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HYDROLOGY AND EROSION OF LOESSIAL WATERSHEDS

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Results are reported which relate vegetation and conservation treatment to the hydrology and erosion of agricultural watersheds that have deep loessial soils. Six years of stream flow and erosion data from five small (75- to 389-acre) research watersheds in the deep loessial soils area of western Iowa are presented and analyzed. The watersheds have been managed to compare the effects of contoured corn, pastured grass, level-terraced corn, and level-terraced mixed crops. Each watershed has been maintained in one of these land-use combinations for the entire study period; thus, the effects on watershed hydrology and erosion can be evaluated by direct comparison.

Results presented are interpreted from time-averaged values, such as annual water and sediment yields. Many interesting and important details are concealed by this averaging; however, the results show significant overall management effects. These general results will be analyzed under categories of water yield, peak runoff rates, sheet-rill erosion, and gully erosion, all of which are closely allied and related to watershed management. Additional details of these data have been published elsewhere (9,12).

PREVIOUS RESEARCH

Numerous summaries have been prepared to state the knowledge, or lack of it, for relating stream performance and watershed erosion to land-use management. For example, the ASAE Committee on Agricultural Hydrology

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(2) issued a joint statement by several research hydrologists. No definite conclusions were presented but many pertinent questions were raised. They urged then, as now, that watersheds be managed for the best conservation of water and soil with available knowledge and good rationale—while continuing research efforts.

TABLE 1.—WATERSHED DESCRIPTIONS

Watershed number (1)	Size, in acres (2)	Crop (3)	Conservation treatment (4)
1	74.5	Continuous corn	Field contoured
2	82.8	Continuous corn	Field contoured
3	107	Brome grass	Rotation grazed
4	150	Continuous corn	Level terraced
5	389	Mixed[a]	Level terraced

[a] Two-thirds row-cropped corn and soybeans; one-third small grain and pastured grass.

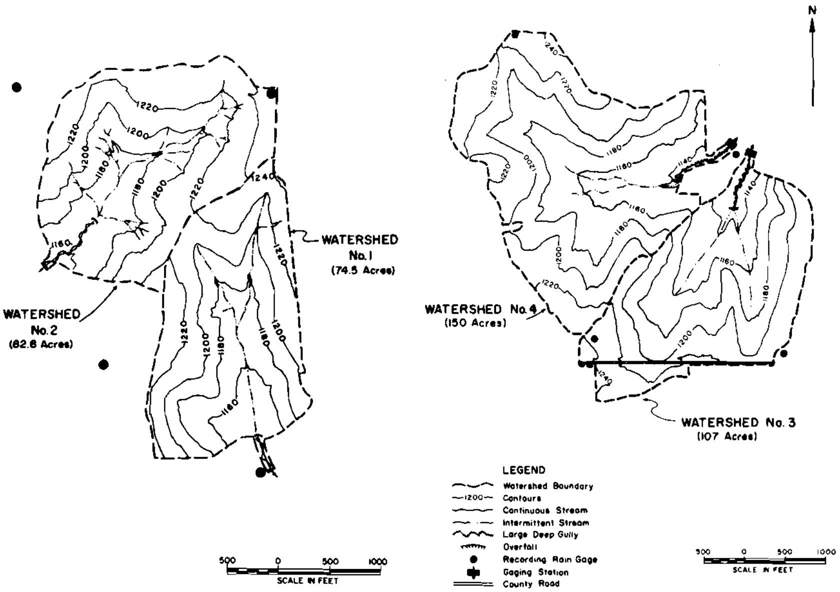


FIG. 1.—TOPOGRAPHY AND INSTRUMENT LOCATION OF TREYNOR, IOWA, WATERSHEDS 1-4

Glymph and Holtan (3) reviewed many of the past research efforts designed to determine the effects of land management on watershed hydrology and how to apply this knowledge to solving hydrologic problems with mathematical watershed models. They reemphasized the complexity of the solution because of different climates and different geographic and geologic domains. Harrold and Dragoun (4) summarized recent research results, but their specific conclusions were limited in their applicability. Moore and Smith (7) emphasized that watershed management includes economic use as well as protection of all watershed resources. They concluded that land treatment is the first line of defense against watershed erosion and sedimentation.

In retrospect, past research has raised many questions and provided some answers and important guidelines for future research. Hydrologic and erosion processes must be defined as a function of land management with the recognition that these relations will vary with climate, physiography, and geology. Soil and water resources must be used with the best possible management and preservation known; at the same time, an attempt must be made to better understand the effects of our actions.

WATERSHED DESCRIPTIONS

Data for this report were obtained from five research watersheds in western Iowa near Treynor. Adjoining watersheds 1 and 2 are 3 miles south of adjoining watersheds 3 and 4. Watershed 5 is about 10 miles east. The topography and primary instrumentation of watersheds 1 through 4 are shown in Fig. 1. Watershed 5 has similar instrumentation but somewhat flatter topography.

