AGNPS GIS-Based Tool for Watershed-Scale Identification and Mapping of Cropland Potential Ephemeral Gullies

H. G. Momm, R. L. Bingner, R. R. Wells, D. Wilcox

Abstract. *The formation of ephemeral gullies in agricultural fields has been recognized as an important source of sediment contributing to environmental degradation and compromising crop productivity. Methodologies are being developed for assessing gully formation and gully sediment yield. The Annualized Agricultural Non-Point Source (AnnAGNPS) pollution model is an important tool for multi-temporal watershed-scale simulations because it contains the necessary components for ephemeral gully investigation, making AnnAGNPS a commonly used tool for evaluations of agricultural conservation and operation practices. AnnAGNPS requires the user to define the location of ephemeral gullies throughout the watershed, what often constitutes a time consuming task where users may not accurately locate and describe all ephemeral gully locations. Alternatively, herein a GIS-based graphical user interface is described for the automated identification of areas with high probability of forming ephemeral gullies, referred to as potential ephemeral gullies (PEGs), based on the modified Compound Topographic Index (CTI). Through the aid of a study case, PEG mouth locations along with their attributes are generated through an iterative procedure by varying different CTI threshold values (99.9%, 99.5%, 99.0%, 98.5%, and 98%). Three sets of yielded PEG mouth locations and corresponding attributes were then integrated with AnnAGNPS for assessment of the impact of potential ephemeral gullies in the watershed sediment erosion. Analysis of the spatial distribution of estimates of annual average of gully erosion identifies the sub-watersheds prone to ephemeral gully erosion, thus enhancing the applicability of AnnAGNPS to evaluate conservation practices and/or targeted interventions designed to address ephemeral gully erosion at the watershed-scale.*

Keywords. *AnnAGNPS, Compound topographic index, Ephemeral gully, GIS, Cropland erosion.*

Soil erosion in agricultural fields is a major problem promoting environmental degradation, threatening food security and economic stability (Pimentel et al., 1995; Lal, 2001; Ananda and Herath, 2003; Van Oost et al., 2007; Lal, 2009). Scientific understanding of soil erosion phenomena is vital when developing methods to minimize the impacts associated with soil erosion (De Ploey, 1989). Research of soil erosion by water in agricultural fields can be categorized by overland flow processes, which in turn influence two main erosion processes: sheet and rill, and gully erosion (Foster and Meyer, 1972; Hutchinson and Pritchard, 1976; Meyer, 1981; Smith, 1993). Various methodologies have been developed to evaluate soil erosion from agricultural fields, particularly for sheet and rill erosion (Wischmeier and Smith, 1978; Knisel, 1980; and Renard et al., 1991). Recently, there has been growing awareness of the significance of ephemeral gullies as an important source of sediment from farm lands (Woodward, 1999; Flanagan et al., 2001; Gordon et al., 2008; Bernard et al., 2010).

Ephemeral gullies are defined as small eroded channels, generally in agricultural fields, formed mainly as a result of concentrated overland flow from a rainfall event. These channel features are considered seasonal/periodical in nature due to their small size (0.5 to 50 cm in depth) and the agricultural producer's capability to remove these channels by refilling them with soil during farming operations (Quadros et al., 2004). Ephemeral gullies often form in the same or nearby locations due to field topographic characteristics that remain relatively unchanged (Foster 1982; Thorne, 1984; Casalí et al., 2000). This dynamic characteristic tends to hide gully formation and subsequent soil losses and, consequently, the contribution of ephemeral gullies to nonpoint source pollution (Casalí et al., 1999). This makes the assessment and quantification of the effectiveness of conservation practices on pollutant loading control more difficult, especially for those associated with ephemeral gully erosion control.

Developed models to assess gully formation and sediment yield vary in their level of complexity, and consequent applicability, as necessary databases of required input parameters are not always available (Souchere et al., 2003). These methodologies have been designed for ephemeral gully investigation at individual field-scale (Woodward, 1999, Souchere et al., 2003) often requiring detailed soil properties collected from each agricultural field considered (Cerdan et al., 2002). In contrast, modeling and simulation

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tools require identification and characterization of potential ephemeral gullies in a watershed-wide fashion and therefore an automated/semi-automated framework is necessary. Systems, such as the Annualized Agriculture Non-Point Source (AnnAGNPS) pollution model (Bingner and Theurer, 2001; Yuan et al., 2003), are important tools for watershed-scale simulations and are commonly used to evaluate conservation and operation practices. AnnAGNPS has been developed with components needed to evaluate the effect of agricultural conservation practices on ephemeral gullies; however, the user is required to define the locations of the *mouth* of individual ephemeral gullies throughout the watershed (Bingner et al., 2009). An ephemeral gully mouth used to represent a gully's point of origination is defined as the knickpoint at a fixed point in the landscape at the gully's most downstream point. The knickpoint plunge pool develops below the gully mouth and before the headcut begins to advance upstream. Selecting the precise location of a gully's mouth is critical in defining the associated parameters used in simulating the evolution of the gully with AnnAGNPS. Identifying this location and related gully characteristics without automated GIS tools is often a difficult and time consuming task where users may not accurately locate and describe all potential ephemeral gully (PEG) locations.

The objective of this article is to describe a GIS-based graphical user interface that has been developed for use as an integrated tool within the existing AGNPS GIS interface (AGNPS, 2010), for the automated identification of potential ephemeral gully mouth based on the Compound Topographic Index (CTI) (Thorne and Zevenbergen, 1990) and subsequent gully characteristics. The AGNPS PEG Evaluation Tool (APET) is composed of two distinct components used to analyze the impact of potential ephemeral gullies on a watershed. The first component involves defining and selecting the locations of pathways and mouths associated with potential ephemeral gullies along with their attributes. The interactive tool allows the user to apply existing knowledge of the formation of gullies within the watershed to provide information that influences the PEGs automated mapping process. In the second component, the watershed PEGs detailed characteristics are determined, including PEG parameters necessary for populating the Ephemeral Gully data section of the AnnAGNPS Input Editor for the creation of the AnnAGNPS input file. These two components are described in this article with example study cases illustrating the application of the APET.

Background

The occurrence of ephemeral gullies depends on a range of physical and management properties such as terrain topography, rainfall duration and intensity, soil moisture, soil properties, vegetation cover, and management practices. An *actual* ephemeral gully will form when a specific combination of these factors leads to overland runoff discharges in excess of the soil shear stress which produces scour holes and headcut upstream migration. The effects of an actual ephemeral gully are measurable, but often are only visible for a short period before the next tillage operation fills in the gully with sediment. Conversely, herein, *potential* ephemeral gullies are defined as a conceptual term to describe geographic locations with high probability of developing an actual ephemeral gully. A potential ephemeral gully may or may not become an actual ephemeral gully depending on the previously described combination of physical and management factors. For illustration, consider a grass-covered field with no soil disturbing operations but, topographic terrain parameters indicating a high probability of forming an ephemeral gully mouth. This potential ephemeral gully will not develop into an actual ephemeral gully, even though topographic parameters indicate the high probability because of the lack of agricultural practices that would disturb the soil. If, for example, the field is tilled (and consequently the soil disturbed) followed by an intense rainfall event capable of producing sufficient overland flow to start a scour hole and produce headcut migration, the actual ephemeral gully could then form producing eroded sediments. Accurate mapping of potential ephemeral gullies can lead to the quantification of erosion from gullies when agricultural practices occur and can help evaluate the effect of conservation practices that can be targeted to the appropriate source of erosion.

