2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

An ASABE Meeting Presentation

Paper Number: 1009663

Monitoring and Estimating Ephemeral Gully Erosion using Field Measurements and GIS

Prasad Daggupati, Graduate Student
Kansas State University, Biological & Agricultural Engineering, 30A Seaton Hall
Manhattan, KS 66506 prasad9@ksu.edu

Kyle R. Douglas-Mankin, Professor
Kansas State University, Biological & Agricultural Engineering, 48 Seaton Hall
Manhattan, KS 66506 krdm@ksu.edu

Aleksey Y. Sheshukov, Research Associate
Kansas State University, Biological & Agricultural Engineering, 49 Seaton Hall
Manhattan, KS 66506 ashesh@ksu.edu

Philip L. Barnes, Associate Professor
Kansas State University, Biological & Agricultural Engineering, 47 Seaton Hall
Manhattan, KS 66506 lbarnes@ksu.edu

Written for presentation at the
2010 ASABE Annual International Meeting
Sponsored by ASABE
David L. Lawrence Convention Center
Pittsburgh, Pennsylvania
June 20 – June 23, 2010

Abstract. *Ephemeral gully (EG) erosion has been recognized as a major source of sediment in agricultural watersheds. Over the past few decades, soil erosion caused by sheet and rill erosion has been studied extensively, and field and watershed-scale models have been used to quantify contributions of sheet and rill erosion. In recent years, many studies have been conducted to understand EG formation, location and model development. The overall goal of this study was to develop a method to locate the potential EGs and further develop a simple model to estimate EG erosion at the watershed scale. To achieve this goal, several EGs were monitored, measured and overall characteristics described. Therefore, this paper focuses on monitoring and estimating sediment yields of few EGs in north eastern and south central Kansas.*

Monitoring results show that the EGs in the study areas formed along the natural depression or drainage lines and when the residue cover on the field is low. Preliminary results showed events with rainfall intensity of greater than 10 mm/hr and total rainfall depth of 25 mm were associated with formation and development of EGs.. The total length of EGs in Goose Creek Watershed was 69,636 m with an EG density of 5.5 m/ha. Total sediment loss after a rainfall event was estimated to be 8,617,455 kg (9,500 tons) with an erosion rate of about 0.25 kg/m^2 watershed area. Ephemeral gully erosion was very prominent in the study areas, and conservation practices need to be implemented to reduce this type of erosion.

Keywords. Ephemeral gullies, Ephemeral gully erosion, Field measurements, Rainfall, GIS.

Introduction

Soil erosion by water is a serious land degradation problem facing the world (Vrieling, 2006). Over the past few decades, soil conservation practices have been implemented to control soil erosion from sheet and rill erosion. The National Resource Inventory (NRI) reported that there has been a 42% decrease in sheet and rill erosion in the United States between 1983 to 2003. However, excessive sediment remains among the most prevalent water quality problems in the U.S. The soil conservation practices that have been implemented over the past few decades have significantly targeted sheet and rill erosion, but their impacts on ephemeral gully (EG) erosion is unclear. Recent studies have shown that EG erosion is a major contributor of sediment.

Ephemeral gullies are concentrated flow channels of various sizes that form in agricultural fields by the scouring of concentrated surface runoff during rain events. They are routinely refilled by farmers using tillage shortly after rains, but often reappear in the same location after subsequent rain events (Foster, 1986; Poesen et al., 2003). Ephemeral gullies generally form in cultivated soils during seedbed preparation, planting and early crop establishment periods when the soils are bare and without any vegetation (Capra et al., 2009). As time progresses through the growing season, soil consolidates, and these channels become less erodible. Figure 1 shows the EG formation in an agricultural field before, during and after a rainfall event.

(a) before (b) during (c) after

Figure 1. Ephemeral gully formation before, during and after a rainfall event.

Soil loss due to EG erosion can contribute about 10% of the total soil loss in small watersheds (Poesen et al., 1996a). However, in actively eroding areas, the contribution of EG erosion can range from 30% to as high as 100% of the total soil loss (Casali et al., 1999). Contribution of EG erosion varies geographically. In the United States, EG erosion contributed from 17% of total soil loss in New York state to 73% in Washington State (Robinson et al., 2000). In central Belgium, the EG erosion accounted for 44% (Poesen et al., 1996a) while in the Mediterranean and southern Portugal regions, the EG erosion contributions were as high as 83% (Vandaele et al., 1996b). In the Loess Plateau of China, the contributions of EG erosion ranged from 41% to 91% (Zheng and Gao, 2000).