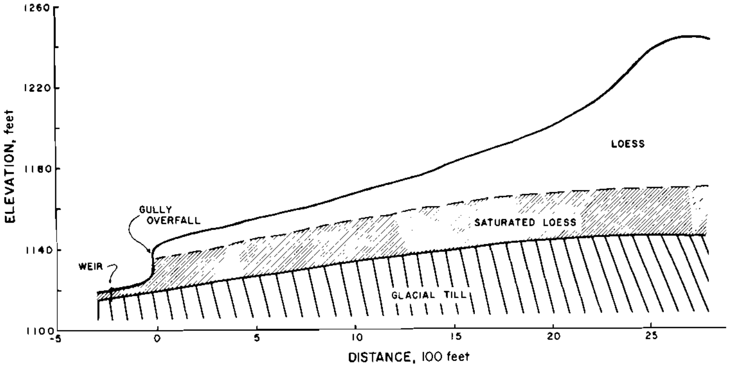


FIG. 2.—GEOLOGIC SECTION OF LOESSIAL WATERSHEDS

Watershed size, cropping, and conservation treatment of the five watersheds are shown in Table 1. Watersheds 1 through 4 are each in a single land use and are farmed according to the more progressive techniques of the area. The conservation treatment field contoured is farming approximately on the contour with conventional tillage tools and corn planter, and the contours are not laid out as precisely as the usual conservation practice of contouring. Watersheds 4 and 5 are level terraced, with 92 % and 85 %, respectively, of their areas above terraces. These terraces have a storage capacity of about 2 in. of surface runoff.

The soils of the watersheds are of the Marshall, Monona, Ida, and Napier series (8). They have developed on a deep loess mantle and are moderately permeable in the surface and subsurface horizons. The watershed slopes range from 2 % to 4 % on the ridges and in the valleys and from 12 % to 18 % on the sides. Each watershed is entirely tillable; however, surface erosion is a severe problem on the steep slopes, and gully erosion occurs in the incised channels.

The surface geology of these watersheds is indicated in Fig. 2 by a cross section scaled from watershed 1 field data. Other investigators have shown similar geologic sections (11). The region is characterized by a deep loess mantle over glacial till. Depths of loess on the watersheds range from 15 ft in the valleys to more than 80 ft on the ridges. Most main and upland valleys have deep, incised channels which terminate upslope in an active gully head. A saturated zone lies above the nearly impermeable glacial till. This loess-till interface forms an important hydrologic boundary. Percolated water apparently moves nearly vertical to the saturated zone, then horizontally, to reappear as seepage in the watershed channels; this results in a continuous stream flow. This base flow becomes a significant hydrologic component when relating land surface management to water yield.

INSTRUMENTATION

Precipitation was measured by 16 recording rain gages. Stream flow was measured at precalibrated, V-notch, broad-crested weirs constructed of formed steel mounted on piling. Rainfall and runoff measurements are the primary hydrologic results reported herein; however, measurements of ground water, soil moisture, and evapotranspiration helped to understand and verify the results.

Suspended sediment samples were taken manually above the gully heads and at the weirs on watersheds 1 through 4 whenever appreciable surface runoff occurred. When combined with the water discharge measurements, data from these samples defined both the upland sheet-rill erosion and the gully erosion on a storm basis. The gully erosion volume computed from sample data was occasionally verified by engineering field surveys and photogrammetric determinations (1).

NORMALCY OF STUDY PERIOD

The 6-yr study period, 1964 through 1969, can be hydrologically characterized by comparison with the long-term precipitation record at Omaha and a nearby, long-term stream flow record. The 6-yr mean precipitation over the five watersheds was 33.1 in., which is 4.6 in. more than the 99-yr average of 28.5 in. recorded at Omaha, Neb., 15 miles northwest of the watersheds. The Omaha station average was 33.0 in. for the study period. Five of the six years had above-normal precipitation. From a frequency analysis of the 99-yr Omaha record, the probability of less precipitation per year than that observed for each of the 6 yrs, 1964 through 1969, is 83 %, 96 %, 22 %, 64 %, 76 %, and 60 %, respectively.

Annual runoff measured by the U.S. Geological Survey at eight gaging sites just east of the research watersheds during the 6-yr period averaged about 0.3 in. below their long-term average of 5.5 in. From a frequency graph of the 33-yr record of the East Nishnabotna River at Red Oak, Iowa, 26 miles southeast of the research watersheds, probabilities of less annual runoff than observed were 68 %, 85 %, 30 %, 38 %, 1 %, and 62 %, respectively, for the 6

