Sheet and Gully Erosion in the Missouri Valley Loessial Region

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STREAMS that drain the loessial lands bordering the lower Missouri River have always carried sizeable quantities of sediment (1)*. These sediments are largely derived by sheet erosion from upland areas and by cyclic erosion activity in gullies and drainageways. This erosion is both natural and manmade.

The interaction of natural erosive forces with those imposed by man is not well understood. Daniels and Jordan (2) postulate that the stream trenching and gullying which began about 1880 in Harrison County, Iowa, for example, could have been related to natural cyclic factors. There is little doubt, however, that cultivation has increased runoff and erosion rates and prolonged this gullying cycle, because stream trenching has continued to the present.

The purpose of this paper is to assay the erosion problem in the Missouri Valley Loessial Region by quantifying, first, the erosion in those upland fields and gullies where much sediment originates and, second, the sediment transported to downstream locations (sediment yield). Data from past and present studies are then utilized to explain some variations in erosion rates and sediment yields, in terms of some affecting variables.

SHEET EROSION AND SEDIMENT YIELD

Sheet-rill erosion rates (hereafter termed "sheet erosion" or "soil loss") have been measured for a variety of cropping and management conditions at experiment stations in northwestern Missouri and western Iowa. Many of these small-plot erosion measurements have been incorporated into empirical expressions (3, 4) that relate soil loss to characteristics of rainfall, soil, topography, land use, and land management. These existing formulas are the basis for much land-resource planning. The records from these field-plot studies, furthermore, show negligible losses for many good-management plots and immense sheet erosion rates for storms occurring on vulnerable soils at critical crop stages. For example, single-storm erosion rates at Bethany, Missouri (5) and Castana, Iowa (6) have been in excess of 20 tons per acre, and annual losses from sheet erosion have exceeded 60 tons per acre on row crops.

Sediment yields at downstream locations are related to the quantities of sediment produced and the efficiency of transport of sediment derived upstream. The ratio of sediment yield to total material eroded on the contributing watershed is termed the sediment delivery ratio. Sediment delivery is often expressed as a fraction or percentage of total upstream eroded soil. Although the onsite erosion rates from field-size watersheds with long, steep slopes can far exceed those measured on small experimental plots (7), many factors operate to reduce the sediment yield, per unit drainage area, at downstream points.

In the Missouri Valley loessial area, most of the soil particles are in the silt-clay size range and can be moved with a minimum velocity of the entraining runoff. Therefore, the most significant transport losses occur during the sheet-erosion process, when soil is moved in sheets and micro-channels, and large local changes in flow gradient are possible. Deposition is usually most prevalent at the base of steep field slopes. Once in a graded channel or gully, there is little opportunity for these fine sediments to deposit.

Sediment yields for some watersheds in the deep loess region have been determined from reservoir surveys and from streamflow sampling programs. Summaries from about 50 small reservoir watersheds in the loess region (8, 9, 10) show only a few sediment yields that average more than 20 tons per acre per year. This approximates the upper limit for land continually row cropped without conservation treatment.

Streamflow sampling programs, intended to show sediment dicharge rates and sediment yields, are usually of short duration but encompass a wide range of watershed sizes. Typical sediment yields from small loessial watersheds in the area – those with the longest gaging and sampling experience – are listed in Table 1.

TABLE 1. SEDIMENT YIELDS FROM STREAMFLOW SAMPLING

Station	Drainage, acres	Record length, years	Sediment yield, tons per acre per year
Mule Creek near Malvern, Iowa	6,780	13¼	3.7
Tarkio River at Blanchard, Iowa	128,000	6	5.2
West Tarkio Creek near Westboro, Missouri	67,200	6	4.8
Thompson Creek near Woodbine, Iowa	4,280	4	4.2
Steer Creek near Magnolia, Iowa	5,950	4	3.5

These sediment quantities seem acceptable at first glance; they are below the 5 to 6-tons-per-acre annual maximum that conservationists allow in erosion-control design for this area. Further study, however, reveals that many parts of these watersheds are noncontributing because dams and terraces effectively control sediment movement; the principal contributory areas are cultivated upland fields, with land slopes to 20 percent, which are presently used beyond their capabilities. Much of the soil eroded from these fields is not flushed through the drainage system.