The soil erosion rates due to EG erosion also varied significantly. In the United States, rates ranged from 0.27 kg m^{-2} yr^{-1} to 2.87 kg m^{-2} yr^{-1} (USDA-NRCS, 1997). In central Belgium, EG erosion rates averaged 0.50 kg m^{-2} yr^{-1} (Vandaele, 1993; Poesen et al., 1996a) while in the southern Portugal, the erosion rates were around 0.1 to 0.68 kg m^{-2} yr^{-1} (Vandaele et al., 1996b). In China, the erosion rates were about 0.43 kg m^{-2} yr^{-1} (Zhang et al., 2007).

Factors that affect the formation and development of ephemeral gullies include storm depth/intensity, soil type, surface roughness, slope, drainage area, antecedent moisture, land cover, tillage, and residue. Rainfall is a major factor in EG formation. Ephemeral gullies form only after a threshold rainfall intensity and duration are attained. Very few studies have investigated threshold rain events required for EG formation and those studies typically are restricted to small areas and examined over short time periods (Carpa et al., 2009). The threshold rains needed for the formation and development of EGs varied geographically depending on soil conditions and initial soil moisture content. Various studies have reported that threshold rains of 14.5 to 22 mm have been observed in cropland. Minimum rainfall depths of 15 mm in winter and 28 mm in summer are needed for the formation of ephemeral gullies, based on a study spanning a 15-year period in central Belgium (Nachtergaele et al., 2001a). Casali et al. (1999) reported that a 17 mm total water depth and peak rainfall intensity of 54 mm h^{-1} are needed for ephemeral-gully formation in Navarra region (Spain). Cerdan et al. (2002) found a rainfall depth of 28.5 mm and maximum 6-minute intensity of 15 mm h^{-1} in December and 21.6 mm depth and 98 mm h^{-1} 6-minute intensity resulted in the formation of rill and EG formation in a cropland area. Capra et al. (2009) observed EG formation for an 8-year period. They used an antecedent rainfall index, the maximum value of 3-days rainfall (H_{max}3-d), a simple surrogate for soil water content, and reported that a H_{max}3-d threshold of 51 mm was needed for EG formation.

Empirical and process based models are being developed to quantify EG erosion at both field and watershed scale. Woodward (1999) developed a process based Ephemeral Gully Erosion Model (EGEM) that was tested by Nachtergaele et al. (2001). In this model, locations of EGs and EG length were given by the user. Gordon et al. (2007) developed a Revised EGEM (REGEM) to address the limitations of EGEM. They made many improvements to the EGEM model and also incorporated it as a subroutine within Annualized Agricultural Non-Point Source Model (Bingner and Theurer, 2001) to predict sheet, rill, and EG erosion. One limitation with this model was that it still required users to input the location of EGs. Considering the lack or difficulty of use of EG process-based models, simple empirical models for EG volume estimates were developed. Capra and Scicole (2002) and Capra et al. (2005) developed a simple regression equation to estimate the eroded volume using total length of EGs in the study area or watershed. Further, Capra et al. (2009) developed a simple power-type equation to estimate the eroded volumes using H_{max}3-d as an independent variable. They reported that this equation did not need field measurements of EG, but the disadvantage was that EGs were not located which precluded its use for the targeting and implementation of conservation practices.

In recent years, many studies are being conducted to understand EG formation, location and model development. The overall goal of this study was to develop a method to locate potential EGs and further develop a simple model to estimate the EG erosion at watershed scale. To achieve this goal, several EGs were monitored, measured, and described. This paper focuses on the following objectives:

- To monitor and measure characteristics of EGs in fields on the North Farm and within Goose Creek Watershed;
- To quantify sediment yield from each EG; and
- To digitize and estimate EG erosion in Goose Creek Watershed.