Compound Topographic Index

Several authors have investigated the relationship between ephemeral gully formation and erosive power of flowing waters through the development of topographic indices. Zevenbergen (1989) identified five main factors as being responsible for gully formation: overland flow discharge, slope and flow depth, planform curvature, soil characteristics, and vegetation characteristics. Soil and vegetation characteristics are important factors in the modeling of ephemeral gullies; however, data is limited or, when existing, not available at the watershed scale. The remaining three factors, overland flow discharge, slope and flow depth, and planform curvature, can be characterized by the stream power concept (Thorne et al., 1984) which is often represented using topographic indices derived from digital elevation models (DEM). Recent improvements in spatial resolution and availability of DEMs have increased its utilization for ephemeral gully investigation. Global-scale datasets are now available at nominal ground sampling distances such as 10 and 30 m. New technologies, such as Light Detection and Ranging (LIDAR), can offer regional-scale datasets at 1 to 5 m.

Thorne et al. (1984) proposed the use of discharge, slope, and planform curvature as a measure of the stream power, Ω. Stream power is defined as:

$$\Omega = \rho \cdot g \cdot q \cdot \tan(\beta) \tag{1}$$

where $\rho \cdot g$ is the unit weight of water, q is the discharge per unit of width, and β is the slope in degrees (Moore et al., 1991). By using the drainage area, A_d, as a surrogate for discharge, the stream power can then be represented by the compound topographic index, CTI:

$$CTI = A_d \cdot \tan(\beta) \tag{2}$$

A modified version of the compound topographic index, proposed by Thorne et al. (1986) and adopted herein, is defined as:

$$CTI = A_d \cdot \tan(\beta) \cdot PLANC \quad (3)$$

where planform curvature (*PLANC*) (m/100) is a measure of landscape convergence, with negative values indicating ridges and positive values indicating swales (Zevenbergen and Thorne, 1987). The upstream area, A_d (m^2), is assumed to be proportional to discharge (Moore et al., 1991). Local slope (β) (m/m) combined with upstream area provides a measure for the stream power. Planform curvature also provides an indication of the degree of concentration of flow and so allows the CTI to represent specific stream power (stream power per unit of bed) providing an indication of converging flow and water content (Moore et al., 1991; Parker et al., 2007). A detailed description of the mathematical calculation of planform curvature is provided by Zevenbergen and Thorne (1987). Compound topographic index values are calculated for each raster grid cell (Parker et al., 2007).

AGNPS PEG Evaluation Tool

The AGNPS/ArcView interface requires the use of Arcview 3.2a or 3.3 with the Spatial Analyst 2.0 extension. Specifically, for the use of the APET, the DEM has to be preprocessed through the TOPOAGNPS components (Martz and Garbrecht, 1998), facilitated with the "AGNPS Data Prep" feature (fig. 1A). This section describes the generation of the CTI raster grid (fig. 1B – Step 1), the identification of PEG Mouths (fig. 1B – Step 2), headcut migration barriers computation, and post-processing of the PEG points dataset (fig. 1B – Steps 3 and 4).

Compound Topographic Index Creation

There are several main steps required within the AGNPS/ArcView Interface to compute CTI (fig. 2). The required terrain slope and upstream area (contributing area) are obtained through TOPAGNPS, which is a subset of the topographic parameterization (TOPAZ) computer program (Garbrecht and Martz, 1996). TOPAZ uses digital elevation models in raster grid format to identify and measure topographic features and define surface drainage in order to support watershed hydrologic modeling and analysis. After a preprocessing phase of the DEM (quality control, smoothing, and depression filling), slope and accumulated upstream area draining in each raster grid cell is computed using TOPAZ. TOPAZ components utilized within TOPAGNPS are included with the distribution of the AnnAGNPS modeling components (http://www.ars.usda.gov/Research/docs.htm?docid=5199). The use of the AGNPS PEG Interface requires that the current directory be defined and that steps 1 through 6 of the pull-down menu "AGNPS Data Prep" in figure 1A be successfully completed (AGNPS, 2010).

The planform curvature determination utilizes a moving 3×3 raster grid to determine the curvature of the terrain at individual raster grid cells. A full quadratic polynomial equation is used to account for elevation values at the nine individual raster grid cells considered (Zevenbergen and Thorne, 1987). The planform curvature is computed using the ArcView internal curvature function.

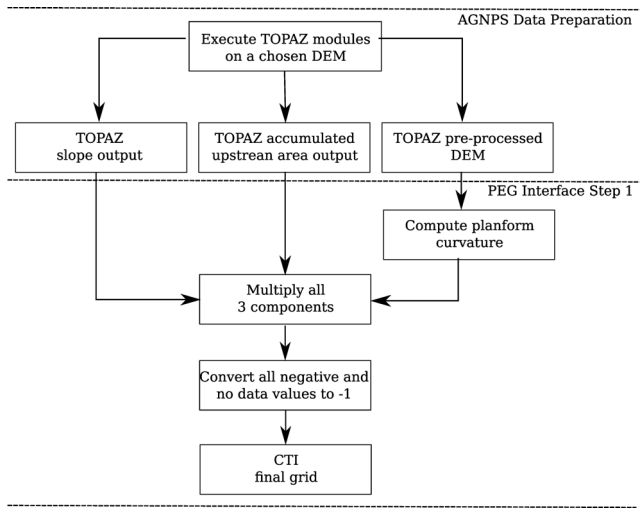


Figure 2. Flowchart shows the main steps performed by the AGNPS PEG Evaluation Tool to compute the compound topographic index from a user-provided DEM.

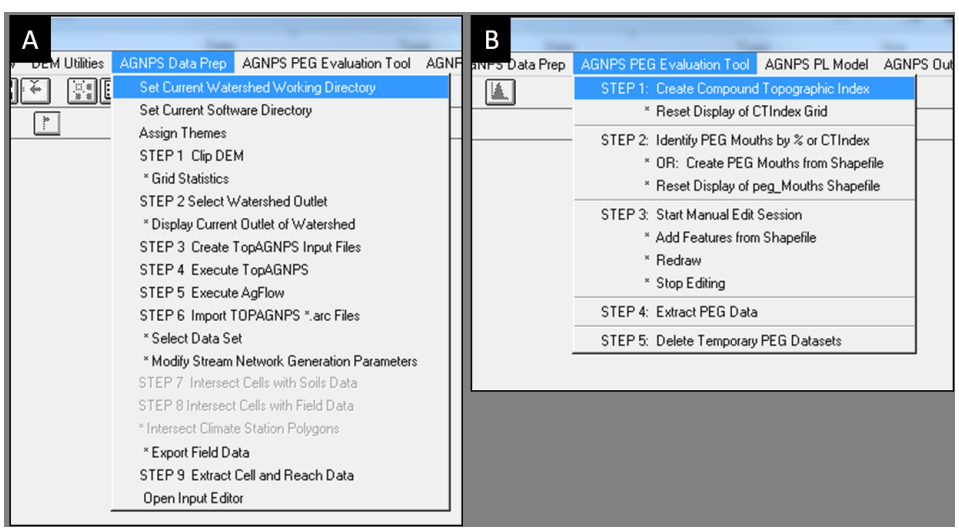


Figure 1. AGNPS/ArcView Interface components. DEM pre-processing (A) and automated identification of potential ephemeral gully locations and characteristics (B).

CTI values for each raster grid cell are obtained by multiplying upstream area, local slope, and planform curvature. All raster grid cells with negative CTI values, indicating a concave surface (ridge), or with no valid data are reassigned to a CTI value of -1. After computing the CTI, two new datasets are added to the project: a table document and a raster grid. The table document contains unique CTI values (Value), the number of raster grid cells with that value (Count), and the cumulative count (CumCount) and percent (CumPct) associated with that value (fig. 3). For instance, the highlighted line in figure 3, the CTI value of 55 correlates with 1271 raster grid cells, or restated as 98.06% of the CTI values are 55 or less. Note that CTI values in the table are rounded to integer numbers, while in the computations the actual real numbers are used.