A better focus on sheet erosion sources in the Missouri Valley loess can be obtained by considering the results from intensive studies on ARS watersheds near Treynor and Macedonia, Iowa. These watersheds, located and described in Fig. 1, have been gaged since 1964. This period is too short for conclusive findings, but some progress has been made in evaluating land-use and treatment effects as well as sheet and gully erosion phenomena.

Annual sediment yields for ARS watersheds, from both sheet and gully sources, are shown in Fig. 2, along with concurrent sediment yields measured at Mule Creek near Malvern, Iowa (10.6 sq miles), Steer Creek near Magnolia, Iowa (9.3 sq miles), and Thompson Creek near Woodbine, Iowa (6.7 sq miles). The paired contour-corn watersheds 1 and 2 experienced much greater soil loss (averaging nearly 30 tons per acre per year) than either the grass (W-3) or the level-terraced (W-4) watershed. These differences

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* Numbers in parentheses refer to the appended references.

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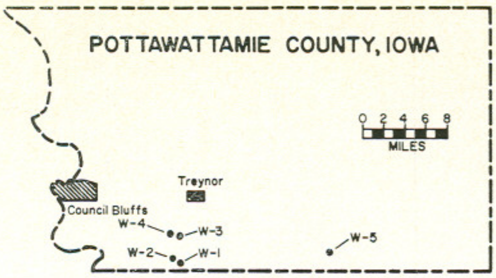


WATERSHED DESCRIPTION

WATERSHED	SIZE	CROPPING	LAND TREATMENT
	ACRES		
1	74.5	Continuous Corn	Field-Contoured
2	82.8	Continuous Corn	Field-Contoured
3	107	Grass	None
4	150	Continuous Corn	Level-Terraced
5	389	Mixed	Level-Terraced

FIG. 1 Location and description of research watersheds.

in sediment yield were especially significant in 1964 and 1965, when annual rainfall averaged 6 and 16 in., respectively, above the 29-in. norm. Sediment yield from both sheet and gully sources was 1 ton per acre or less on grassed watershed 3 and level-terraced corn watershed 4. The sheet erosion rates between terraces were significantly higher, but nearly all the eroded soil was retained in the level-terrace channels. Confirming the erosion control effected by terraces, the measured sediment yield from the 339-acre, level-terraced, mixed-crop watershed near Macedonia, Iowa, was 1 ton per acre or less.

These sediment yields from single-crop or single-treatment watersheds are also compared (Fig. 2) with those from three nearby watersheds having varied cropping and treatment. As would be expected, the sediment yields for Mule, Steer, and Thompson Creek watersheds are intermediate in magnitude.

The variation in sediment yield from active sheet erosion sources is perhaps exemplified by the erosion history of watersheds 1 and 2, which are field-contoured and ~~and~~ in continuous corn, with an average land-surface slope of 8 to 10 percent. It was possible to separate sediment yield according to source – sheet-rill erosion or gully erosion – by sampling streamflow above and below the raw gully headcut at the outlet of each watershed. Fig. 3 summarizes the effect of the rainfall variable, 1964-66, when annual precipitation for each of the 3 years was abnormal.

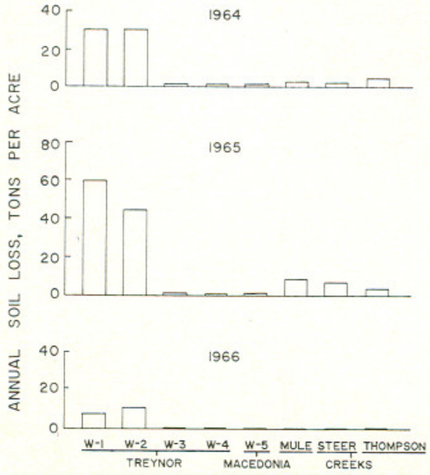


FIG. 2 Variation in sediment yields for watersheds with different land use-treatment histories.

A 20-ton per acre per year sediment yield from sheet erosion appears to be near the long-term normal for mismanaged cropland in this soil area, but the within-year and year-to-year rainfall variation” is so large that a “normal” erosion year is unlikely.