Study Area

The areas selected for this study were the North Farm and Goose Creek Watershed (Figure 2). North Farm is a KSU research farm located north of Manhattan, KS. The North Farm encompasses 154 ha (382 ac) with a major crop of continuous corn. Two fields with four EGs were selected for monitoring, measuring and estimating erosion volumes. The Goose Creek

Watershed is a subwatershed of Cheney Lake Watershed and is located between Reno and Kingman counties. The area of Goose Creek Watershed is13574 ha (33,600 ac) and the major crop is continuous wheat. The access to enter the agricultural fields was limited in Goose Creek Watershed due to the fact that the fields were private property. Therefore, seven fields were selected for monitoring, measuring and estimating EG erosion volumes as permission was acquired to enter those fields.

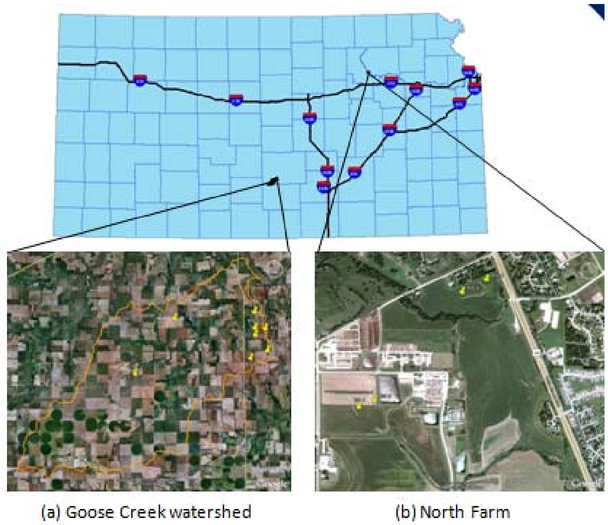


Figure 2. Study area

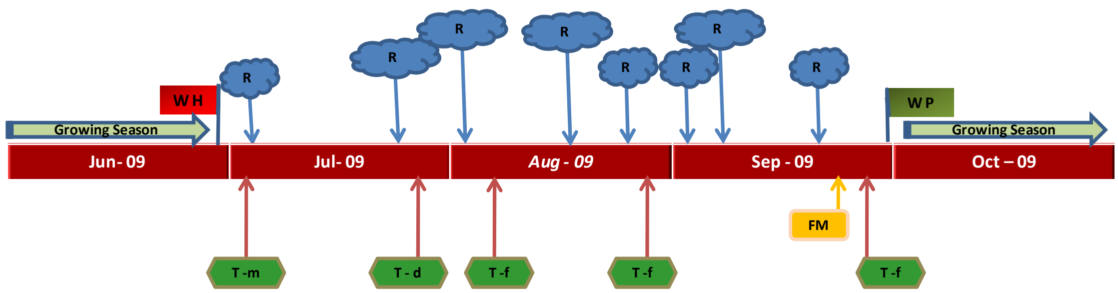
Methods and Materials

Monitoring EGs

(a) North Farm: Two fields in North Farm were monitored from April 1st 2009 to September 1st 2009. The EGs were either observed or measured after every rain event during the non-growing season because of the fact that the soil would be bare and have less vegetation. Ephemeral gullies were observed in the month of April, and field measurements were taken in the month of September. The hourly rainfall data during the study period was used from Manhattan Regional Airport weather station located about 15 km south of the study area. The detailed management operations in the study area were obtained from the Kansas State University personnel who manage the fields. The timeline of monitoring in North Farm is shown in Figure 3.

(b) Goose Creek Watershed: Seven fields in Goose Creek Watershed were monitored from July 1st 2009 to September 31st 2009. The ephemeral gullies were not observed after every rain event but measurements were taken of the EGs on September 24st and 25nd Hourly rainfall data during the study period was used from South Hutchinson weather station located around 40 km north of study area. The detailed management operations in the study area were obtained from the watershed specialists working in the watershed. The timeline of monitoring in the Goose Creek Watershed is shown in Figure 3.

(a) North Farm



(b) Goose Creek Watershed

R- Rainfall; WH- Wheat harvested; WP- Wheat planted; CP- Corn harvested; FM- Field Measurements taken; GO- Gully observation; T-m – Tillage (mould board plough); T-d – Tillage (disc); T-f – Tillage (field cultivator); T-c – Tillage (chisel plow)

Figure 3. Timeline for monitoring EGs in North Farm and Goose Creek Watershed.