CTI values are then graphically represented by categories of cumulative percentage values (fig. 4). Raster grid cells whose CTI values are less than the 90% category are not displayed.

Identifying PEG Mouths through Compound Topographic Index Threshold

Ephemeral gully formations are controlled by different physical properties and conservation practices. Empirical relationships have been developed between the physical properties responsible for gully formation and a critical CTI value for individual situations (Thorne et al., 1986; Vandaele et al., 1996; Desmet et al., 1999; Parker et al., 2007 and 2010). The selection of this value would represent the location of the mouths of ephemeral gullies where headcuts begin migrating upstream (Parker et al., 2007). Utilization of the APET provides the ability to iteratively adjust (through a trial-and-error process) threshold values until a satisfactory CTI value is found that best represents the location of potential ephemeral gullies within the watershed (repeating steps 2 through 4 in fig. 1B). This can be based on comparison of CTI values of locations with observed active gully in the field.

The threshold value used to identify PEG mouths can be selected using either a percent value or a unique CTI value. For example, if the user enters a percentage value, the critical CTI value will also be computed and vice-versa. Once the most appropriate threshold has been selected for the area of interest, procedures to manually add or remove PEG points can be performed.

When evaluating ephemeral gully erosion within AnnAGNPS, the user needs to identify the location of each potential ephemeral gully, which can be performed using the trial and error process mentioned above (fig. 5). The location of PEG mouths is an important component in watershed-scale simulations using AnnAGNPS. The application of AnnAGNPS generates estimates of movement of water, sediment, and chemicals at different locations in the watershed by different erosion processes such as sheet, rill, and tillage-induced ephemeral gullies. The use of the APET can significantly expedite this process by providing gully mouth locations based on topographic analysis (Parker et al., 2007).

The process starts by identifying all the raster grid cells with CTI values above the user-provided threshold (fig. 5, box 2). This step can produce a large number of raster grid cells and therefore can lead to lengthy computational efforts. The identified potential ephemeral gully locations are then reevaluated for classification into one of two groups: AnnAGNPS cell-located and AnnAGNPS reach-located PEG mouths. An AnnGNPS cell is defined as either a homogeneous sub-area or part of a sub-area. A DEM describing the subarea can include many raster grid cells. A potential ephemeral gully is considered to be cell-located when the gully is contained wholly in a single AnnAGNPS cell or is considered to be reach-located when the gully is located within the thalweg of an AnnAGNPS reach.

peg_cti_table.dbf

Value	Count	Cumcount	Cumpct
51	1488	7215118	97.99
52	1475	7216593	98.01
53	1376	7217969	98.03
54	1292	7219261	98.04
55	1271	7220532	98.06
56	1274	7221806	98.08
57	1179	7222985	98.09
58	1224	7224209	98.11
59	1180	7225389	98.13

Figure 3. Screen capture example of table summarizing CTI values computed using the AGNPS PEG Evaluation Tool. Column *Value* lists the unique CTI values, *Count* the number of raster grid cells with that value, *Cumcount* the cumulative count, and *Cumpct* the cumulative percent associated with the CTI value in that row.

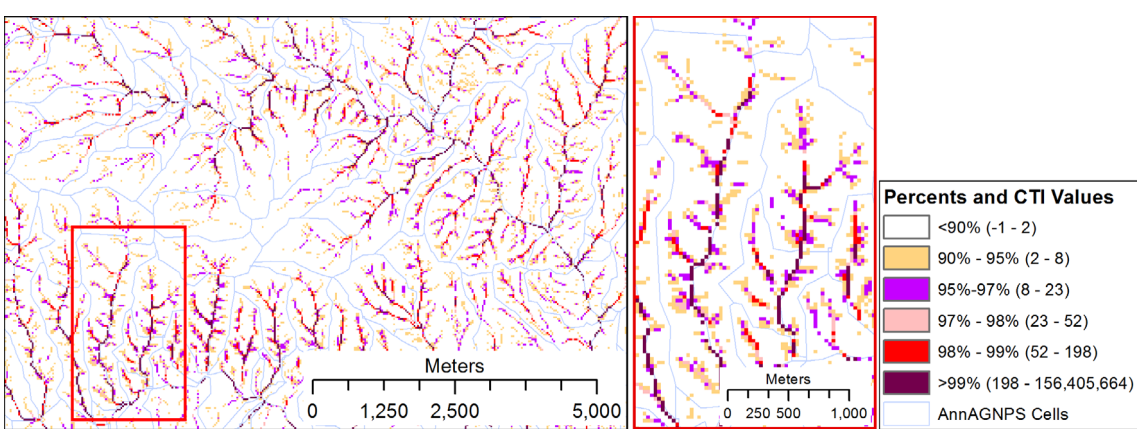


Figure 4. Raster grid of Compound Topographic Index (CTI) values generated using the AGNPS PEG Evaluation Tool used in the identification potential ephemeral gully locations at watershed-scale.

Within AnnAGNPS, generally runoff and pollutant loads are routed from cells to the upper or lower ends of reaches. Cell-located ephemeral gully loadings have been designed to enter at any lateral point along a reach, requiring unique information that is not needed for reach-located gullies. In the procedure to identify cell-located PEGs, raster grid cells located both outside the watershed boundaries and within the AnnAGNPS defined reaches are removed from the dataset (fig. 5, boxes 3 and 4). Finally, groups of connected raster grid cells (referred to as a cluster) are numbered and, for each cluster, the most downstream raster grid cell is selected as the mouth (fig. 5, box 5).

AnnAGNPS reach-located raster grid cells are located in the stream network associated with AnnAGNPS defined reach segments. The AnnAGNPS reach-located procedure is applied to each individual reach by converting the user-provided CTI threshold value into a percentage (if not provided as such) and is used to define a local CTI threshold value for each reach segment considered (fig. 5, box 6). For example, if the user-provided threshold is 55 and the correspondent percentage is 98.06%, this percentage will be used to define a new CTI threshold value for each Strahler stream order in the stream network (fig. 5, box 7).

A reach-located PEG mouth is flagged when the CTI value of a raster grid cell first exceeds the threshold limit when transversing the reach starting at the upstream position. For illustration purposes, consider the CTI threshold value of 6 for a reach class number, and the CTI values of 7,7,5,7,4,7,8,4, and 7 from top (upstream) to the downstream mouth for the raster grid cells located in that reach (fig. 6).

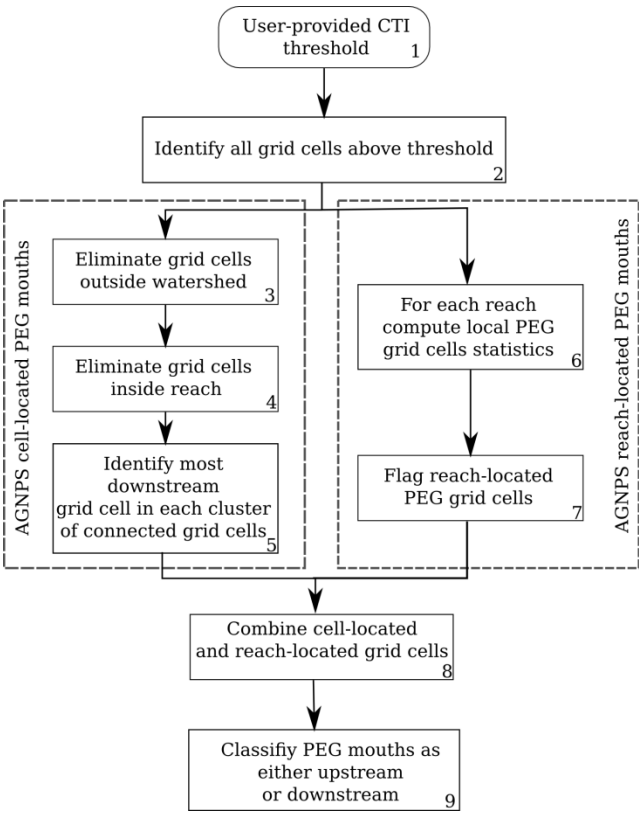


Figure 5. Schematic of the steps performed by the AGNPS PEG Evaluation Tool to compute potential ephemeral gully mouths classified into four groups: upstream or downstream and AnnAGNPS cell-located or AnnAGNPS reach-located.