Other characteristics of sheet-erosion phenomena are evident from a study of Table 2, which includes the storm sediment yields from sheet erosion sources for 1965 and 1966. More data are needed before precise relationships are drawn, but the 2-year experience shows that, although sediment yield from sheet erosion sources is runoff-entrained and is correlated with runoff amount and intensity, it is still highly variable. The overall runoff-sediment relation (not shown) indicates that, on the average, each inch of runoff might be expected to move about 3 tons of soil from each acre of cornfield and through the drainage system. Note, however, that the 1.9-in. total rainfall of May 22, 1965, produced less than 1 inch of runoff but more than 8 tons per acre of sediment from the drainage systems of watersheds 1 and 2.

Findings from Table 2 also reveal that soil loss equations, which are usually reliable predictors of long-term soil losses from field areas, do not predict individual-storm soil losses to the same accuracy. Comparisons between computed storm soil loss and measured sediment yields from sheet-rill sources show excessive sediment delivery, especially during the early crop-stage periods. Sediment delivery at watersheds 1 and 2 during May and June 1965, for example, was quite high. The measured sediment yields sometimes exceeded the computed storm soil losses. By contrast, the sediment delivery averaged about 20 percent for the September 1965 storms.

These excessive sediment yields and high-delivery ratios during the early crop-stage periods must be the result of conditions and processes that are not encountered in the usual application of the soil-loss equation to compute long-term yields. Two causes are:

1 Antecedent moisture conditions, which vary from storm to storm within season. The soil-loss equation assumes average antecedent moisture from all storms.

2 The development of large, complex rill systems, especially in tilled, unsodded drainageways.

GULLY EROSION

Gullying is prevalent throughout most of the United States, and Bennett (11) estimated that 200 million active gullies were in existence in 1939. Gullies void farmland, dissect fields, impede efficient tillage operations, create safety hazards, and contribute to downstream sediment problems. They are particularly troublesome in the deep loessial soils bordering the entrenched Missouri River and its major tributaries.

Brice (12) described the essential features of a gully to be its size (must be larger than a rill), recency of extension in length, steepness of head and sides, incision into unconsolidated materials, and ephemeral transmission of

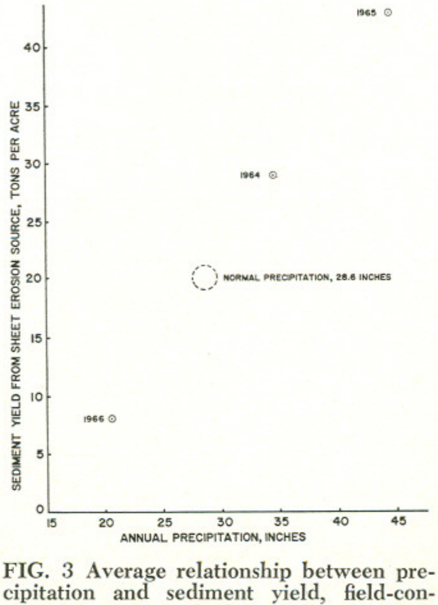


FIG. 3 Average relationship between precipitation and sediment yield, field-contoured corn watersheds 1 and 2, 1964-66.

