Water yield and erosion response to land management

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ABSTRACT—Eight years' observation of five research watersheds revealed nearly equal water yields on level-terraced corn and contoured-corn watersheds. Water yield from a grassed watershed was 37 percent less. Surface runoff was 10 percent of water yield from the terraced watershed and 65 percent of water yield from the contoured watersheds. Peak runoff rates from terraced-corn and grassed watersheds were 10 percent of those from contoured-corn watersheds. Sheet erosion averaged 24 tons per acre per year on the contoured-corn watersheds and less than 1 ton per acre per year from the terraced-corn watersheds. Gully erosion averaged 450 tons per year from the contoured-corn watershed, but was negligible on the terraced and grassed watersheds.

RESEARCH on five loessial watersheds in southwestern Iowa, near Treynor, shows that water yield and erosion respond significantly to conservation and vegetative treatments. Eight years' data were collected on the watersheds, which range in size from 75 to 389 acres. Continuous land use treatments included contoured corn, level-terraced corn, pastured grass, and level-terraced mixed crops.

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The watersheds are located in an area of thick loessial deposits. Their topography is undulating. Slopes range from 2 to 4 percent on ridges and in valleys and from 12 to 18 percent on hillsides. Each watershed is entirely tillable. However, surface erosion is severe on the hillsides, and gully erosion occurs in the incised channels. Soils are of the Marshall, Monona, Ida, and Napier series (*3*), which are moderately permeable in the surface and subsurface horizons.

Geology of the watersheds is characterized by a thick loess mantle over glacial till. Loess thicknesses range from 15 feet in the valleys to more than 80 feet on the ridges. A saturated zone lies above the slowly permeable glacial till. Water percolates almost vertically to the saturated zone and then moves laterally, causing seepage and continuous streamflow. Published maps show watershed locations, soils, topography, geology, and primary instrumentation (*4, 5, 6*).

Four watersheds were maintained in a single land use treatment for direct comparison of land management effects on watershed hydrology and erosion (Table 1). Rainfall, runoff, and soil moisture were measured, and amounts of sheet-rill and gully erosion were determined from suspended-sediment samples and physical measurements of gullies.

Average precipitation for the 8-year study period, 32.09 inches, was 3.64 inches more than the long-term average of 28.45 inches at Omaha, Nebraska, 20 miles away. Seven of the eight years had above-average precipitation (Table 2).

Water Yield

Differences in land use and conservation treatments on these otherwise comparable watersheds significantly affected water yield [total water, both surface runoff and base flow (seepage), passing the gaging site, usually expressed as inches of depth over the contributing watershed]. Annual values and 8-year averages for precipitation, water yield, and components of surface runoff and base flow are given in table 2. Separation of surface and base flow is quite accurate because surface runoff events are usually of short duration (1 to 2 hours) and base flow is uniform and quite small (less than 0.1 cfs).

Although annual streamflow varied because of precipitation differences, surface and base flows followed a similar pattern among the watersheds

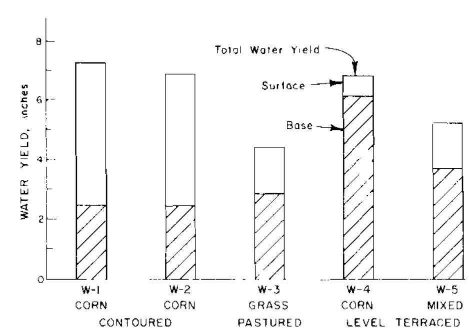

Figure 1. Land use and conservation treatment effects on average annual water yield, Treynor, Iowa, watersheds.

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each year (Figure 1). Average annual water yields from contoured-corn watersheds 1 and 2 and level-terraced corn watershed 4 were nearly equal. However, surface flow on contoured watersheds 1 and 2 accounted for 65 percent of the water yield; 35 percent occurred as base flow. On level-terraced watershed 4, surface runoff contributed 10 percent of the water yield, and base flow was responsible for 90 percent. Runoff from the terrace interval was stored in the terrace channels and infiltrated into the soil profile. This percolating water increased groundwater levels and base flow for several months after the ponded water had disappeared.