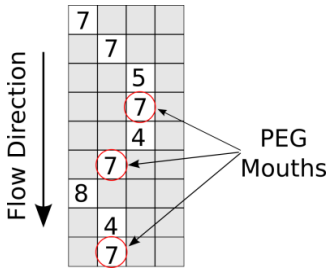


Figure 6. Conceptual framework of the PEG mouth assignment procedure.

In this hypothetical situation, three raster grid cells with 7 would be flagged as PEG mouths (the fourth, sixth, and ninth downstream raster grid cells with values of 7). The most upstream raster grid cell with a value of 7 is not selected because it receives flow only from the source cell. The next downstream raster grid value of 7 is also not selected because only raster grid cells rising above the threshold after being under the threshold are flagged. The number 8, after the sixth raster grid cell with value of 7, is not selected because by definition only the first raster grid cell with CTI value greater than the threshold is flagged.

The resulting grid cells flagged in both procedures are then combined and further classified as either "upstream" or "downstream" (fig. 5, box 9). This classification is based on drainage area and is especially critical when more than one PEG mouth is flagged in the same AnnAGNPS cell or AnnAGNPS reach (fig. 7). The "upstream" PEG mouth classification always flows into another PEG mouth. The downstream PEG mouth classification may be defined as another "upstream" PEG mouth or a "downstream" PEG mouth. A "downstream" PEG mouth may receive flow from an "upstream" PEG mouth, or, may simply stand alone and not be part of a multi-PEG mouth flow. Within a reach, a single PEG mouth will be classified as "downstream." If there is more than one PEG mouth in a single reach, one will

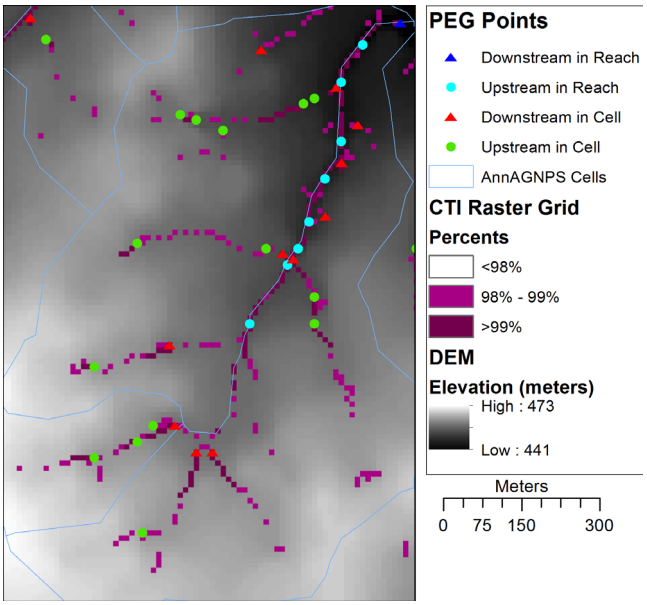
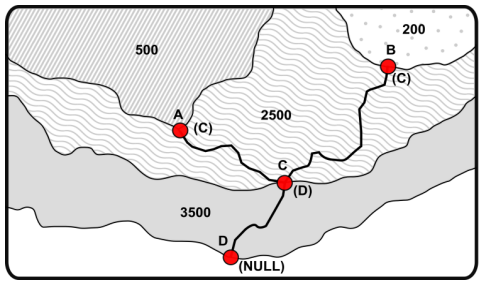


Figure 7. Illustration of the interplay of CTI raster grid values and PEG mouths points.



PEG ID	Catchment Area	Headcut Migration Barrier	Downstream PEG ID
A	500	0	C
B	200	0	C
C	2500	700	D
D	3500	2500	NULL

Figure 8. Schematic describing headcut migration barrier parameter determinations.

be classified as "downstream" and all the others as "upstream."

PEG Headcut Migration Barriers

When gully headcuts migrate upstream they may encounter headcuts that have already been defined for other gullies. In order to account for the migration of gullies into other defined gullies and not double count the erosion from existing gullies, a headcut barrier parameter can be defined for each AnnAGNPS-cell and AnnAGNPS-reach ephemeral gully. In the APET procedure, the sum of the drainage areas of all immediate upstream barriers to headcut migration is computed by the sum of the drainage areas of upstream gullies (fig. 8). Gullies "A" and "B" are considered upstream PEGs and therefore no headcut migration barrier is assigned and the minimum barrier is determined internally based on encountering either a watershed boundary or where rill erosion is considered to end. Gully "C" is located immediately downstream from gullies "A" and "B," and its headcut barrier is calculated as the sum of the upareas of these two points (fig. 8). Gully "D" is the most downstream gully and only gully "C" is included in the headcut barrier calculation because the further upstream points "A" and "B" have already been accounted for in the headcut barrier calculation for point "C" (fig. 8). AnnAGNPS will use the headcut barrier parameter information from each ephemeral gully to adjust the drainage area of each PEG to better reflect the sediment yield from each gully as they migrate upstream.

Post-Processing the Generated PEG Dataset

Experience and knowledge of the watershed being investigated by the user is often critical for a successful simulation. The user's information on where ephemeral gullies occur can be incorporated into the modeling process by a post-processing procedure to manually edit identified PEG mouths. Users can add/remove PEG mouths using a graphical user interface by either adding/removing or importing PEG mouth locations from a point feature class (ESRI Shapefile format). As a PEG mouth is added by the user, the APET is designed to automatically compute all the attributes associated with the PEG mouth and recalculate all the PEG points in the same AnnAGNPS cell or reach, such as classification (downstream or upstream and AGNPS cell-located or AGNPS reach-located), CTI value, catchment area, slope, and others. Similarly, when a PEG mouth is removed, all the remaining points are recalculated with respect to "upstream" and "downstream" status.

The completed PEG dataset can then be exported to comma separated values (*.csv) text files for use by the user to import into the AnnAGNPS Input Editor for inclusion in the AnnAGNPS watershed input file (table 1). Each ephemeral gully defined using the interface has a unique identifier where the first letter is either "r" or "c" identifying whether the gully is classified as AnnAGNPS cell-located or AnnAGNPS reach-located. This letter is followed by a five-digit number, representing the AnnAGNPS cell ID or AnnAGNPS reach ID, plu ".gxx" where xx is the sequence that each gully was processed by the interface.

Different fields are populated depending on whether the ephemeral gully is an AnnAGNPS cell- or reach-located gully. The "drainage area to the mouth" constitutes the total drainage area upstream of the mouth of the ephemeral gully, whereas the AnnAGNPS "cell's drainage subcell" represents the drainage area upstream of the raster grid cell before entering an AnnAGNPS reach. This raster grid cell is identified by calculating the flow path from the gully's mouth to the AnnAGNPS reach (fig. 9).

The APET provides user's the option of selecting management and soil information specifically and uniquely

Table 1. AnnAGNPS ephemeral gully fields generated with the AGNPS/PEG interface.