TABLE 2. HYDROLOGIC AND SEDIMENT INFORMATION FOR ALL MAJOR STORMS ON WATERSHEDS 1 AND 2, 1965-1966

	Watershed 1						Watershed 2					
			Sediment yield						Sediment yield			
Date	Rainfall, inches	Runoff, inches	From sheet erosion source tons per acre	From gully erosion source, tons	Computed total sheet erosion, tons per acre	Sediment delivery based on sheet erosion, percent	Rainfall, inches	Runoff, inches	From sheet erosion source tons per acre	From gully erosion source, tons	Computed total sheet erosion, tons per acre	Sediment delivery based on sheet erosion, percent
1965												
April 4, 5	1.13	0.32	1.63	40	0.66	247	1.13	0.42	1.80	40	0.47	383
April 8	1.01	0.10	0.21	32	0.82	26	1.09	0.06	0.11	17	0.88	12
May 17, 18	1.12	0.20	3.80	30	5.07	75	0.88	0.12	2.15	8	2.39	90
May 21	0.87	0.25	2.93	77	2.68	109	0.89	0.23	2.49	112	2.32	107
May 21, 22	1.92	0.95	9.64	223	3.08	313	1.88	0.96	8.01	116	3.07	261
May 24	0.77	0.28	3.01	32	2.37	127	0.65	0.25	2.14	15	1.20	178
May 25, 26	0.47	0.11	1.21	15	0.57	213	0.41	0.11	1.09	5	0.98	111
June 2	0.48	0.03	0.12	10	0.63	19	0.34	0.03	0.08	1	0.24	33
June 6	0.64	0.37	2.39	115	1.70	140	0.78	0.36	2.05	75	1.44	142
June 28, 29	4.24	1.59	14.00	97	25.30	55	4.02	1.61	11.30	52	17.40	65
July 1	0.93	0.18	0.97	37	0.96	101	0.82	0.18	0.74	14	0.72	103
July 30	0.76	0.03	0.09	3	0.80	11	0.81	0.05	0.10	3	0.87	12
Aug. 29, 30	1.89	0.23	0.32	43	4.55	7	1.74	0.23	0.51	21	3.19	16
Sept. 7	4.28	1.15	1.07	134	9.80	11	3.97	1.03	0.94	94	7.78	12
Sept. 8	1.17	0.23	0.25	40	0.66	38	0.99	0.15	0.13	2	0.36	36
Sept. 17, 18	0.55	0.06	0.04	8	0.45	9	0.51	0.04	0.03	1	0.30	10
Sept. 18	0.52	0.06	0.07	12	0.18	39	0.91	0.12	0.17	6	0.56	30
Sept. 20	1.82	0.33	0.11	68	1.06	10	1.92	0.28	0.07	10	1.12	6
Sept. 27	0.86	0.07	0.04	17	0.46	9	0.95	0.06	0.04	3	0.43	9
Sept. 29, 30	0.96	0.09	0.09	25	1.82	5	0.90	0.08	0.07	5	0.42	17
1966												
May 15	0.53	0.03	0.42	5	1.37	31	0.65	0.10	1.81	22	1.07	169
May 23	0.50	0.01	0.03	1	0.75	4	0.48	0.01	0.03	1	0.32	9
June 5	0.88	0.08	1.01	19	3.60	28	0.88	0.12	2.18	0	2.53	86
June 25, 26	2.44	0.46	5.19	67	8.71	60	2.76	0.50	4.51	161	8.25	55
July 14, 15	1.62	0.01	<.01	1	4.20	0	1.91	<.01	<.01	0	3.28	0

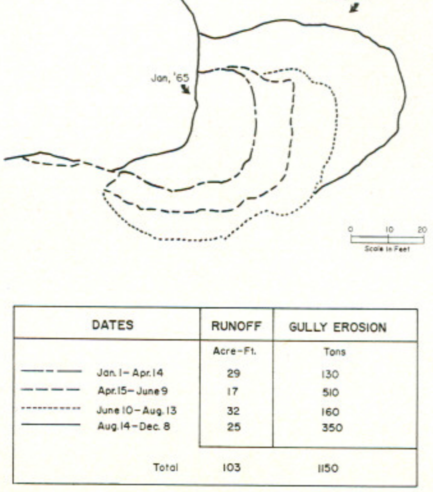
flow. Gully cutting can begin at any location in a drainageway where gradients or local disturbances permit concentration of runoff. Gully growth is then continued by upstream movement of the overfall, channel degradation, and lateral enlargement of the channel.

The quantities of sediment moved from gully systems in loessial regions are highly variable. Brice (12), in studies of gully erosion in the deep loess of western Nebraska, found from measurements on aerial photos that the 216 active upland gullies in the 20-square-mile Dry Creek Watershed contributed 66 acre-ft of sediment in the 15-year period, 1937 to 1952. This is 6 percent of the estimated average annual sediment yield (13). In addition, erosion of the main channels by enlargement and headcutting accounted for a large amount of sediment.