TABLE 2.—WATER AND SEDIMENT YIELD SUMMARY OF TREYNOR, IOWA WATERSHEDS

Year	Watershed number	Annual Precipitation, in inches	Streamflow, in inches			Sediment Yield, in tons per acre		
(1)	(2)	(3)	Base (4)	Surface (5)	Total (6)	Sheet-rill (7)	Gully (8)	Total (9)
1964	1	35.61	1.92	4.56	6.48	25.0[a]	9.0[a]	34.0
	2	35.16	2.15	4.02	6.17	25.0[a]	4.0[a]	29.0
	3	33.49	2.36	0.42	2.78	0.3	0.6	0.9[b]
	4	34.80	5.66	0.80	6.46	0.7	0.1	0.8[b]
	5	35.84	2.55	1.40	3.95			—[c]
1965	1	45.35	3.56	10.62	14.18	44.0	15.6	59.6
	2	44.34	2.97	10.68	13.65	36.4	8.0	44.4
	3	44.28	4.62	4.60	9.22	0.4[a]	0.8[a]	1.2
	4	44.87	10.56	2.51	13.07	0.9[a]	0.1[a]	1.0
	5	44.18	7.40	3.99	11.39			
1966	1	20.32	2.54	0.65	3.19	6.7	1.2	7.9
	2	20.53	2.40	0.88	3.28	8.6	2.1	10.7
	3	22.01	2.54	0.38	2.92	0.1[a]	0.1[a]	0.2
	4	21.88	5.91	0.19	6.10	0.6	0.1	0.7
	5	20.49	3.84	0.25	4.09			
1967	1	38.25	2.27	11.57	13.84	99.1	19.4	118.5
	2	37.61	2.50	10.45	12.95	75.2	16.4	91.6
	3	34.23	3.30	2.65	5.95	0.6	1.1	1.7
	4	34.55	7.28	0.73	8.01	2.9	-0.2[d]	2.7
	5	34.34	5.22	3.13	8.35			
1968	1	32.30	1.67	1.15	2.82	3.7	1.4	5.1
	2	32.50	1.82	1.13	2.95	4.1	0.5	4.6
	3	31.10	1.59	1.02	2.61	0.2	0.1	0.3
	4	32.18	4.23	0.12	4.35	0.3	0.0	0.3
	5	27.03	1.57	0.31	1.88			
1969	1	31.42	3.18	2.53	5.71	1.8	1.6	3.4
	2	31.54	2.97	2.35	5.32	1.0	0.7	1.7
	3	30.64	3.29	1.73	5.02	0.1	0.2	0.3
	4	30.70	6.11	0.27	6.38	0.1	0.0	0.1
	5	30.13	4.18	1.02	5.20			
Average (1964-69)	1	33.88	2.52	5.18	7.70	30.0	8.0	38.1
	2	33.61	2.47	4.92	7.39	25.0	5.3	30.3
	3	32.63	2.95	1.80	4.75	0.3	0.5	0.8
	4	33.16	6.63	0.77	7.40	0.9	0.0	0.9
	5	32.00	4.13	1.68	5.81			—[c]

[a] Division between sheet-rill and gully erosion estimated.
[b] Total and component erosion values estimated.
[c] No total erosion data available for watershed 5.
[d] Negative value indicates channel fill.

yr, 1964 through 1969. These probabilities compare well with those of the Omaha precipitation except for 1967 and 1968, when the runoff probabilities were lower. This USGS watershed region experienced a very dry year in 1968, resulting in near record-low runoff amounts. In contrast, the Omaha and Treynor locations had slightly above-normal rainfall for this same year. Mean precipitation over the USGS-gaged watershed for the 6 yr was 32.3 in., compared with 33.1 in. on the Treynor watersheds. These comparisons indicate that precipitation on the Treynor watersheds was about 16 % above normal during the gaging period and stream flow was probably above normal a smaller amount.

WATER YIELD

One of the major objectives of this study was to determine the effect on land use on water yield from a watershed. Water yield and its components, base flow and surface runoff, are governed by so many variables in the processes between precipitation and stream flow that land-use effects are often very difficult to quantify, particularly in the western plains region, as shown by Sharp, et al. (13). However, the land-use effects on the Treynor watersheds are particularly distinguishable because the soils and geology of the watersheds are similar and the land-use differences are great.

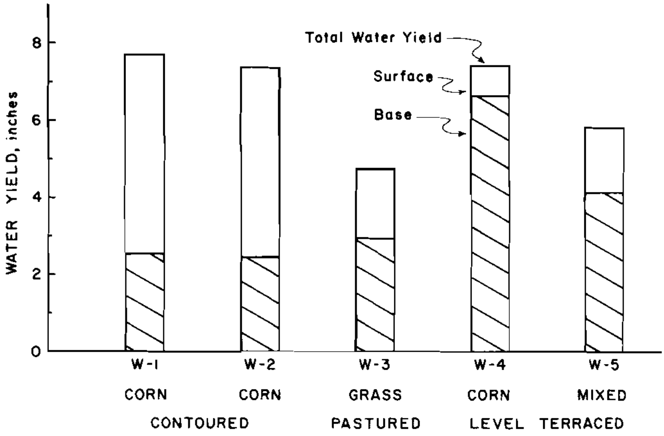


FIG. 3.—LAND USE EFFECTS ON AVERAGE ANNUAL WATER YIELD OF TREYNOR, IOWA WATERSHEDS, 1964-1969

The annual and 6-yr average values of total stream flow are given in Table 2, and each annual value is divided into amounts from surface runoff and base flow (ground-water discharge). Surface and base flow amounts were separated by using semilogrithmic graphs of daily runoff to estimate daily base flow amounts for those days having surface runoff. This procedure was quite accurate because the base flow rates were low compared with surface runoff rates, and surface runoff, from these steep watersheds persisted only a few minutes after rainfall ended.

Stream flow varied considerably from year to year, mostly in response to precipitation amounts and distributions. However, both surface and base flow amounts showed a similar pattern among the watersheds each year. Six-year average values plotted in Fig. 3 show these relations.