Field	Description
Ephemeral gully ID	Alphanumeric string identifying the ephemeral gully
Gully location	"T" for AnnAGNPS cell-located and "F" for AnnAGNPS reach located
Cell ID[a]	AnnAGNPS Cell ID whose gully's drainage area is wholly contained within this cell.
Reach ID[b]	AnnAGNPS cell ID of the reach whose thalweg contains the gully mouth.
Drainage area to mouth[a]	Total drainage area contributing to the mouth of the gully.
Cell's drainage subcell[a]	Total drainage area of the cell before the reach receiving the flow from the mouth.
Local drainage area[b]	Total drainage area contributing to the mouth of the gully.
Soil ID	Assigned soil ID found in the soil database.
Gully slope	Land slope immediately upstream from the mouth.
Management ID	Assigned management ID found in the management database.
Headcut migration barrier	Sum of drainage areas of all upstream ephemeral gullies.

[a] AnnAGNPS cell-located only.
[b] AnnAGNPS reach-located only.

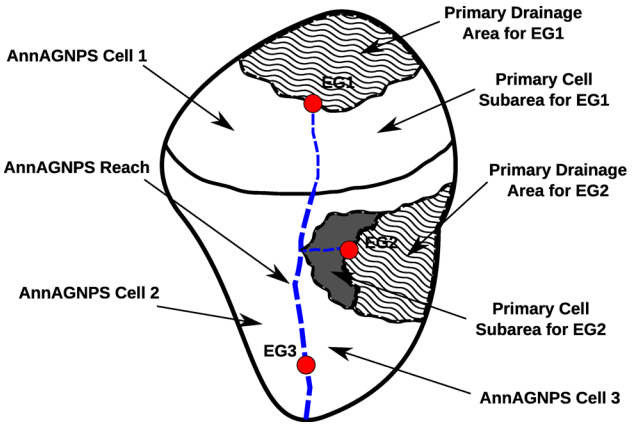


Figure 9. Illustration of drainage area computations for AnnAGNPS cell-located gullies.

for each gully. This feature is important when accounting for differences in management and soil type between the gully area and what may be applied for the AnnAGNPS cell. For instance, an AnnAGNPS cell could have management operations that are different than those used within the gully, such as tillage in the field, but not in the gully. Similarly, soil types could be different in the gully than in the field. If no management or soil type is provided by the user, a default of what would occur in the associated AnnAGNPS cell management and soil information for the gully would be defined for the gully.

Example Watershed Application

Watershed Description

The selection of ephemeral gully locations within large watersheds can be very difficult and time consuming when trying to visually inspect the landscape for gullies using aerial photographs or traveling throughout the watershed. This manual process can lead to missing ephemeral gully locations or locations that are inadvertently identified as gullies. Subwatersheds of the Cheney Lake Watershed in South-Central Kansas (fig. 10) were used as an example application of the APET tool when identifying the location of ephemeral gully mouths. Cheney Lake Reservoir watershed was selected by the USDA as a Special Emphasis watershed in the Conservation Effects Assessment Project (CEAP) to evaluate the effects of specific agricultural conservation-practices problems and to assess the impact of these practices on water quality that may be included by the larger-scale, national assessment effort of CEAP. Cheney Lake Watershed has a total drainage area of 642,584 acres in which 73% is agricultural land use consisting of cropland and rangeland. Sediments eroded from this watershed flow into Cheney Lake, which is currently designated a high priority impaired water body under the Clean Water Act, with impairments listed for eutrophication and sedimentation. Goals have been established to reduce sediment loadings by 40% to 45% for the watershed. A critical aspect of the CEAP effort is to assess the effects of reducing sediment loadings from various conservation practices associated with the Conservation Reserve Program, reduced or no-tillage, irrigation-scheduling, and ephemeral gully erosion control.

Simulations of the Red Rock Creek sub-watershed (12,150 ha) of the Cheney Lake Reservoir watershed (fig. 10) using the AnnAGNPS model were calibrated using the USGS Gauging Station located at the watershed outlet (Bingner et al., 2010) and used to evaluate erosion generated from ephemeral gullies. Runoff was calibrated by varying the SCS runoff curve number to match observed average annual streamflow measured at the watershed outlet from 1997-2008 (Theurer et al., 2010). Sheet and rill erosion, ephemeral gully erosion, and bed and bank erosion comprised the total sediment load from the watershed. Total sediment load simulated with AnnAGNPS was calibrated based on NRCS estimates of bed and bank erosion and measured suspended sediment load at the watershed outlet. For this study, sheet and rill erosion was produced based on RUSLE technology (Renard et al., 1997) and was assumed to be reliably attained through the use of AnnAGNPS. The remaining sediment was calibrated for ephemeral gully erosion by adjusting the gully width algorithm (Nachtergaele

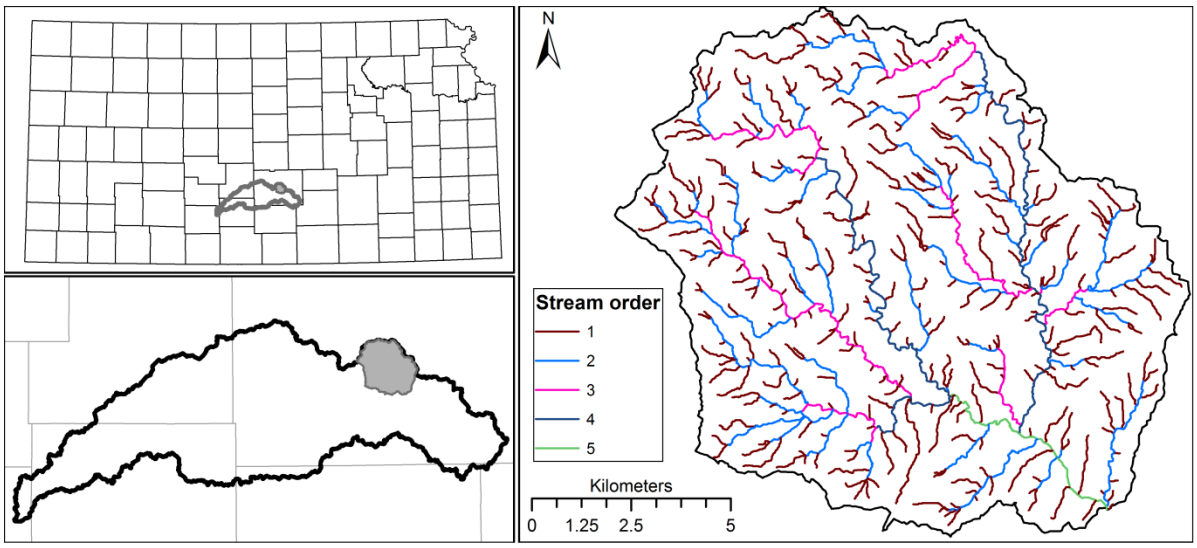


Figure 10. Geographic location of the Redrock Creek Sub-Watershed, part of the Cheney Lake Reservoir Watershed in Kansas, used as a study site describing the AGNPS PEG Evaluation Tool description. The stream network color schema illustrates the Strahler stream order generated with the AGNPS ArcView Interface.

et al., 2002) using an optimal calibration coefficient approach for the user-selected actual ephemeral gully locations (Bingner et al., 2010). The development of ephemeral gully width parameters are one of the most sensitive parameters within AnnAGNPS affecting sediment.

Discussion of AnnAGNPS Simulation Results

A digital elevation model (DEM) with spatial resolution of 30 m for the entire Cheney Lake Watershed, obtained from the United States Geological Survey, was used. This DEM was pre-processed using the tools in the "AGNPS Data Prep" (steps 1 to 6) components available within the AGNPS ArcView interface (fig. 1A). These components are used to generate TOPAZ output files, necessary for the APET, along with the raster grid layers: *netful*, *subwta*, *bound*, *ntgcod*, and *netw*.