Measuring EGs

Field measurements were taken for each EG in the study area. Flags were placed at 5 or 10-m increments along the length of the EGs. The 5-m interval was used when the length of the EG was small (< 50 m), and the 10-m interval was used if the length was large. At every flag point, top width, bottom width and depth at the center of the EG were measured using ruler or tape measure and were recorded (Figure 4). Hand-held GPS was used to record the location, flow path, and length of each EG measured. A field notebook was developed to record the measurements as well as other information related to the field in which the EGs were present (Appendix 1). The trapezoidal and rectangular cross sectional areas were used to calculate the volume contributed by each EG using

$$V = \sum_{i=1}^{n} V_i = \sum_{i=1}^{n} \frac{A_{i-1} + A_i}{2} \cdot s$$

where

V = Total volume of eroded soil; n = number of sub reaches considered; V_i = Volume of soil eroded within each sub reach; A_{i-1} = Downstream cross-sectional area; A_i = Upstream cross-sectional area; s = Distance between adjacent cross-sections

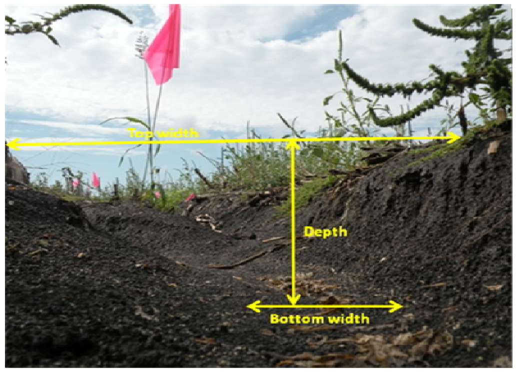


Figure 4. Cross-sectional area measurements

The soil bulk density at each EG location was derived from SSURGO soils (USDA-NRCS, 2005) SURGO soils were processed to derive various soil properties using Soil Data Viewer, an extension to ArcGIS. The total sediment mass leaving each EG was estimated by using total volume and bulk density.

Digitizing EGs

EGs were present in many fields across the Goose Creek Watershed. Because of the limitation that we could not enter and measure the EGs in all the fields, we drove around the Goose Creek Watershed and recorded the fields that had EGs. A CLU field boundary shapefile was edited in ArcGIS to record and make notes on fields that had EGs. An Earthmate LT-40 GPS (Delrome, Yarmouth, ME) was connected to ArcGIS to know the exact spatial location of the field. In the lab, the shapefile of fields that had EGs were overlaid on a corresponding aerial image, and the EGs were digitized. Google Earth also was used to verify the location of EGs. The length of each EG was derived, and the overall length of EGs in the watershed was calculated. The average cross sectional area of nine EGs that were measured, as discussed in the earlier section, was used to estimate the volume of each EG in the Goose Creek Watershed. The bulk density at each of the EG location was derived from SSURGO soils as described earlier. The total sediment mass from each EG was estimated and subsequently the erosion rate (kg/m^2 watershed) and total sediment yield (kg/ watershed) were calculated to evaluate the effect of EG erosion in the watershed.

Results and Discussion

Rainfall Characteristics

Rainfall is one of the major factors contributing for formation and development of the EGs. Hourly rainfall during the non-growing season in North Farm and in Goose Creek Watershed was recorded. Total event rainfall, maximum intensity and duration of the event were derived from the hourly rainfall data (Table 1). In the North Farm, EGs were monitored after every one or two rainfall events (Figure 3a), and important notes on EG formation, EG development and field conditions were recorded. The fields the Goose Creek Watershed were cultivated (field cultivator) towards the end of August so that the bare soil was exposed. Rains on September 4th, 9th and 21st resulted in the formation and development of EGs. The EGs were only monitored and measured towards the end of September (Figure 3b), but notes on field conditions during the non-growing were obtained from watershed specialists.