Water yield from pastured-grass watershed 3 was 37 percent less than from contoured-corn watersheds 1 and 2 (Figure 1). Base flow contributed 64 percent of the water yield from watershed 3. Water yield from this grass-covered watershed was less than from corn-covered watersheds 1 and 2 because of the larger annual evapotranspiration requirement of grass. The grass cover also maintained good infiltration rates and impeded overland flow of water, which extended the infiltration period.

Level-terraced watershed 5, with mixed crops (Table 1), had streamflow amounts similar to those that might be predicted by data on watersheds 3 and 4. Water yield exceeded

Table 1. Description of Treynor, Iowa, watersheds and treatments.

Watershed Number	*Size (a)*	*Crop*	*Conservation Treatment*
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]Approximately two-thirds row-cropped corn and soybeans, one-third small grain and pastured grass in random rotation.

Table 2. Annual water yield summary, Treynor, Iowa, watersheds.

Year	*Watershed Number*	*Annual Preciptation (in)*	*Water Yield (in)* Base Flow	*Water Yield (in)* Surface Runoff	*Water Yield (in)* Total
1964	1	35.61	1.92	4.56	6.48
	2	35.16	2.15	4.02	6.17
	3	33.49	2.36	.42	2.78
	4	34.80	5.66	.80	6.46
	5	35.84	2.55	1.40	3.95
1965	1	45.35	3.56	10.62	14.18
	2	44.34	2.97	10.68	13.65
	3	44.28	4.62	4.60	9.22
	4	44.87	10.56	2.51	13.07
	5	44.18	7.40	3.99	11.39
1966	1	20.32	2.54	.65	3.19
	2	20.53	2.40	.88	3.28
	3	22.01	2.54	.38	2.92
	4	21.88	5.91	.19	6.10
	5	20.49	3.84	.25	4.09
1967	1	38.25	2.27	11.57	13.84
	2	37.61	2.50	10.45	12.95
	3	34.23	3.30	2.65	5.95
	4	34.55	7.28	.73	8.01
	5	34.34	5.22	3.13	8.35
1968	1	32.30	1.67	1.15	2.82
	2	32.50	1.82	1.13	2.95
	3	31.10	1.59	1.02	2.61
	4	32.18	4.23	.12	4.35
	5	27.03	1.57	.31	1.88
1969	1	31.42	3.18	2.53	5.71
	2	31.54	2.97	2.35	5.32
	3	30.64	3.29	1.73	5.02
	4	30.70	6.11	.27	6.38
	5	30.13	4.18	1.02	5.20
1970	1	31.51	2.21	2.14	4.35
	2	30.82	2.35	1.79	4.14
	3	28.86	2.19	.37	2.56
	4	28.79	3.99	.13	4.12
	5	27.72	2.27	.46	2.73
1971	1	28.93	2.06	4.94	7.00
	2	29.02	2.62	3.84	6.46
	3	29.70	2.84	1.52	4.36
	4	29.96	5.49	.71	6.20
	5	26.69	3.16	1.06	4.22
Averages (1964-1971)	1	32.96	2.43	4.77	7.20
	2	32.69	2.48	4.39	6.87
	3	31.79	2.84	1.59	4.43
	4	32.22	6.16	.68	6.84
	5	30.80	3.78	1.45	5.23

Table 3. Annual sediment yield on Treynor, Iowa, watersheds.

Year	*Watershed Number*	*Sediment Yield* Sheet-Rill (t/a)	*Sediment Yield* Gully (t)	*Sediment Yield* Total (t/a)
1964	1	25.0[a]	670[a]	34.0
	2	25.0[a]	331[a]	29.0
	3	.3	64	.9[b]
	4	.7	10	.8[b]
1965	1	44.0	1,162	59.6
	2	36.4	660	44.4
	3	.4[a]	86[a]	1.2
	4	.9[a]	16[a]	1.0
1966	1	6.7	93	7.9
	2	8.6	177	10.7
	3	.1[a]	10[a]	.2
	4	.6	14	.7
1967	1	99.1	1,455	118.5
	2	75.2	1,374	91.6
	3	.6	120	1.7
	4	2.9	−23[c]	2.7
1968	1	3.7	102	5.1
	2	4.1	44	4.6
	3	.2	13	.3
	4	.3	2	.3
1969	1	1.8	118	3.4
	2	1.0	55	1.7
	3	.1	19	.3
	4	.1	−5	.1
1970	1	11.8	177	14.0
	2	7.4	171	9.5
	3	<.1	5	.1
	4	.1	<1	.1
1971	1	20.0	399	25.4
	2	13.3	241	16.2
	3	.4	30	.6
	4	1.5	6	1.6
Averages (1964-1971)	1	26.5	522	33.5
	2	21.4	382	26.0
	3	.3	43	.7
	4	.9	3	.9