The first step in the APET procedure generates a raster grid with CTI values. Visual inspection of the CTI raster grid contrasted to an aerial photograph reveals that the values are oriented with a dendritic drainage pattern, as expected for ephemeral gullies (fig. 11). In the majority of the fields the agricultural practices are performed without regard to the existence of ephemeral gullies (tilling and planting over the channels resulting in refilling of gully channels). For example, in figure 11, CTI values for some of these areas such as CTI values >28 could indicate a high probability for potential ephemeral gully occurrence. Conversely, many isolated raster grid cells with smaller CTI values show no indication for ephemeral gully formation. Subsequently, the selection of a critical CTI threshold value is needed to eliminate many of the raster grid cells with small CTI values as potential ephemeral gully mouths. No universal procedure currently exists to define what the CTI threshold value should be. Typically, threshold values range from 95% to 99.9% depending on terrain (flatter = higher thresholds) and other factors such as how much of the watershed is representative of the surrounding areas. The selection of the CTI threshold for potential ephemeral gully mouth locations also depends on factors, such as DEM resolution, geographic location, and watershed topography, and therefore users should use additional information as an aid in this process. Watersheds with mixed topographic characteristics would be better suited to utilize unique CTI for each topographic setting. For example, in watersheds containing both flat and steep terrain, the CTI threshold values could be determined independently for each terrain and then the resulting PEG points for each evaluation merged. Alternatives when defining CTI threshold value include the use of known locations of gullies and/or a trial-and-error approach combined with local experience of specific local conditions.

A user-defined set of actual gully mouth locations collected by a combined approach of field inspection and historic aerial photograph interpretation by the U.S. National Resource Conservation Service (NRCS) were used in comparison with generated locations. This dataset originally described 989 actual gully locations for the entire Cheney Lake Reservoir Watershed. Using the option "Create PEG Mouths from Shapefile" of the APET, user-defined gully locations were translated into PEG Mouths. In this procedure, the user-defined gully locations are assigned to a raster grid cell and evaluated in terms of the upstream gully area, CTI value, and watershed boundaries. User-defined gully locations are not assigned as a mouth if there is no upstream gully area, the CTI value is negative, or the gully is outside the watershed area. When a user-defined gully location is not located on a generated CTI value then there are three options available in the APET that can be used to move the location of the gully mouth to the center of a raster grid cell with acceptable CTI values. One option would move individual gully mouth locations to the center of the raster grid cell that the mouth spatially coincides. While selecting two other options would move the user-defined gully mouths from the raster grid cell where the mouth spatially coincides to a 3×3 or 5×5 raster grid cell nearest neighbor approach, respectively. All the raster grid cells in the nearest neighbor approach are evaluated, and the raster with the highest upstream drainage area and positive CTI value would be selected. By definition, gully mouths centered at raster grid cells classified as AnnAGNPS cell-located gullies can only be moved to other AnnAGNPS cell-located raster grid

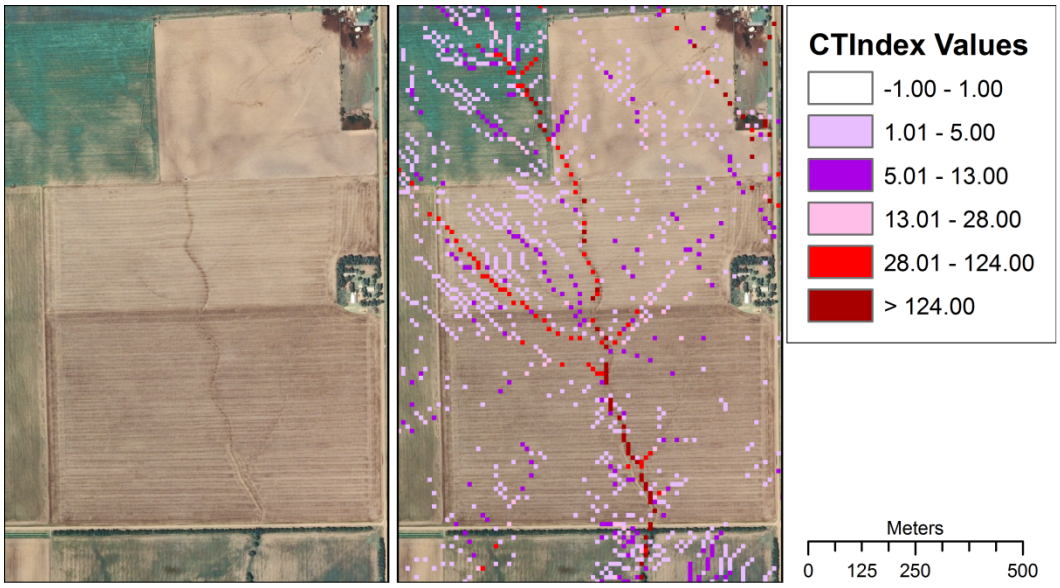


Figure 11. Subset of the raster grid dataset containing CTI values. The dendritic drainage system agrees with aerial photographic visual interpretation.

cells. AnnAGNPS reach-located gully raster grid cells tend to have higher upstream drainage areas and CTI values, often resulting in an unrealistic number of AnnAGNPS reach-located PEG mouths being produced.

User identified gully mouths for the entire Cheney Lake Watershed were imported using the 3×3 nearest neighbor approach (option 1) and resulted in 977 valid PEG points.

Using the mean plus one standard deviation of the CTI values obtained from the user-defined gully points (fig. 12) yielded a CTI threshold value of 126 or 98.85%. A second approach utilized was a trial-and-error method that iteratively varied the threshold value and compared with the user-identified PEG mouth locations. Five threshold values were considered 99.9%, 99.5%, 99.0%, 98.5%, and 98.0% yielding a total number of PEG mouth locations of 36, 767, 3,197, 6,810, and 11,231 respectively. Visual inspection of the locations obtained for the Red Rock Creek sub-watershed indicated that thresholds of 99.9%, 99.5%, and 99.0% generated less PEG mouths than the user-identified gully locations. Conversely, the threshold value of 98% generated more PEG mouths than the user-identified gully mouths. The cumulative percentage thresholds of 98.85% (CTI value of 126) and 98.5% indicated a close representation of the user-identified gully mouth locations. Producing a perfect match between potential ephemeral gullies obtained using the APET and user-defined actual gully mouths is not possible with the existing DEM resolution available in this study. The main objective of the study is rather to describe the technology and to demonstrate the capabilities and possible uses for watershed analyses.

Additionally, ephemeral gullies are linear features that are usually represented by a single point. The APET identifies potential ephemeral gully mouths that are used within the AnnAGNPS model to simulate ephemeral gully erosion as the headcut migrates upstream. A single concentrated flow path can contain more than one ephemeral gully mouth (fig. 13). For example, in figure 13, the user identified one active gully point (green star) while the APET identified four potential ephemeral gully mouths (three upstream represented as blue circles and one downstream represented by blue triangle) for the same location (fig. 13). Visual inspection of AnnAGNPS reach-located PEG points (blue triangles and circles) overlaid on contour lines are identified in the stream channels and concentrated flow paths (fig. 13).

The potential ephemeral gullies generated using the APET (99%, 98%, 126, and user identified) were subset to the Red Rock Creek sub-watershed boundaries. The DEM was subset to the watershed boundaries, the set of PEG points (one set for each scenario) were also subset, re-evaluated using the APET to repopulate the PEG points parameters according to the smaller DEM, and exported to comma delimited files in the format required for the AnnAGNPS Input Editor (fig. 14). Four AnnAGNPS simulations were performed (one for each of the gully scenarios) by varying only the potential ephemeral gully information. The United States Geological Survey (USGS) Gauging Station ID 07144780 was used in the process to generate the necessary calibration coefficients (Bingner et al., 2010; Frees et al., 2010; Theurer et al., 2010). The simulation period was from 1979 to 2008 with two years of initialization using a total of 169AnnAGNPS cells.