Paired, contoured-corn watersheds 1 and 2 had nearly the same precipitation and runoff. Their total stream flow differed less than 4 %, and the water yield components for both watersheds were 33 % base flow and 67 % surface runoff. Pastured-grass watershed 3 had the lowest total runoff of all five watersheds, i.e., 38 % less than that from watershed 1. However, 62 % of its total was base flow. This lower water yield apparently reflects the larger annual evapotranspiration of grass compared with corn. Measured soil moisture and ground water volumes confirm this effect. Surface runoff was less from grass than from corn, because infiltration rates were greater. The good grass stand prevented the soil surface from sealing, and the increased evapotranspiration from grass, especially in the early and late growing seasons, depleted the soil moisture more than did the corn.

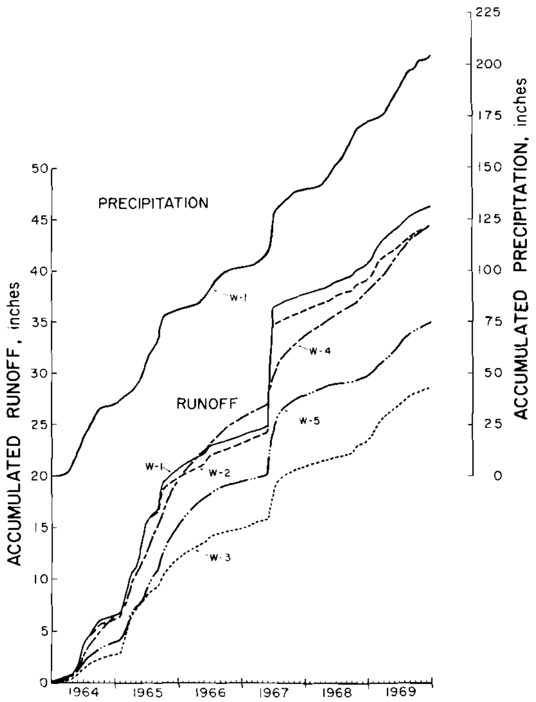


FIG. 4.—ACCUMULATIVE PRECIPITATION AND RUNOFF OF TREYNOR, IOWA WATERSHEDS

Water yield from level-terraced corn watershed 4 and contoured-corn watersheds 1 and 2 have been nearly identical (Fig. 3 and 4). There is a significant difference, however, in the water source. Base flow produced 89 % of the total stream flow from the level-terraced watershed. This change in flow path from surface to subsurface was apparently caused by the increased percolation from the level-terraced channels. Measured soil moisture and groundwater responses confirmed that there was additional water in this subsurface flow system. Apparently the temporary ponding of water in the terrace channels did not create significant losses by increased evapotranspiration (ET). This is logical for the years gaged because precipitation was usually adequate and soil water seldom limited ET. For drier years, this water ponding may cause an irrigation effect and the increased ET may reduce stream flow from the terraced watersheds.

These effects of level terraces have significant implications to planners of soil and water resources. Level terraces trap nearly all of the runoff water on the upland areas, thereby nearly eliminating downstream flooding. Most of the ponded water percolates to the ground water, which increases base stream flow for several months; thus, the water normally lost during floods is released more slowly and is nearly free from sediment and other surface water pollutants.

Land-use effects observed on these four small watersheds (74.5 acres to 150 acres) were verified by data from watershed 5 which is larger (389 acres), level terraced, and in mixed crops of about one-third grass and small grain and two-thirds row crops of corn and soybeans. The total water yield was less than from corn watershed 4 but more than from grassed watershed 3 (Figs. 3 and 4). Base flow was 71 % of the total stream flow (Table 2). This base flow is more than the 62 % from grassed watershed 3 but less than the 89 % from level-terraced watershed 4. These stream flow values of watershed 5 are all comparable to those that would be predicted using data from watersheds 3 and 4.

Details of watershed hydrologic performance are illustrated in Fig. 4 by accumulated monthly precipitation and total stream flow volumes. Precipitation for watershed 1 is quite representative of that for the other watersheds. Stream flow amounts were similar from watersheds 1 and 2 and were consistently lower from grassed watershed 3. The smoother lines of accumulative stream flow for watersheds 4 and 5 show the effectiveness of level terraces in reducing storm surface runoff and sustaining base flows. This is particularly apparent during very wet periods, such as June, 1967, when contoured watersheds 1 and 2 had large amounts of surface runoff, indicated by the nearly vertical lines. There was little change in base flow accumulation, as indicated by similar line slopes before and after the wet period. Level-terraced watersheds 4 and 5 had much less stream flow from surface runoff in June, 1967, but their base flow increased and was sustained for the next several months.

COMPARISON WITH LARGER WATERSHEDS

The value of hydrologic data from small experimental watersheds is greatly enhanced if these data can be applied to larger watersheds. To test the applicability of the Treynor water yield values to larger areas, data were obtained from eight watersheds gaged by the U.S. Geological Survey. These watersheds are adjacent to and east of the Treynor watersheds, as shown in Fig. 5.