[a]Division between sheet-rill and gully erosion estimated.
[b]Total and component erosion values estimated.
[c]Negative value indicates channel fill.

that from grassed watershed 3 but was less than that from level-terraced corn watershed 4 (Figure 1). Base flow contributed 72 percent of the water yield.

To test the applicability of the water yield data to larger watersheds, 1964-69 data were obtained for eight nearby watersheds gaged by the U. S. Geological Survey. The soils and geology are similar; however, the loess mantle is thinner, and the topography is less undulating. Land use for these watersheds was similar to that of watershed 5, except that only a small percentage of the area was treated with conservation practices (7). Average annual water yield on the eight USGS-gaged streams for the 6-year period was 0.8 inch less than from watershed 5. However, annual precipitation averaged about 1 inch less on the USGS watersheds. The analyses indicated that the Treynor data can be used to predict water yield from larger ungaged watersheds in the region if adjustments are made for precipitation, land use, and conservation treatment differences.

Peak Runoff Rates

Observed peak-runoff-rate differences were attributed largely to land use and conservation treatments because watersheds 1 through 4 have similar geology, topography, channel characteristics, and precipitation. Adjoining watersheds 1 and 2 are only 2½ miles from adjoining watersheds 3 and 4. In figure 2, peak runoff rates on watersheds 2, 3, and 4 for 62 of the largest events that occurred during the 8-year study are compared with peak runoff rates on watershed 1. Storms with peak runoff rates of more than 0.50 inch per hour or a runoff volume of 0.15 inch or more on watershed 1 or 2 were plotted.

Watersheds 1 and 2 had similar peak runoff rates (Figure 2). Precipitation differences accounted for most of the scatter. The 5.5 inches of rain in 2 hours on June 20, 1967, on watershed 1 exceeded the 4.2 inches expected for a 100-year return period and produced an exceptionally high peak runoff rate of 5.87 inches per hour (3,790 cfs per square mile) (*1*). Adjacent watershed 2 had a peak runoff rate of 4.87 inches per hour. Similarly high rates have been reported for other small watersheds in this loessial area (2). For this same storm, the

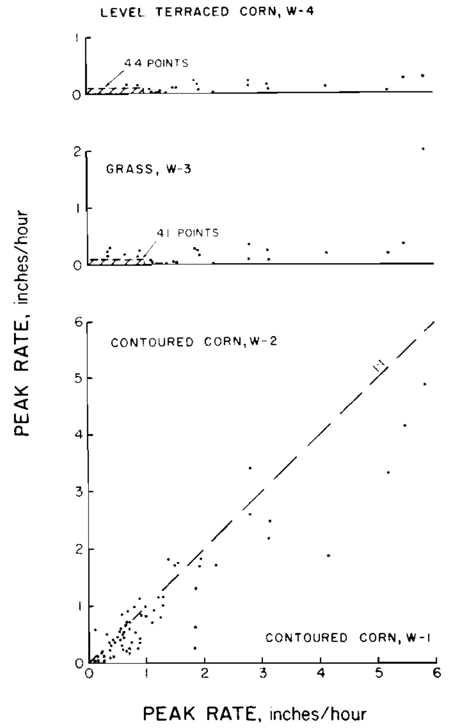

Figure 2. Land use and conservation treatment effects on peak runoff rates, Treynor, Iowa, watersheds.