The spatial distribution of the gully annual average erosion varies with the number of PEG mouths (fig. 15). The threshold of 98% produced gully erosion estimates in 96 of the total 169 AnnAGNPS cells. Conversely, a threshold of 99% produced gully erosion estimates in 24 AnnAGNPS cells. Comparison between the estimates produced using a CTI threshold of 126 and the user identified points indicates spatial agreement of AnnAGNPS cells located in different parts of the sub-watershed.

The identification of where ephemeral gullies occur is critical in assessing the effects of conservation practices in controlling erosion within watersheds. It is possible to evaluate the overall sediment contribution of ephemeral gullies through the investigation of ranked land area within the watershed according to its predicted sediment contribution to the overall loading of the watershed. Figure 16 illustrates this relationship showing that roughly

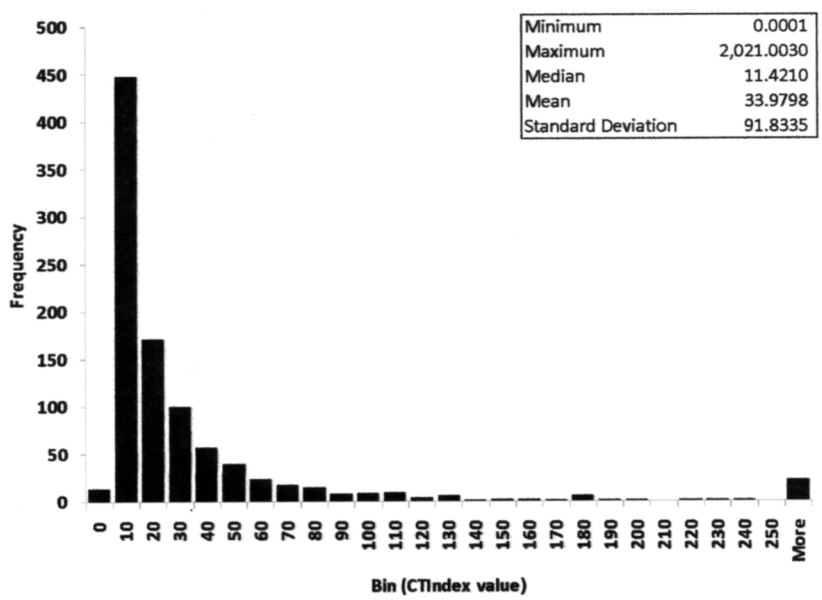


Figure 12. Histogram of the CTI values for Cheney Lake Reservoir Watershed generated from 30-m spatial resolution digital elevation model.

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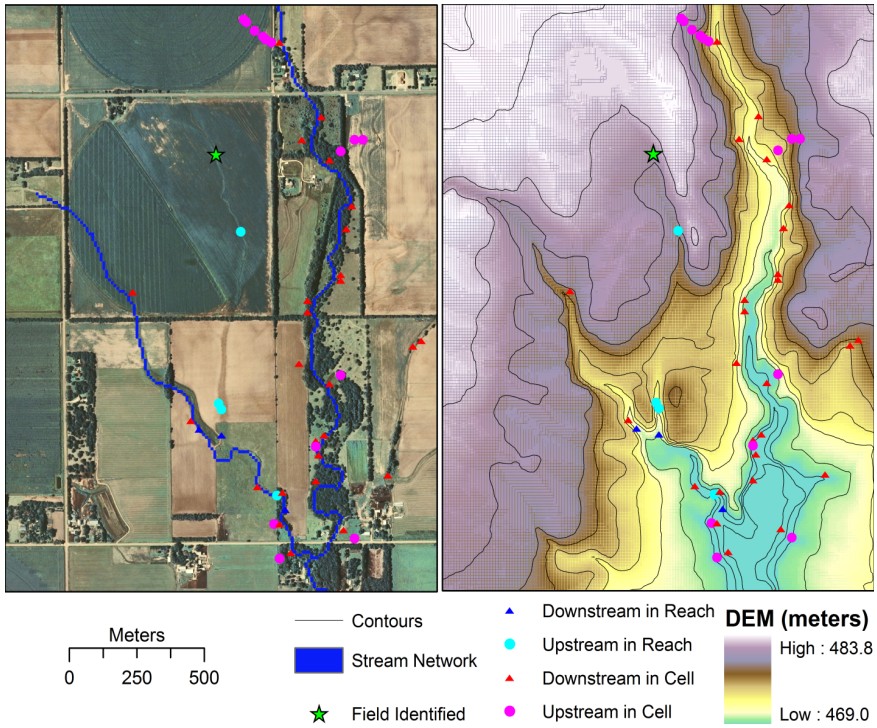

Figure 13. Detailed illustration of PEG mouths produced with the AGNPS PEG Evaluation Tool compared to a field identified actual gully point (green star).

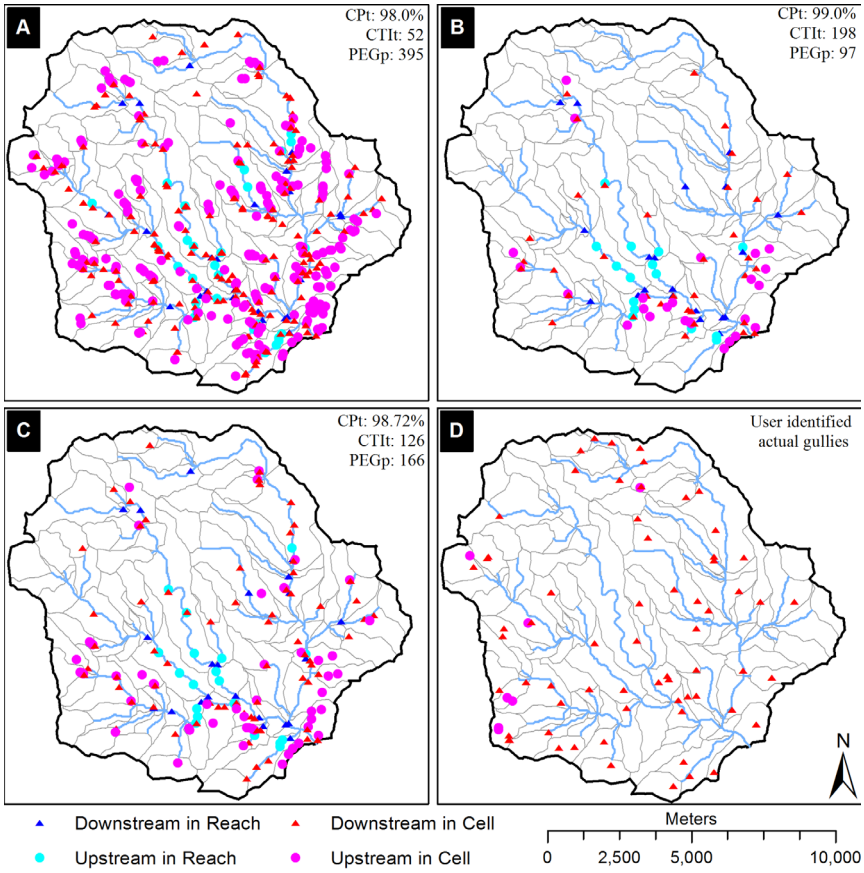

Figure 14. PEG mouths produced with varying CTI value thresholds. This iterative procedure allows users to adjust gully mouth locations to local environmental/producing conditions. The acronyms CPt, CTIt, and PEGp represent Cumulative Percentage threshold, CTI threshold, and number of Potential Ephemeral Gully points, respectively.