Geology of the USGS watersheds is similar to that of the ARS watersheds near Treynor, except that the loess mantle is somewhat thinner on the USGS

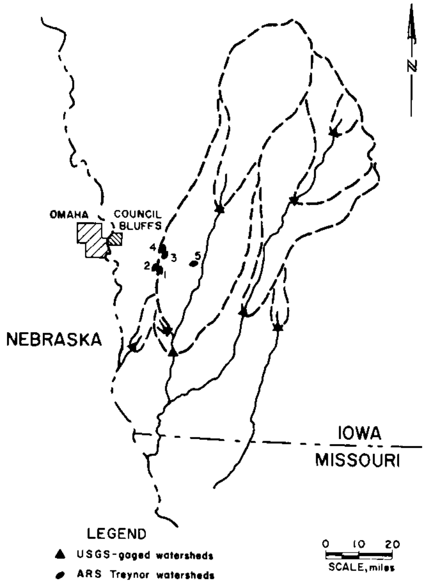


FIG. 5.—WATERSHED LOCATIONS GAGED BY ARS AND USGS

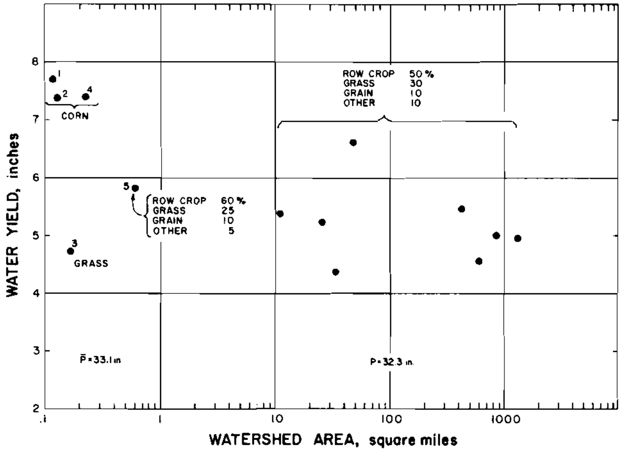


FIG. 6.—AVERAGE ANNUAL WATER YIELD OF WATERSHEDS GAGED BY ARS AND USGS, 1964-1969

watersheds. The larger streams intersect only the aquifer at the loess-till interface (the same as that observed on the ARS watersheds), the transmission losses are probably small. The soils are similar to those on the Treynor watersheds, but the topographic features are broader and more level. Land-use of the area was approximately 50 % row crops, 30 % grass, 10 % small grain, and 10 % other use (16). Conservation practices such as level terraces are used on only a small percentage of the watersheds.

The average water yield from the eight USGS-gaged streams shown in Fig. 6 was only 0.6 in. less than that from ARS watershed 5, which has land uses similar to those estimated for the larger watersheds. Annual precipitation for the 6-yr study period averaged nearly 1 in. less on the USGS watersheds, primarily because these watersheds were drier in 1968. The higher average water yield of the 49-sq mi watershed was mostly the result of more precipitation and runoff in 1967 than was experienced by the other USGS-gaged watersheds. Water yields tended to decrease only slightly with increased area. After accounting for precipitation and land-use differences, these results indicate that the Treynor watershed data could reliably be used to estimate the water yields of larger ungaged watersheds in the study region.

PEAK RATES

Peak runoff rates, like water yields, are related to land use by a large number of variables and processes. Peak rates are determined by all of the processes that determine surface runoff volumes, plus others such as the time distribution of the runoff, watershed topography, size, shape, and channel characteristics. These research watersheds, having developed in the same geographic unit, have similarities in shape and channels, and their closeness, particularly those adjoining, provides precipitation similarities. Therefore, observed peak rate differences from these watersheds can be attributed mostly to watershed land use.

Peak rates of the 50 largest events that occurred during the 6-yr study period are shown in Fig. 7. Those of watershed 1 are plotted versus those of watersheds 2, 3, and 4 for the same storm. These peaks represent the runoff events that had a peak rate greater than 0.50 in. per hr or a runoff volume greater than 0.15 in. from either watershed 1 or watershed 2. A storm was defined as any runoff event which had a nearly complete recession; thus, a few of the peaks occurred from separate rainfall bursts within the same general storm period. Peak rates from watershed 5 were not used in the comparison because of a large variation in rainfall on the study areas (which are 10 miles apart); however, they were quite low i.e., in the magnitude of those from terraced watershed 4.

Contoured-corn watersheds 1 and 2 had similar peak runoff rates (Fig. 7). Much of the data scatter is related to measured precipitation differences. Peak rates from the pastured-grass watershed have been significantly less than those from the contoured-corn watershed, and the level terraces have had an even greater reducing effect. Only one event on the pastured-grass watershed had a peak rate of more than 0.50 in. per hr, and none exceeded this rate from the level-terraced area; however, 42 of the 50 events considered from contoured watersheds 1 and 2 had peaks of more than 0.50 in. per hr.

Averages of the 17 events that had peak rates of more than 1 in. per hr from watershed 1 show that grass reduced the peak rates 90 %, and level terraces reduced them 95 %. Two different methods were apparently responsible for these reductions. On the grass watershed, which has a topography and channel system similar to those of the contoured-corn watersheds, the peak rate reductions are due to a decrease in surface runoff volumes. This was illustrated by the surface runoff amounts analyzed when considering water yields (Table 2). The level-terraced watershed, however, intercepts the surface runoff and prevents it from rushing downstream except in extreme runoff periods, when terrace overtopping might occur. Surface runoff in the terrace intervals is apparently about the same as that from contoured watersheds 1 and 2, but it is trapped in the terrace channel, infiltrates, percolates, and reappears as the base flow component, making the total water yields of watersheds 1, 2, and 4 similar.