Dvorak and Heinemann (14) found, from channel surveys and a streamflow sampling program, that the 111 acre-ft of sediment eroded from the main valley-bottom gullies of Dry Creek constituted 68 percent of the measured sediment load passing the streamflow-sampling station during the above-normal rainfall period, May 1951 to May 1952. For the dry years, 1952 to 1953, surveys showed that only 14.6 acre-ft was eroded from valley-bottom gullies, and this constituted a much smaller portion of the total sediment load. On the average, however, gully erosion accounts for 10 to 30 percent of the total sediment yield from those small watersheds where active gullying is not inhibited by remedial measures.

In western Iowa, Beer (15) estimated the 1942 to 1962 gully erosion in the 9-sq-mile Steer Creek watershed to be 10.5 tons per acre annually. This rate dropped to 2 tons per acre per year in 1962-1963 and averaged less than 2 tons per acre per year, 1964 through 1967. Gottschalk and Brune (8) used reservoir sedimentation surveys and aerial photo measurements as a basis for their conclusion that gullies can be the major sediment contributor on some watersheds.

Many factors relating to gully formation and growth have been identified but need further quantification. In the loessial region under consideration, Thompson (16) found that the square root of watershed size was best correlated with gully growth. Beer and Johnson (17) included an index of surface runoff and the distance from gully head to watershed divide in an equation to estimate areal changes in a gully with time; these are also correlated with watershed size. Leopold et al (18) cite the moisture in the substratum and several other factors, but conclude that "surprisingly little is known, at least quantitatively, about the mechanics of the process."



DATES		RUNOFF	GULLY EROSION
		Acre-Ft.	Tons
— – —	Jan. 1–Apr. 14	29	130
– – – –	Apr. 15–June 9	17	510
------------	June 10–Aug. 13	32	160
———	Aug. 14–Dec. 8	25	350
	Total	103	1150

FIG. 4 Runoff and accompanying gully growth during 1965, watershed 1 near Treynor, Iowa.

Erosion rates from raw gullies located at the outlets of watersheds 1 and 2 are listed in Table 2, columns 5 and 11, for most storms in 1965 and 1966. In 1965 alone, 1150 tons was eroded from the vicinity of the gully head of watershed 1, whereas only 230 tons was removed from the gully head and channel immediately below the headcut of watershed 2. The data for watershed 1 are of special interest because the extremely large quantities of material removed during the period must be near the upper limit of gully erosion that is possible for the given energy inputs. For this reason, these records probably offer the best opportunity for identifying the unattenuated basic interactions responsible for gully erosion; once identified, complementary model experiments can be designed that will further isolate and evaluate these erosive forces.

Fig. 4 locates the moving gully head of watershed 1 at different times during the high runoff year of 1965 and shows the runoff quantities associated with this erosion. Although the exact role of runoff in gullying is not known, the storm runoff component is the principal mover of gully debris. It is responsible for bed and bank scour by virtue of the tractive forces exerted; it causes localized scour by plunge-pool action at the headcut; it is responsible for some bank saturation and sloughing activities. Other contributory forces result from wetting of gully banks by rainfall, seepage from ground water, subsequent wet-dry, freeze-thaw cycles, and the effect of gravity.

The process of gully cleanout during the course of the storm of May 25, 1965, and the erosive effect of the runoff are shown in Fig. 5. The continuous concentration curve of gully erosion was obtained by gaging the runoff and by collecting 33 streamflow samples above and below the gully head of watershed 1. In this way, it was possible to separate the sediment concentration (and discharge) into sheet erosion and gully erosion components.

At the outset of the storm, the sediment concentrations were near maximum, but rapidly decreased before the runoff rate reached a maximum. Soon thereafter, from 2116 to 2121 hr, the supply of soil debris in the channel was exhausted. The later increase in sediment concentration is attributed to massive slumping of the gully bank at the headcut.

SUMMARY

The limits of upland erosion rates in the Missouri Valley Loessial Region — from sheet and gully sources have been generally defined for several types of land use on the basis of measurements from experiment station plots, reservoirs, and streams. For the highly erodible loessial soils bordering the lower Missouri Valley, small-plot soil losses from poorly managed row crops have exceeded 60 tons per acre per year and 20 tons per acre per storm.