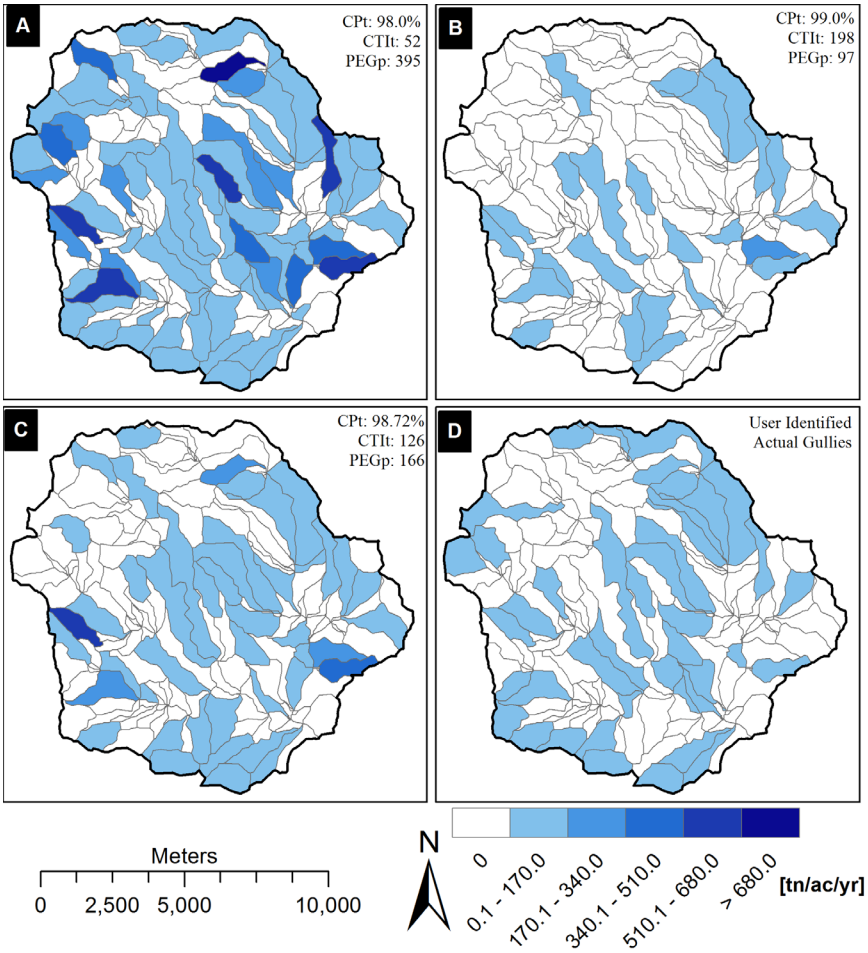

Figure 15. Spatial distribution of annual average gully erosion estimated using the AnnAGNPS model with varying potential ephemeral gully information processed using the AGNPS PEG Evaluation Tool. The acronyms CPt, CTIt, and PEGp represent Cumulative Percentage threshold, CTI threshold, and number of Potential Ephemeral Gully points, respectively.

20% of the contributing area of all AnnAGNPS cells in the watershed are producing approximately 75% of the sediment load as a result of sheet and rill and gully erosion. Based on these estimates, addressing all the ephemeral gullies in the watershed would reduce the sediment load at the outlet by approximately 85%. However, programs designed for controlling ephemeral gully erosion of the entire watershed are not practical and often times expensive. An alternative is to use a more targeted approach of designing conservation practices for the most contributing areas. For example, according to figure 16, conservation practices designed to treat ephemeral gullies when applied to 20% of the watershed could reduce 70% of the sediment load at the outlet.

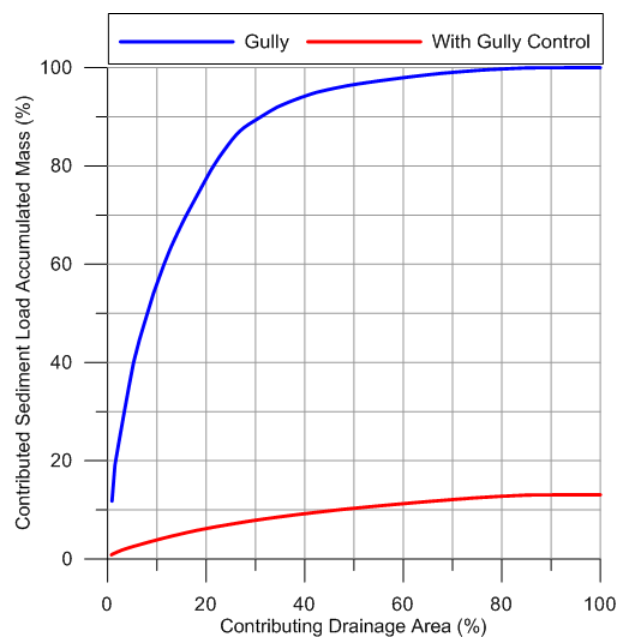

Figure 16. Watershed sediment load contribution by ranked unit area.

Conclusions

The ArcView AGNPS/GIS Interface was enhanced with tools to identify where ephemeral gully mouths would form in agricultural watersheds. This information can be linked to the USDA watershed planning tool, AnnAGNPS, for use in evaluating conservation practices used for ephemeral gully erosion control. The APET tool has been developed within a graphical GIS-based interface to provide the capability to automatically locate potential ephemeral gullies based on topographic index values at a watershed-scale that are based

on modified compound topographic index values that includes planform curvature. This is an important modification in order to predict local specific values of stream power rather than global stream power.

The APET tool complements the capabilities of existing AnnAGNPS pollution modeling components by identifying areas with a high probability of ephemeral gully formation or with existing ephemeral gullies. These new capabilities greatly enhance the applicability of AnnAGNPS to evaluate conservation practices that address ephemeral gully erosion and/or suggest targeted interventions based on localized points prone to ephemeral gullying formation. The interactive option of the APET to identify CTI threshold values, used to define PEG's downstream mouths, permits users to incorporate local knowledge and experience to account for topographic differences in distinct regions in the watershed. The integration of the APET with the AnnAGNPS Input Editor facilitates and expedites the generation of detailed gully information necessary to account for individual gully soil and management information that may differ from the AnnAGNPS cell's management and soil information. This feature allows for simulation of alternative scenarios involving various conservation practices, such as grass waterways and drop pipes that would be more appropriate for gully erosion control than for sheet and rill erosion control.

The APET tool can be a valuable instrument in watersheds with conservation management agreements designed to reduce cropland erosion by maintaining a vegetative cover (Conservation Reserve Program). As these contracts expire and/or crop prices increase, fields may return to farming practices increasing the erosion amounts produced by ephemeral gulling. Fields with potential ephemeral gullies, but no visible gullies due to grass cover, may develop ephemeral gullies when the soil is disturbed during agricultural operations. In these circumstances, the use of the APET at a watershed scale can help identify areas prone to ephemeral gully occurrence, once the land cover changes to cropland, and thus the development of target conservation measurements (French et al., 2010).

Practical methods exist to define critical CTI value, such as utilization of CTI values of observed actual gullies in the field and iterative procedures based on calibration of models, such as AnnAGNPS, associated to sheet and hill erosion; however, further investigation is required. A current limitation of the approach is that ephemeral gullies are relatively small features in size (typically a few meters wide and up to 25 cm in depth) while the terrain is often modeled using DEMs with spatial resolution between 10 to 30 m. Better terrain representations are expected to become more accessible as result of advances in technology such as airborne and ground-based LIDAR. As the resolution of terrain representation improves, additional research is needed to assess the effects of topographic representation spatial resolution in the selection of the CTI threshold. Furthermore, ephemeral gully phenomenon is driven by a combination of different physical and chemical factors where topography is only one of them. Future investigations should be conducted to enhance the proposed APET to incorporate other physical factors controlling the formation of potential ephemeral gullies in agriculture fields, such as vegetation cover and soil properties.

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