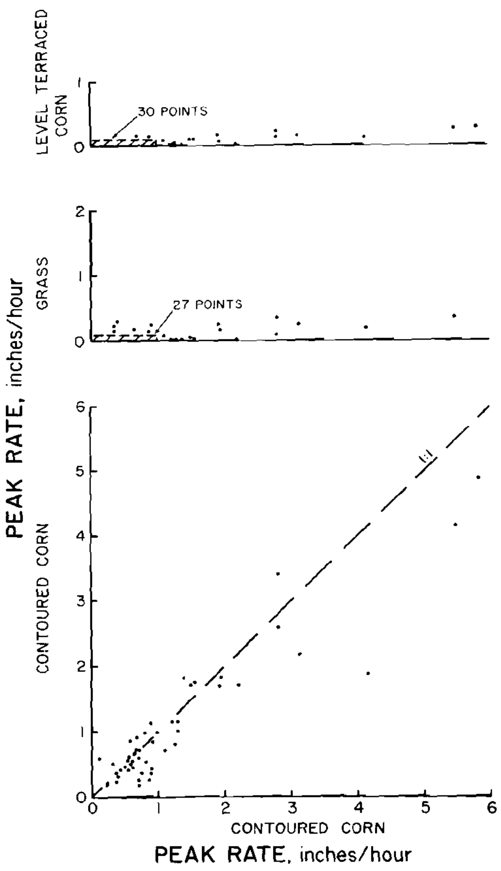


FIG. 7.—LAND USE EFFECTS ON PEAK RUNOFF RATES OF TREYNOR, IOWA WATERSHEDS

Several of the events have had extremely high peak rates, as much as 5.84 in. per hr (3,769 cfs per sq mile). Similar rates have been reported for other small watersheds in this loessial area (6). Of the six events with the highest peak rates observed on watersheds 1 and 2, only the largest was caused by precipitation of unusual frequency. That event, on June 20, 1967, had 5.5 in. of rainfall in 2 hr, which is much more than the 4.2 in. expected for a 100-yr return interval and a 2-hr duration (5). Five other rains during the gaging period had return intervals in excess of 5 yr, but none of these produced significant peak rates. This reemphasizes the generally known, but often ignored, fact that rainfall and runoff frequencies do not coincide.

On June 20, 1967, rainfall on watersheds 1 and 2 was 5.7 in., compared with only 3.6 in. on watersheds 3 and 4. If the larger rainfall had occurred on the level-terraced watershed, the terrace storage capacities might have been exceeded, resulting in higher peak rates of runoff than those observed. This effect was shown by Reh (10) in computer studies of a 7.17-sq mile, 50 % level-terraced area, where peak rate reductions were 60 % with 2.7 in. of rain, 50 % with 7.6 in., and only 12 % with 13.5 in. This June 20, 1967 storm caused the maximum peak runoff rate, 2.01 in. per hr, from the grassed watershed during the gaging period. Antecedent conditions were exceptionally wet for this storm 12.51 in. of rainfall during the preceding 22 days; thus, infiltration rates were low, even with the grass cover (15).

SEDIMENT YIELD

Sheet Erosion.—Loessial soils of the Missouri Valley region are among the most easily eroded in the world and, when the steep slopes are tilled, erosion is often serious. Sheet-rill erosion (hereafter referred to as sheet erosion) and gully erosion were measured on all watersheds. Continuous corn in approximately contoured rows on watersheds 1 and 2 represents one of the most common land management practices used in this loessial soils area, but one that often results in excessive erosion. Grassed watershed 3 represents good vegetative conservation management, and terraced watersheds 4 and 5 represent good mechanical conservation management.

Sheet erosion from contoured watersheds 1 and 2 was extremely high in 1964, 1965, and 1967, ranging from 25 tons per acre per yr to 99 tons per acre per yr (Table 2). In contrast, sheet erosion from grassed watershed 3 and terraced watershed 4 was less than 1 ton per acre per yr except in 1967, when sheet erosion from the terraced watershed was 2.9 tons per acre per yr. Sheet erosion was low from all watersheds in 1966, 1968, and 1969, because rainfall was below average or high-intensity rains occurred after the crop provided a protective canopy for the soil.

The 6-yr average values of sediment yield shown in Fig. 8 indicate the effectiveness of conservation land treatment in reducing sediment yields from sheet erosion. Contoured watersheds 1 and 2 averaged 38 tons per acre per yr and 30 tons per acre per yr, respectively, compared with less than 1 ton per acre per yr from the pastured-grass and level-terraced corn watersheds. Although there has been sheet erosion from interterrace intervals on watershed 4, storage in the terrace channels has minimized sediment yield. Measurements for determining sediment yield from watershed 5 have been less frequent than on the other watersheds; thus, amounts are not shown in Table 2 nor in

Fig. 8. However, the data show that the sediment yield of watershed 5 has been less than 1 ton per acre per yr, which confirms the erosion control by level terraces observed on watershed 4.

Sheet erosion was excessive during a 30-day period in 1967 when 18 in. to 22 in. of rain fell, 4 in. to 8 in. more than expected for a 100-yr return period (15). For this 30-day period, the rainfall energy index, defined as the kinetic energy of the rainfall times the maximum 30-min storm intensity (17), was three times the average annual value for this location. This 30-day rainfall caused sheet erosion of 99 tons per acre and 75 tons per acre, respectively, from contoured watersheds 1 and 2 and only 0.6 tons per acre and 2.9 tons per acre, respectively, from pastured-grass watershed 3 and level-terraced watershed 4. These 1967 sediment yields must be near the expected maximum, since they occurred during an extreme 30-day rainfall when the soil was clean tilled and corn plants were too small to protect the soil. Data from watersheds 3 and 4 prove that proper land management can reduce sheet erosion to acceptable levels, even from an extremely large rainfall during the most vulnerable erosion period.

TABLE 3.—AVERAGE SEDIMENT YIELDS OF LARGER WATERSHEDS IN LOESSIAL REGION, 1964-1969

Station (1)	Drainage area, in acres (2)	Sediment yield, in tons per acre per year (3)
Mule Creek near Malvern, Iowa	6,780	3.0
Thompson Creek near Woodbine, Iowa	4,280	3.3
Steer Creek near Magnolia, Iowa	5,950	2.4

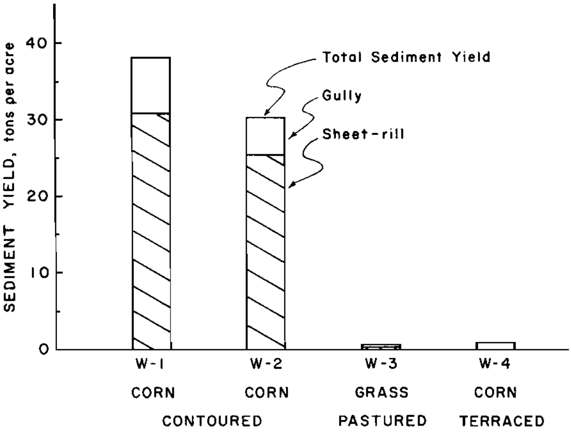
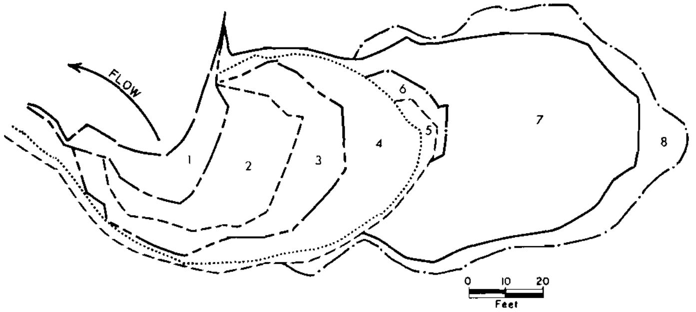


FIG. 8.—LAND USE EFFECTS ON AVERAGE ANNUAL SEDIMENT YIELD OF TREYNOR, IOWA WATERSHEDS, 1964-1969

Average annual sediment yields for 1964 through 1969 are shown in Table

3 for three nearby, larger watersheds which are gaged and sampled by the U.S. Geological Survey. These watersheds are considerably larger than those of the ARS near Treynor and have varied and mixed cropping and land treatment. The small, annual values of 2.4 tons per acre to 3.3 tons per acre may, at first, seem acceptable since they are below the annual maximum of 5 tons per acre to 6 tons per acre that conservationists consider acceptable (14). However, some areas of these watersheds are noncontributing, because dams, terraces, grassed areas, and level bottomlands trap the sediment. Much of the sediment from sheet erosion is deposited within the watershed; thus, sediment yield data at the outlet of such large watersheds do not reflect the quantity of actual sheet erosion. Sediment yields from ARS watersheds 1 and 2, which are contour formed and have no large depositional areas, show the magnitude of the sheet erosion that occurs on many continuously cultivated, deep loess, upland areas not protected by conservation practices.



AREA	PERIOD	SURFACE RUNOFF acre-feet	GULLY EROSION tons
1	NOV. 15, '64-APR. 14, '65	25	130
2	APR. 14, '65-JUNE 9, '65	17	510
3	JUNE 9, '65-AUG. 13, '65	12	160
4	AUG. 13, '65-NOV. 15, '65	14	350
5	NOV. 15, '65-JULY 15, '66	4	90
6	JULY 15, '66-MAY 30, '67	1	< 10
7	MAY 30, '67-JUNE 27, '67	70	1430
8	JUNE 27, '67-DEC. 31, '69	24	230
	TOTAL	167	2910

FIG. 9.—MEASURED GULLY HEAD ADVANCE AND GULLY EROSION ON TREYNOR, IOWA, WATERSHED 1

Gully Erosion.—Gully erosion is serious in the Missouri River loessial area. The magnitude of the problem is evident in aerial photographs of the area, and aerial photographs at intervals of a year or more show that gully overfalls advance rapidly, voiding farmland and impeding farm operations.

Annual sediment yields from gully erosion on the research watersheds near Treynor are given in Table 2. Although gully erosion is usually expressed as tons, values in Table 2 are given in tons per acre to allow direct comparisons with sheet erosion. Sampling and surveying to determine gully erosion were initiated in 1965 on watersheds 1 and 2 and in succeeding years on watersheds 3 and 4. Estimates of annual gully erosion were made for earlier years of the

6-yr study period, based on runoff, measured gully erosion, and visual observations.

Gully erosion averaged about 15 tons per acre per year on contoured watersheds 1 and 2 in 1965 and 1967, when surface runoff volumes exceeded 10 in. per yr. A rapidly eroding headcut on watershed 1 contributed most of the gully sediment yield, and lateral bank erosion was the major source of watershed 2, where the headcut was more stable. Although gullying is serious on watersheds 1 and 2, the sediment yield from this source was less than one-fourth of that from sheet erosion.

The effect of conservation land treatment in reducing gully growth on watersheds 3 and 4 is very evident from the 1967 data. Surface runoff on watersheds 3 and 4 was about one-fourth and one-tenth, respectively, of that from contoured watersheds 1 and 2. Gully erosion on watershed 3 was less than one-tenth of that from watersheds 1 and 2, and the gully of watershed 4 actually filled slightly.

During the 5-yr period of observation, the gully on watershed 1 advanced about 135 ft, with an average width of 50 ft to 60 ft and maximum depths of 15 ft to 20 ft, as shown in Fig. 9. More than 2,900 tons of sediment eroded and moved downstream. Significant gully erosion was related to periods of large surface runoff. The advancement rate during 1965 is evident from the five surveys (Fig. 9), and the excessive erosion during June, 1967 voided area 7. Although the exact role of runoff in gully development is not known, storm runoff is the principal mover of gully debris, and a significant reduction of runoff is accompanied by reduced gully erosion.

CONCLUSIONS

Land use significantly affected water yields, peak runoff rates, surface erosion, and gully erosion from five small research watersheds in the deep loessial soils region on western Iowa. Contoured corn, pastured grass, level-terraced corn, and level-terraced mixed crops were maintained on separate watersheds. During the 6-yr gaging period, 1964 through 1969, precipitation averaged 4.6 in. above the long-term mean of 28.5 in. Several unusual precipitation periods and storms occurred. Specific findings were:

1. Total water yields from the contoured-corn watersheds were nearly identical with those from the level-terraced corn watershed; however, the water yields were 67 % surface runoff from the contoured watershed, compared with only 11 % from the level-terraced watershed. This change in flow path due to level terraces greatly reduced flood peaks and erosion.
2. Compared with continuous corn, grass cover reduced total water yield 38 %, mostly by reducing surface runoff. This was attributed to greater infiltration and ET of grass as compared with corn.
3. Water yields of these small watersheds compared closely with those from much larger watersheds (as large as 1,326 sq miles) when land-use and precipitation differences were considered. Thus, small watershed data can be useful for predicting water yields of larger, ungaged watersheds in this loessial region.
4. Peak runoff rates from level-terraced and grass watersheds were less than 10 % of those observed from the contoured-corn watersheds. Several large

events have been recorded with peak rates of as much as 5.84 in. per hr (3,769 cfs per sq mile) from the 74.5-acre, contoured-corn watershed.

5. Sheet erosion from the contoured-corn watersheds was severe, averaging more than 30 tons per acre per yr for the 6-yr period. Nearly 100 tons per acre eroded during 1967, mostly during an unusually wet 30-day period. Sheet erosion from the level-terraced corn and pastured-grass watersheds averaged less than 1 ton per acre per yr.

6. Gully erosion was significant in the channels of the contoured-corn watersheds, with average erosion equivalent to more than 5 tons per acre per year; but channels were nearly stable on the grass and level-terraced areas.

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APPENDIX.—REFERENCES

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8523 HYDROLOGY AND EROSION OF LOESSIAL WATERSHEDS

KEY WORDS: **Conservation**; **Erosion**; Gully erosion; **Hydraulics**; **Hydrology**; **Land** use; Loess; **Sedimentation**; Sediment yield; Values; **Water resources**; Water yield

ABSTRACT: Five agricultural watersheds in the Missouri Valley deep loess soils region in western Iowa were instrumented to determine their hydrology, gully erosion, and surface erosion. Two watersheds (75 and 83 acres) were singly cropped in contoured corn, another (150 acres) in level-terraced corn, and a fourth (107 acres) in pastured grass. A fifth watershed (389 acres) was level terraced with varied cropping. Average annual stream flow (1964-1969) from the level-terraced corn watershed was almost identical with the 7.5 in from the contoured corn watersheds; but 86% was base flow, compared with only 32% from the contoured areas. Total stream flow from the grass watershed was 60% of that from the corn watersheds. Peak rates from the grassed and level-terraced watersheds have been less than 10% of those from the contoured watersheds which ranged up to 5.84 in per hr. Measured suspended sediment, derived from both gully and surface erosion, was 38 tons per acre per yr and 30 tons pera r and 30 tons per yr from the two contoured-corn watersheds, but the grassed and level-terraced corn watersheds had only 0.8 tons per acre per yr and 0.9 ton per acre per yr, respectively.

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