Long-term sediment yields from field-size areas should generally not exceed 20 tons per acre annually for field-contoured row crops; this estimate is based on interpretation of reservoir sedimentation surveys and measurements at ARS watersheds near Treynor, Iowa. By comparison, losses from level-terraced cornfields or from meadows were usually less than 1 ton per acre annually. Sediment yields from sheet erosion and gully erosion sources are highly variable but probably average 80 and 20 percent, respectively, for the loessial region.

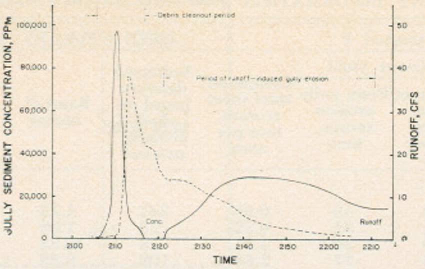


FIG. 5 The process of gully cleanout and the erosive effect of runoff, storm of May 25, 1965, watershed 1.

Results from sheet erosion measurements and soil loss computations near Treynor, Iowa, show high sediment-delivery percentages during the critical period in late spring and indicate that large rill development, especially on tilled, sidehill drainageways, is significant.

It is difficult to quantify gully erosion in terms of causative factors, but four gullied watersheds are being intensively gaged in western Iowa — and erosion rates are being measured — for this purpose. The growth of a particularly active gully was traced for the high runoff year of 1965.

The contribution from gully erosion was measured throughout the course of a storm. Typically, gully debris (from bank slumping prior to the storm) is cleaned out during the early period of runoff. Subsequent gully erosion is then a consequence of the active erosion forces of the runoff working on new materials.

References

1 Glymph, L. M. Relation of sedimentation to accelerated erosion in the Missouri River basin. SCS-TP-102, July 1951.

2 Daniels, R. B., and Jordan, R. H. Physiographic history and the soils, entrenched stream systems, and gullies, Harrison County, Iowa. SCS Tech. Bul. 1348, 1966.

3 Musgrave, G. W. The quantitative evaluation of factors in water erosion, a first approximation. Jour. of Soil and Water Conservation 2:133-138, 1947.

4 Wischmeier, W. H., and Smith, D. D. Rainfall energy and its relationship to soil loss. Amer. Geophysical Union Trans. 39:285-291, 1958.

5 Zingg, A. W. Compilation of rainfall and runoff from the watersheds of the Shelby loam and related soils, Bethany, Mo. SCS-TP-39, Supplement No. 1, 1939.

6 Unpublished data from Western Iowa Experiment Station, Castana, Iowa.

7 Smith, D. D., and Whitt, D. M. Evaluating soil losses from field areas. **Agricultural Engineering** 29:394-396, 398, 1948.

8 Gottschalk, L. C., and Brune, G. M. Sediment design criteria for the Missouri basin loess hills, SCS-TP-97, 1950.

9 Farnham, C. W. Relationship of factors contributing to reservoir sedimentation in loess soils of Iowa and Missouri. Unpublished thesis, ISU, 1966.

10 Interagency Subcommittee on Sedimentation. Appendix A to USDA Misc. Pub. 964, February 1965.

11 Bennett, H. H. Soil Conservation first edition, McGraw-Hill Book Co., Inc., New York, N. Y., 1939.

12 Brice, J. C. Erosion and deposition in the loess-mantled Great Plains, Medicine Creek Basin, Nebr. U.S. Geological Survey professional paper 352-H, 1966.

13 Piest, R. F. Long-term sediment yields from small watersheds. International Association of Scientific Hydrology, Pub. No. 65, 1964.

14 Dvorak, V. I., and Heinemann, H. G. Cooperative runoff and sediment investigations on Medicine Creek watershed in Nebraska. USDA, ARS 41-130. June 1967.

15 Beer, C. E. Personal communication, 1967.

16 Thompson, J. R. Quantitative effect of watershed variables on the rate of gully head advancement. **Transactions of the ASAE** 7:(1) 54-55, 1964.

17 Beer, C. E., and Johnson, H. P. Factors related to gully growth in the deep loess area of western Iowa. From ARS Misc. Pub. 970, Proceedings of the Federal Interagency Conference, 1963.

18 Leopold, L. B., Wolman, M. G., and Miller, J. P. Fluvial processes in geomorphology. pp. 442-448. W. H. Freeman & Co., 1964.