The total event rainfall ranged from 14 to 78 mm in North Farm and 13 to 28 mm in Goose Creek Watershed. The maximum rainfall intensity measured nearby the North Farm ranged from 2.3 to 17.3 mm/hr and nearby Goose Creek Watershed ranged from 4.8 to 19.6 mm/hr. The duration of the rainfall ranged from 1 to 2 days in North Farm and 1 to 3 days in Goose Creek Watershed.

Preliminary monitoring results from both study areas showed that a maximum rainfall intensity of 10 mm/hr or greater was associated with EG formation, and total rainfall depth of 25 mm or greater was associated with those EG-forming high-intensity events (Table 1). Though preliminary, these rainfall intensities and total depths are generally within the ranges cited in the literature discussed above. The fields were tilled and bare soil was exposed during all EG-forming events. This reiterates that EG formation is likely when the soil is bare with less vegetation. Since these results are for just one year, more data are needed to confirm these preliminary rain thresholds for the formation of EGs. Table 1. Rainfall characteristics in North Farm and in Goose Creek Watershed. More detailed timing of events is shown in Figure 3.

Table 1. Rainfall characteristics in North Farm and in Goose Creek Watershed. Timing of events is also shown in Figure 3.

Date	Total event rainfall (mm)	Max intensity (mm/hr)	Duration (days)	Notes	Field operations
North Farm					
10-Apr	26.92	9.65	2		Disc cultivator
12-Apr	14.22	2.29	1	Gully formed	
26-Apr	78.23	16.26	1	Gully formed	Field cultivator
16-Aug	39.88	12.95	2		
19-Aug	15.49	12.70	1		Chisel plow
26-Aug	25.40	12.19	2	Gully formed	
3-Sep	17.78	8.89	2	Gully not extended	
12-Sep	29.97	17.27	1		
21-Sep	27.18	15.75	2	Gully extended	
Goose Creek Watershed					
4-Jul	17.78	8.89	1		Harvest
20-Jul	26.92	10.67	3		MB plow
1-Aug	32.77	19.56	1		Disk cultivator
18-Aug	27.69	12.19	3		Field cultivator
25-Aug	19.30	15.75	1		
4-Sep	15.24	10.16	1	No observation	
9-Sep	26.42	7.37	3	Gullies formed	
21-Sep	13.21	4.83	3	Gullies formed	

Characteristics of EGs

The field measurements of EGs in North Farm and Goose Creek Watershed were conducted in the month of September 2009. The length of EGs varied from 45 to 160 m in North Farm and 45 to 150 m in Goose Creek Watershed (Table 2). The average depth of the EGs varied from 0.05 to 0.10 m in North Farm and 0.03 to 0.11 m in Goose Creek Watershed (Table 2). These data show that the depth of EGs were fairly consistent between the two study areas. The width to depth ratio varied from 6.9 to 30.2 in North Farm and 14.2 to 78.6 in Goose Creek Watershed (Table 2). Poesen and Govers (1990) reported that width to depth ratio of greater than one are considered wide and shallower gullies, which can be erased easily using tillage and can cause crop damage. The results of our study showed that EGs in Goose Creek Watershed were much wider and shallower than the gullies in North Farm (Table 2).

Table 2. Characteristics of EGs

Gully no	Length (m)	Avg top width (m)	Avg bottom width (m)	Avg depth (m)	w/d ratio	Avg area[T] (m^2)	Avg area[R] (m^2)	Gully location	Residue cover (%)
North Farm									
EG 1	143	0.64	0.26	0.09	6.94	0.05	0.07	ND[a]	20
EG 2	145	0.73	0.29	0.10	7.33	0.05	0.07	ND[a]	20
EG 3	160	1.51	1.08	0.05	30.20	0.06	0.07	ND[a]	20
EG 4	45	0.54	0.23	0.06	8.49	0.04	0.05	ND[a]	20
Goose Creek Watershed									
EG 1	45	2.05	1.88	0.05	37.96	0.10	0.11	ND[a]	<15
EG 2	100	1.56	1.45	0.05	29.40	0.08	0.08	ND[a]	<15
EG 3	60	0.62	0.54	0.04	14.23	0.03	0.03	ND[a]	<15
EG 4	140	2.40	2.14	0.11	21.15	0.20	0.22	ND[a]	<15
EG 5	90	1.54	1.43	0.05	30.36	0.07	0.07	ND[a]	<15
EG 6	150	2.27	2.08	0.03	75.63	0.06	0.07	ND[a]	<15
EG 7	110	1.13	0.98	0.05	22.15	0.04	0.05	ND[a]	<15
EG 8	120	1.48	1.27	0.05	30.08	0.07	0.07	ND[a]	<15
EG 9	120	1.70	1.30	0.08	20.23	0.14	0.15	ND[a]	<15