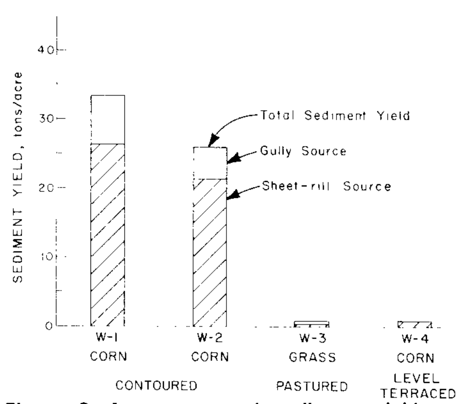

Figure 3. Average annual sediment yield as affected by land use and conservation treatments, Treynor, Iowa, watersheds.

peak runoff rate on grassed watershed 3 was 2.01 inches per hour. Greater infiltration and less precipitation (3.6 inches) accounted for the differences. Level-terraced watershed 4 trapped runoff in terrace channels where it infiltrated and percolated. The peak runoff rate was 0.28 inch per hour. Averages of the 23 largest events that had peak runoff rates of more than 1 inch per hour on watershed 1 show that grass reduced peak rates 92 percent and level terraces reduced them 96 percent. Only one event exceeded a 0.50-inch-per-hour peak runoff rate on watershed 3. This (2.01 inches per hour) occurred on June 20, 1967, when 3.6 inches of rain fell in 2 hours after 12.51 inches had fallen during the preceding 22 days. No peak runoff rate exceeded 0.50 inch per hour on terraced watershed 4.

Sheet Erosion

Planting corn in contoured rows, as on watersheds 1 and 2, is common practice in the region, even though erosion is often severe. Grass represents good vegetative conservation management, and level terraces represent good mechanical conservation management to reduce runoff and erosion.

Eight-year average sediment yields (Table 3, Figure 3) demonstrate that land use and conservation treatments can reduce sheet erosion. Sheet erosion from contoured watersheds 1 and 2 averaged 26 and 21 tons per acre per year, respectively, compared with less than 1 ton per acre from grassed watershed 3 and terraced watershed 4. Limited data from level-terraced watershed 5 show that sheet erosion also averaged less than 1 ton per acre per year.

Exceptionally large amounts of sheet erosion occurred in 1967 when rainfall for the 30-day period, May 29 to June 27, ranged from 18 to 22 inches, 4 to 8 inches more than expected for a 100-year return period (*6*). These storms occurred when row-cropped watersheds were cleanly tilled and corn plants were too small to provide a protective canopy. Sheet erosion from contoured watersheds 1 and 2 was 99 and 75 tons per acre, respectively, but was less than 1 ton per acre from grassed watershed 3 and 2.9 tons per acre from terraced watershed 4. These values must be near the annual maximum that can be expected.

The 8-year average annual sheet erosion values of 26 and 21 tons per acre for watersheds 1 and 2, respectively, compared with only 3 tons per acre from three nearby, larger watersheds (gaged and sampled by USGS). Sediment yield from these larger watersheds, which had varied and mixed crops (7), seemed small; however, much of the sheet erosion within these watersheds was deposited on level bottomlands, in grassed areas, behind fence rows, and within the relatively few terraces and dams. Contoured watersheds 1 and 2 had small depositional areas, but they showed the magnitude of sheet erosion that occurs on many continuously cultivated, deep loess upland areas not protected by conservation practices. Care should be taken when data from these small watersheds are used to predict sediment yield from larger watersheds.

Gully Erosion

To determine gully erosion, streamflow sampling and gully surveys were initiated in 1965 on watersheds 1 and 2 and in 1966 on watersheds 3 and 4 (Table 3). Gully erosion for 1966 and earlier years was estimated on the basis of runoff, measured gully erosion on watershed 3 since 1966, and visual observations.

Excessive gully erosion occurred on watersheds 1 and 2 in 1965 and 1967, when surface runoff exceeded 10 inches per year. A rapidly advancing overfall contributed most of the erosion on watershed 1, and lateral bank erosion was the major source on watershed 2. Effects of land use and conservation treatments on gully erosion were most evident in 1967, when gully erosion on grassed watershed 3 was less than one-tenth that on watersheds 1 and 2 and the gully on watershed 4 actually *filled* slightly.

The gully overfall on watershed 1 advanced about 152 feet during the 8 years. The gully averaged 50 to 60 feet in width and was about 15 feet deep. During the 8-year period, more than 4,100 tons of sediment eroded and moved downstream. Most gully erosion was related to periods of large surface runoff (*4*, *5*, *6*).

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