and depth are defined, and also the equivalent prismatic gully (EPG). This approach permits the determination of the most important characteristics of a complete gully (V, L, W_{me} and D_{me}), using objective criteria. Besides, the gully properties defined here can be incorporated into statistical analyses using a common language among different researchers. On the other hand, by using the EPG, sets of complete gullies can be easily graphically represented, which allows for an explanatory visual comparison. The definition of the width of each gully cross section assumes that the topography of the area before the gully appearance is known. This is, in fact, really infrequent, so that a new line of research arises. Anyway, we believe that the proposal is a considerable advance in the applied research on gullies, because it allows one to standardize the definition and determination of the most important characteristics of these erosion forms.

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Figures

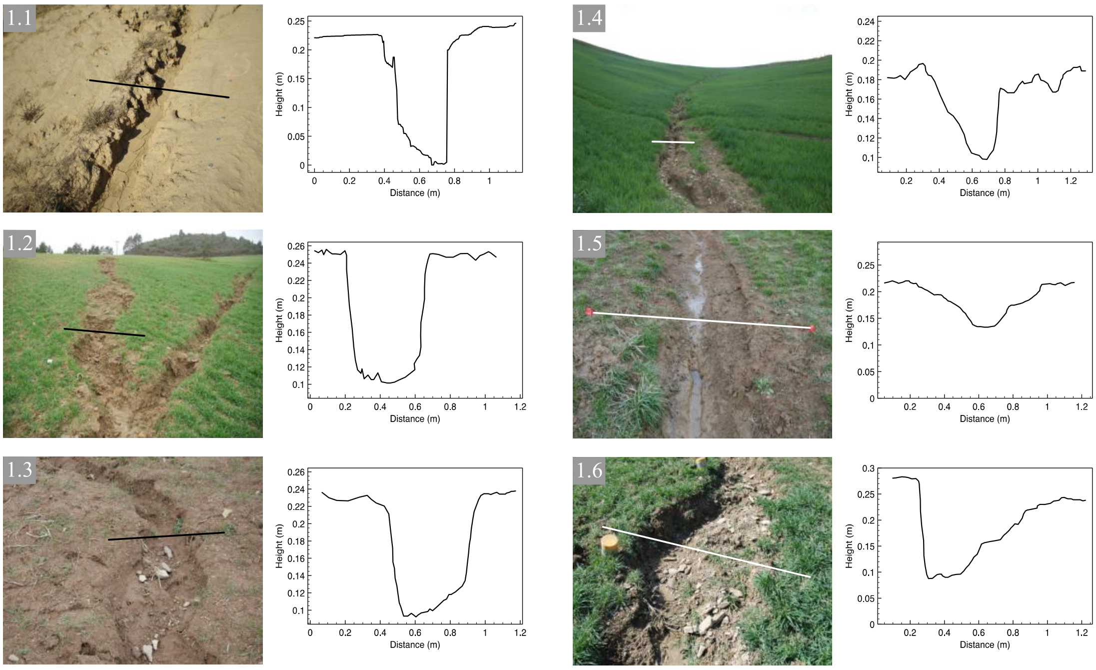

Figure 1. Examples of cross-sections of typical ephemeral gullies (Navarre, Spain).

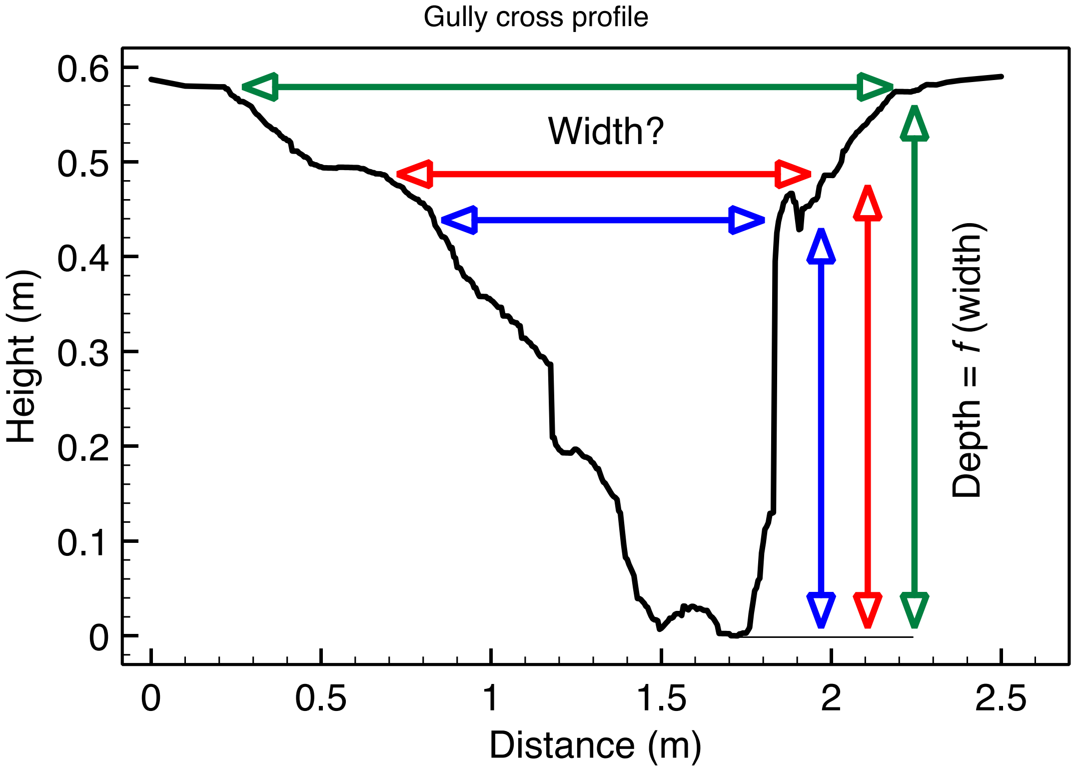

Figure 2. Uncertainty in the determination of a width in a cross-section of a gully (real example).

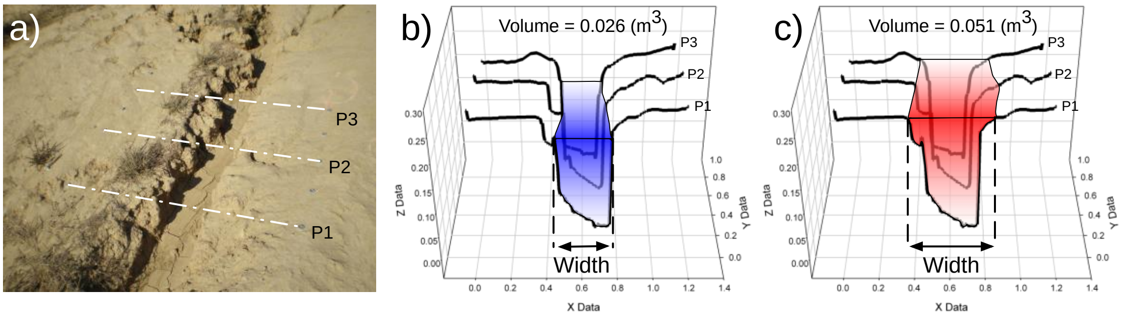

Figure 3. Illustration of the effect that the criterion followed to determine the cross section width exerts on the computed volume of a gully reach. a) Selected gully reach and location of the three cross sections used for calculating the volume of the reach (*P1*, *P2* and *P3*); the distance between cross sections is known. b) Calculated eroded volume (in blue) when considering a possible criterion for defining the gully cross sections widths. c) Calculated eroded volume (in red) when considering another possible criterion for defining the gully cross sections widths.

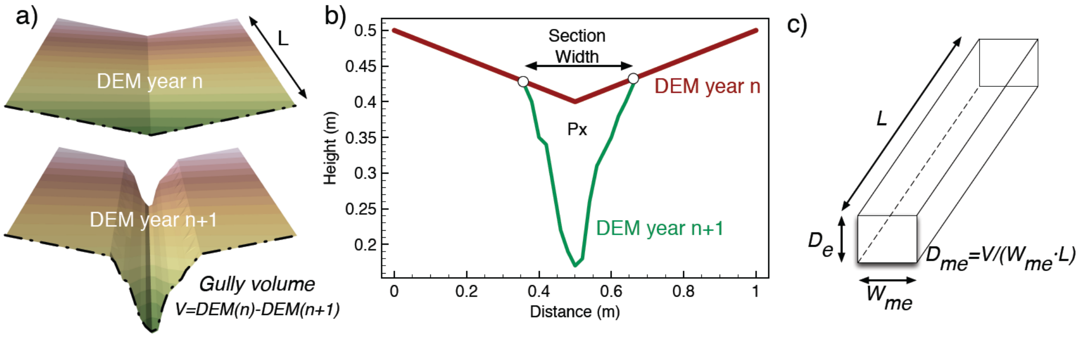

Figure 4. a) Sketch of two separated digital elevation models of a fictitious plot before ($DEM_{year\ n}$) and after ($DEM_{year\ n+1}$) a gully has been formed in the plot thalweg; b) sketch cross section area depicted at any point *x* along the longitudinal axis of the gully; c) equivalent prismatic gully (EPG). See section 3 for details.

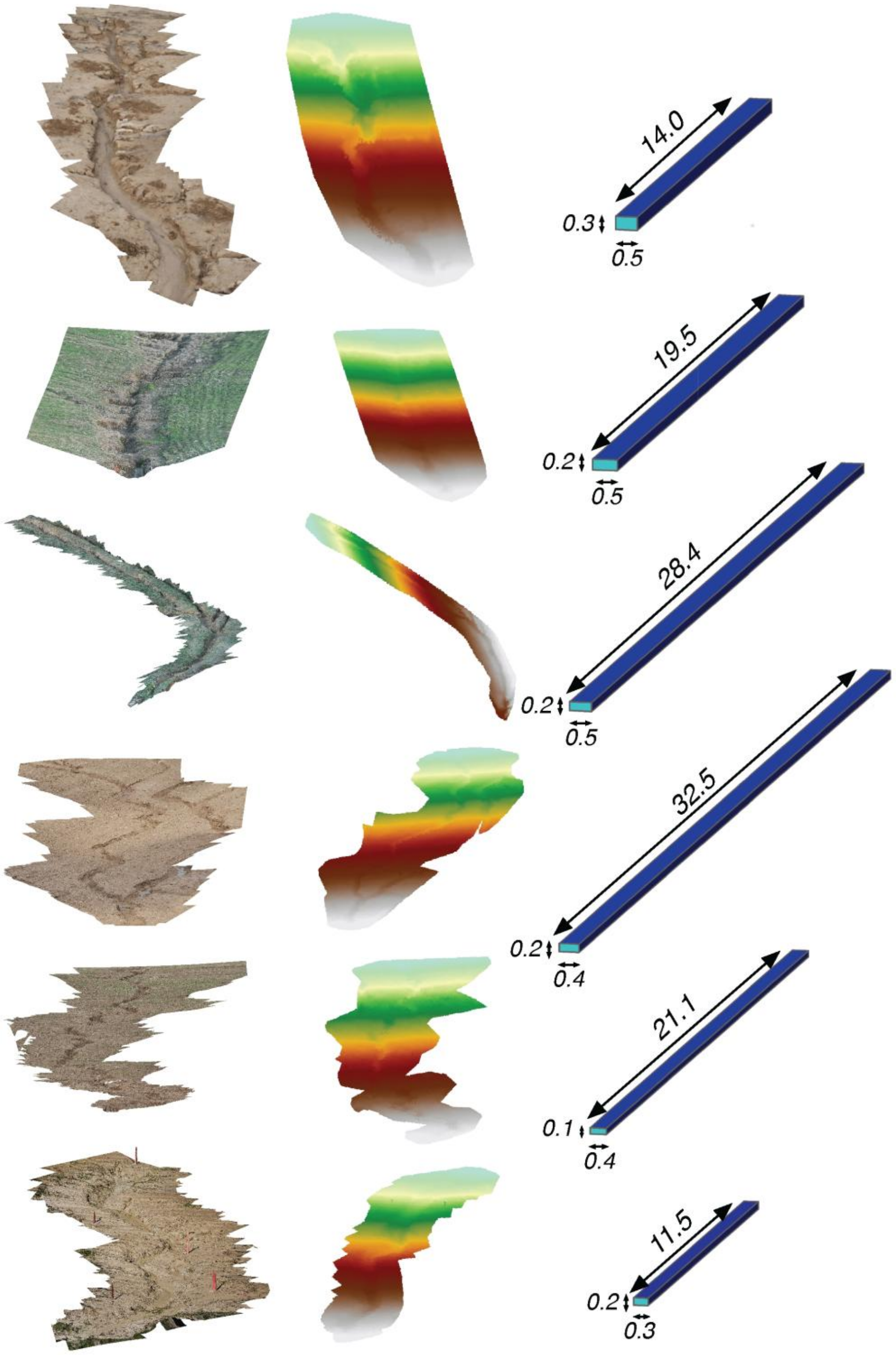

Figure 5. a) Pictures of ephemeral gullies of different shapes (Navarre, Spain); b) Digital elevation model ($DEM_{year\ n+1}$, see Figure 4) of each gully; c) Equivalent prism of the gullies (since there was not a DEM available prior to the gully formation ($DEM_{year\ n}$, see Figure 4) the width was arbitrarily defined from abrupt changes at both gully banks (see text for more explanation). It should be made clear that the geometry of the equivalent prisms could have (dramatically) changed if we had also counted with the corresponding $DEM_{year\ n}$. (Lengths in m)