[T]: Trapezoidal cross-section

[R]: Rectangular cross-section

ND[a]: EG formed along the natural depression and drainage lines

The trapezoidal and rectangular cross sectional areas were calculated using the field measurements. Trapezoidal and rectangular cross sectional areas did not vary much among the gullies (Table 2). The residue cover during the field measurements was 20% in North Farm and 15% or less in the Goose Creek Watershed; all measured EGs were located along natural depression or drainage paths.

The soil loss from each EG in North Farm and Goose Creek Watershed was calculated using field measurements. The total volume and total sediment for rectangular and trapezoidal cross-section channels are given in Table 3. The total volume ranged from 2 to 10 m^3 and 2 to 12 m^3 for trapezoidal and rectangular cross-sectional areas in North Farm and 2 to 28 m^3 and 2 to 31 m^3 in Goose Creek Watershed (Table 3). The estimated total sediment loss ranged from 1,947 to 13,184 kg (trapezoidal cross-section) and 2,794 to 15,090 kg (rectangular cross-section) in North Farm and 2836 to 37,314 kg (trapezoidal cross-section) and 3024 and 41,763 kg (rectangular cross-section) in Goose Creek Watershed. The results show that the use of trapezoidal or rectangular cross-sectional area estimation methods did not have much impact on the total volume and total sediment calculations. Trapezoidal cross-section calculations require top width, bottom width and depth while the rectangular cross-section calculations require top width and depth. The results of this study suggest that the measurements of top width and depth are sufficient to derive soil losses due to EGs.

Table 3. Measured soil loss from each monitored ephemeral gully (EG).

Gully no.	Bulk density (kg/m^3)	Total volume^T (m^3)	Total volume^R (m^3)	Total sediment^T (kg)	Total sediment^R (kg)
			North Farm		
EG 1	1270	7	10	8,592	12,675
EG 2	1270	8	11	9,726	14,132
EG 3	1270	10	12	13,184	15,090
EG 4	1270	2	2	1,947	2,794
			Goose Creek Watershed		
EG 1	1250	5	5	6,234	6,550
EG 2	1350	8	9	11,075	11,492
EG 3	1350	2	2	2,836	3,025
EG 4	1350	28	31	37,314	41,763
EG 5	1350	10	11	13,759	14,720
EG 6	1500	10	11	14,858	15,750
EG 7	1500	5	6	7,862	8,487
EG 8	1350	9	10	11,969	12,879
EG 9	1350	17	19	22,791	25,549

^{T}: Trapezoidal cross-section

^{R}: Rectangular cross-section

EG erosion in Goose Creek Watershed

The location of each EG was recorded in Goose Creek Watershed and was digitized using aerial images, as described earlier. Figure 5 shows digitized EGs in Goose Creek Watershed. The digitized results show that there were around 178 active EGs in Goose Creek Watershed with lengths of individual EGs ranging from 34 to 1079 m. The total length of EGs in Goose Creek Watershed was 69,636 m (46 mi) with an EG density of 5.5 m/ha. The total sediment and erosion rate in Goose Creek Watershed was derived as described earlier. The total sediment leaving the EGs during the period between tillage and measurement (including 3 rainfall events; Figure 3b was 8,617,455 kg (9,500 tons) while the erosion density for this period was around 0.25 kg/m^2 watershed area. More monitoring and field measurements are needed to derive the annual erosion density (i.e., kg/m^2/yr).

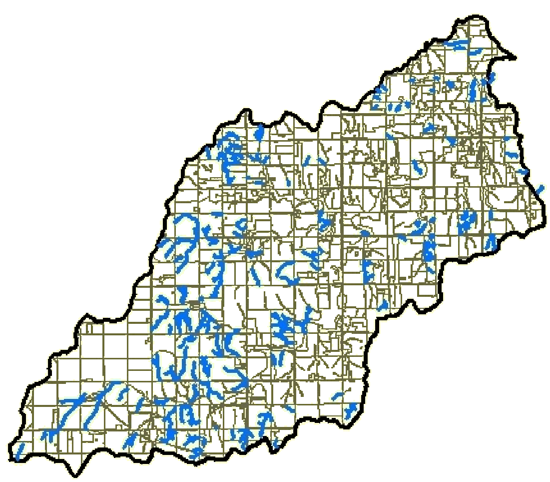


Figure 4. Digitized ephemeral gullies in Goose Creek Watershed.

Conclusions

The EGs were monitored and measured in North Farm and Goose Creek Watershed, which are located in north eastern and south central parts of Kansas. Preliminary results showed events with rainfall intensity of greater than 10 mm/hr and total rainfall depth of 25 mm were associated with formation and development of EGs. All the EGs that were monitored and measured formed along the natural depressions or drainage flow paths. During field measurements of EGs, top width and depth at regular intervals were adequate to estimate the soil losses from the EGs. The total length of EGs in Goose Creek Watershed was 69,636 m with a EG density of 5.5 m/ha and total sediment loss after a rainfall event was 8,617,455 kg (9,500 tons) while the event-based erosion density was around 0.25 kg/m^2 watershed area. The EGs that were monitored in the study area formed after some kind of tillage operation in the field and when the residue cover in the field was low. This suggests that conservation practices in other, nearby fields appear to have been effective in reducing EG erosion.

Future Work

We plan to continue to collect data on EG location, size and characteristics and develop a stand-alone, simple model to identify the EG location and estimate EG sediment yield.

Acknowledgement

This material is based on work supported by the USDA Cooperative State Research, Education, and Extension Services (CSREES) under Agreement No. 2005-51130-02364.

References

Bingner, R. L. and F. D. Theurer. 2001. AnnAGNPS: Estimating sediment yield by particle size for sheet and rill erosion. *Proceedings of Sedimentation, Monitoring, Modeling, and Managing, 7th Federal Interagency Sedimentation Conference*, Reno, NV, 25-29.

Capra, A., and B. Scicolone. 2002. Ephemeral gully erosion in a wheat-cultivated area in Sicily, Italy. *Biosyst. Eng* 83(1): 119-126

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

Capra, A., P. Porto, and B. Scicolone. 2009. Relationships between rainfall characteristics and ephemeral gully erosion in a cultivated catchment in Sicily (Italy). *Soil & Tillage Research* 105: 77-87.

Casali, J., J. J. Lopez, and J. V. Giraldez.1999. Ephemeral gully erosion in southern Navarra (Spain). *Catena* 36: 65– 84.

Cerdan, O., Y. Le Bissonnai, A. Couturier, H. Bourennane, and V. Souche re. 2002. Rill erosion on cultivated hillslopes during two extreme rainfall events in Normandy, France. *Soil & Tillage Research* 67: 99–108.

Foster, G.R. 1986. Understanding ephemeral gully erosion. *In* Committee on conservation needs and opportunities. Assessing the National Resources Inventory. Soil Conservation Service, 90-125. Board on Agriculture, National Research Council. National Academy Press, Washington, D.C.

Gordon, L. M., S. J. Bennett, and C. V. Alonso. 2007. Simulating ephemeral gully erosion in AnnAGNPS. *Trans. ASABE* 50(3): 857.

Nachtergaele, J., J. Poesen, L. Vandekerckhove, D. O. Wijdenes, and M. Roxo. 2001. Testing the Ephemeral Gully Erosion Model (EGEM) for two Mediterranean environments. *Earth Surface Processes and Landforms* 26(1): 17.

Poesen, J., and G. Govers. 1990. Gully erosion in the loam belt of Belgium: Typology and control measures. Soil Erosion and Agricultural Land. John Wiley & Sons, London. pp. 513-530.

Poesen, J., J. Boardman, B. Wilcox, and C. Valentin.1996a. Water erosion monitoring and experimentation for global change studies. *J. Soil Water Conserv* 51(5): 386–390.

Poesen, J., J. Nachtergael, G. Verstraeten, and C. Valentin. 2003. Gully erosion and Environmental change: Importance and research needs. *Catena* 50 (2–4): 91–133.

Robinson, K. M., S. J. Bennett., J. Casali and G. J. Hanson. 2000. Processes of headcut growth and migration in rils and gullies. *Intl. J. Sediment Res* 15: 69-82.

USDA-NRCS, 1997. America's Private Land. A Geography of Hope. United States Department of Agriculture, Natural Resources Conservation Service, Washington, DC, p. 39.

USDA-NRCS. 1995. Soil data mart. Washington, D.C.: USDA Natural Resources Conservation Service. Available at: http://soildatamart.nrcs.usda.gov/Default.aspx. Accessed January 2009.

Vandaele, K. 1993. .Assesment of factors affecting ephemeral gully erosion in cultivated catchments of the Belgian Loam Belt. *In* Farm Land Erosion in Temperate Plains Environment and Hills. S. Wicherek, ed. 125-136. Elsevier, Amsterdam

Vandaele, K., J. Poesen, J. R. Marques da Silva, and P. Desmet. 1996b. Rates and predictability of ephemeral gully erosion in two contrasting environments. *Geomorphologie: Relief, Processus, Environment* 2: 83-96

Vrieling, A. 2006. Satellite remote sensing for water erosion assessment: A review. *Catena* 65: 2-18.

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

Zhang, Y., Y. Wu, B. Liu, Q. Zheng, and J. Yin. 2007. Characteristics and factors controlling the development of ephemeral gullies in cultivated catchments of black soil region, Northeast China. *Soil & Tillage Research* 96: 28-41

Zheng, F., and X. Gao. 2000. Process and modeling of soil erosion on loess slope. Shaanxi peoples press, Xian, pp. 96-119

Apendix 1

Ephemeral Gully Measurements – Field Note Book

Name of the Investigators:

General Information

Date and Time of data collection	Date:	Time:
Name of the Watershed where gully is present		
Navigable location of the Gully		
Weather conditions during data collection	☐ Sunny ☐ Cloudy	
Conditions of the ground during collections	☐ Wet ☐ Dry ☐ Muddy	

Gully Information

Gully in the Drainage Line (convex areas)	☐ Follows natural drainage line ☐ Others**:**
Where it Starts	☐ Within the field ☐ Edge of the field
Where it Ends	☐ Within the field ☐ Edge of the field
Overall Length of the gully(m) (tape measure)	
Record the length with GPS unit*	
Place a flag at knick point	☐ Yes
Place flags at every 10m interval along thalweg	☐ Yes
Take pictures of gully	☐ Yes

*Procedure to record length using GPS unit is given in appendix

Additional Notes

Measurements at every 5m interval

Interval	Top width (cm)	Bottom width (cm)	Depth (cm)	Soil Sample*	Branching		
					Y/N	Number	Direction*
0				X			
5							
10							
15							
20				X			
25							
30							
35							
40				X			
45							
50							
55							
60				X			
65							
70							
75							
80				X			
85							
90							
95							
100				X			
105							
110							
115							
120				X			
125							
130							
135							
140				X			
145							
150							

Interval	Top width (cm)	Bottom width (cm)	Depth (cm)	Soil Sample*	Branching		
					Y/N	Number	Direction*
155							
160				X			
165							
170							
175							
180				X			
185							
190							
195							
200				X			
205							
210							
215							
220				X			
225							
230							
235							
240				X			
245							
250							
255							
260				X			
265							
270							
275							
280				X			
285							
290							
295							
300				X			
305							

Field Notes

Present field conditions	☐ Bare soil ☐ Crop ☐ Perennial grass
Soil Roughness in field* (cm)	
Residue cover during measurements (%)*	
Residue from which crop	
Management practice in the field	☐ NT ☐ CT ☐ Contour Farming ☐ Terraces ☐ Others:

* Use ruler to find out the depth of the soil at 5 locations and do an average and report here in cm

* use the attached appendix photos to assess the residue cover

Data from the Farmer

When was the gully first seen (year)	
How often does the gully form	
Tillage implement used in the field	
Depth of tillage (cm)	

Additional Notes: