Sediment Yields from Blackland Watersheds

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THE effect of land use and conservation practices on sediment yields is an important consideration in the evaluation of conservation practices and in the design of floodwater detention structures. A study of this effect is being made at the Blacklands Experimental Watershed near Riesel, about 16 miles southeast of Waco, Texas. Here measurements of runoff and sediment concentration from two watersheds, one with conservation practices and the other without, have served to indicate the magnitude of this effect. The comparison required the development of a method of calculating sediment yield which could be useful for prediction purposes.

Description of Watersheds

The watersheds are in an area typical of the Blackland prairie. Soils of this region are derived primarily from Coastal Plain marls and chalks, with Houston black clay predominating (3)*. When this study was started in 1939, about 80 percent of the area was cultivated. Of the cultivated land about one-half was in cotton, one-fourth in corn, and the remainder in oats and other crops. Row crops were generally planted in straight rows and only a small number of terraces or other soil conservation practices were used. The area not cultivated was largely unimproved grassland with a small area in farmsteads and roads.

Two watersheds, one containing 176 acres and the other 132 acres, were selected for this study. During the period 1939 through 1942 both watersheds were farmed alike, with a large percentage of row crops planted in straight rows and with no special conservation practices. Through 1942 the cultivated land in both watersheds had a 4-year rotation of cotton, corn, cotton, oats. No change was made in the 176-acre watershed (W-1, non-conservation), but starting in September 1942 and effective for the year 1943, a conservation program was established on the 132-acre watershed (Y-2). This program included a reduction in acreage of cultivated land coupled with an increase in permanent grass (Table 1), the construction of graded terraces where needed, and a change to a 3-year rotation of cotton, corn, oats seeded with annual sweet clover (Fig. 1). All tillage in the new program was on the approximate contour, parallel to the terraces.

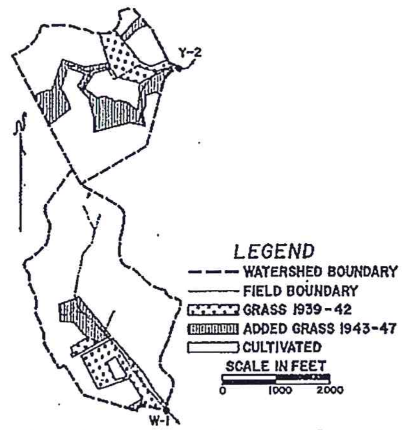

FIG. 1 Map showing location and amount of permanent grass in the watersheds for the period 1939-42, and the additional grass, 1943-47.

TABLE 1. LAND USES FOR THE WATERSHEDS

Land Use	Watershed W-1 176 acres	Watershed Y-2 132 acres
	Percent of area	
Period 1939-42*		
Cultivated land	86.4	90.0
Permanent grass	10.6	8.8
Farmsteads	1.8	0
Roads	1.2	1.2
Period 1943-47†		
Cultivated land	84.8	73.3
Permanent grass	12.2	25.5
Farmsteads	1.8	0
Roads	1.2	1.2

* Both watersheds treated alike without conservation practices.
† No change in treatment on watershed W-1. Conservation practices, including 6.1 miles of terraces established on watershed Y-2.

Data Available for Study

Good runoff records from both watersheds are available for the period 1939 to 1961. Records of sediment concentrations are available from watershed W-1 for the period 1940-47 and from watershed Y-2 for the period 1944-47. These were obtained from sediment samples collected manually at the runoff measuring stations during times of runoff. Pairs of samples were taken every five minutes during the first part of the runoff period, but during the receding-flow period the time interval was increased. The lack of sediment concentrations for watershed Y-2 during the period 1939-43 when both watersheds were treated alike posed a difficult problem in the subsequent analyses.

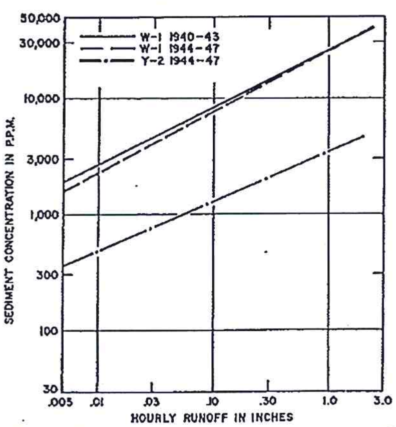

FIG. 2 Relation between hourly runoff and average hourly sediment concentration.

Method of Analysis

Good correlations were found between sediment concentrations and discharge rate during receding stages. During rapid rises, however, factors other than discharge affected the concentration. It was found that the relationship between the average hourly discharge rate and the corresponding hourly average sediment concentration was the most useful. These relationships were determined for watershed W-1 for the two periods, 1940-43 and 1944-47, and for watershed Y-2 for the period 1944-47 (Fig. 2).

The relation that best fitted the data was the logarithm of the average clock-hour runoff in inches vs the logarithm of the sediment concentration in parts per million. The regression equations and correlation coefficients developed were:

Area	Period	Regression equation*	r†	n	Equation number
W-1	1940-43	$\log Y = 0.4864 \log X + 4.4005$	0.63**	398	[1]
W-1	1944-47	$\log Y = 0.5340 \log X + 4.4238$	0.75**	401	[2]
Y-2	1944-47	$\log Y = 0.4269 \log X + 3.5380$	0.50**	179	[3]

* Y = Sediment concentration in parts per million.
X = Average runoff for clock hours in inches.
† Double asterisks denote statistical significance at the 1 percent level.

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* Numbers in parentheses refer to the appended references.

TABLE 2. COMPARISONS OF RUNOFF AND COMPUTED* SEDIMENT YIELD BETWEEN WATERSHEDS W-1 AND Y-2

Range in discharge rate, cubic feet per second	Station W-1 (176 acres)			Station Y-2 (132 acres)		
	Runoff, inches	Time, hours	Sediment yield, tons per acre	Runoff, inches	Time, hours	Sediment yield, tons per acre
Period 1944-47						
Trace to 0.309	3.618	25,629.00	0.096	3.996	12,000.00	0.051
0.310 to 0.999	1.476	459.90	0.207	3.140	788.10	0.116
1.000 to 3.090	2.614	253.10	0.684	4.608	359.40	0.280
3.100 to 9.990	4.838	152.10	2.306	5.806	143.70	0.577
10.000 to 30.900	9.501	93.65	8.414	10.726	83.44	1.747
31.000 to 99.900	9.508	32.02	14.940	9.967	26.07	2.585
100.000 to 309.000	9.660	9.80	28.806	5.876	5.55	2.353
310.000 or more	5.906	2.06	31.148	4.832	1.58	3.044
Totals	47.121		86.601	48.951		10.753
Period 1939-61						
Trace to 0.309	9.816	106,764.00	0.203	7.822	30,413.00	0.089
0.310 to 0.999	5.065	1,573.00	0.711	6.887	2,042.20	0.237
1.000 to 3.090	9.043	891.10	2.342	11.319	858.30	0.697
3.100 to 9.990	18.394	601.30	8.587	18.144	446.10	1.808
10.000 to 30.900	33.688	339.50	29.481	34.055	275.70	5.450
31.000 to 99.900	28.090	95.55	43.903	27.298	68.76	7.194
100.00 to 309.000	28.626	29.78	84.229	18.847	16.65	7.768
310.000 or more	12.394	4.51	63.903	7.306	2.32	4.660
Totals	145.116		233.359	131.678		27.903

* Runoff data for both periods are the measured amounts. Sediment concentrations for both periods are computed, using the relationships developed for the two areas from 1944-47 data.
Computation procedure: (a) Runoff in inches ÷ time in hours = average runoff rate in inches per hour. (b) From runoff rate and Fig. 2 or equations [2] or [3], determine sediment concentration in parts per million. (c) Parts per million times runoff amount in inches × 0.000113256 equals tons per acre sediment yield.

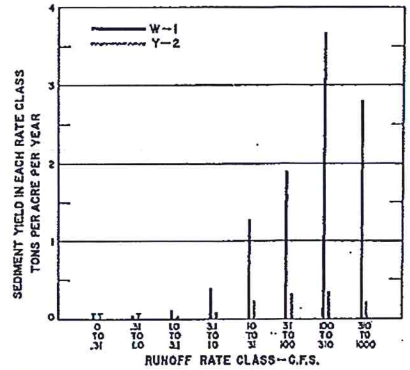

FIG. 3 Computed average annual sediment yield by rate classes for areas W-1 (non-conservation) and Y-2 (conservation) for the period 1939-61.

These relations are highly significant, but the variation between individual observations may be quite large. For hourly amounts of less than 0.03 in., concentrations may be as small as one-half, or as much as eight times as great as the regression equations would indicate.

These relationships provided the tools for estimating sediment yield for periods when only runoff measurements were obtained. They were employed to compare the probable sediment yield from the conservation-treated watershed Y-2 with the probable sediment yield from the non-conservation watershed W-1.

During the period 1944-47 when sediment measurements were made from both watersheds Y-2 and W-1, there were numerous storms including one storm with extremely high runoff rates, so a wide range of conditions was sampled. The runoff periods were also well distributed throughout the year. Since the equations fit the data well, it seems reasonable to use these equations and the runoff data for the 23-year period 1939-61 to compute average annual sediment yield.

To make these computations, runoff was divided into eight rate classes and the total time of runoff in each rate class obtained (Table 2). Using the regression equations [2] and [3], sediment concentrations were computed for the average runoff rate in each rate class. From the amount of runoff in each rate class and the computed concentration, the probable sediment yields were computed for watersheds W-1 and Y-2 for the period 1939-61 and also for the period 1944-47. The distribution of the computed average annual sediment yields by rate category is shown in Fig. 3. The computation shows that the probable average annual sediment yield for the 23-year period from watershed W-1 was 10.1 tons per acre, and from watershed Y-2 it was 1.2 tons per acre. This is a ratio of 8.4 to 1 which compares favorably with a ratio of 8 to 1 for the 4-year period, 1944-47, the period which supplied the data for the runoff rate-sediment concentration relationship.

Discussion

The computed sediment yields for the two watersheds are different for the different treatments. What would the relative sediment yields have been if the two watersheds had been treated alike? Since sediment measurements were not made on both watersheds during the calibration period, the answer must be obtained from an examination and comparison of the rainfall and runoff records and of the physical characteristics of the watersheds.

Note, first, that there are no extreme differences in rainfall and runoff for these two watersheds, either in total amounts or monthly amounts (Fig. 4). Also, the distribution of runoff by rate classes is very similar for rates greater than 0.1 in. per hour (Fig. 5). Thus, the effects of the conservation treatment have not greatly affected the distribution of runoff by rate classes (Fig. 6) although runoff from watershed Y-2 was 90 percent and the rainfall 99 percent of that for watershed W-1, during the 23-year period 1939-61.

Consider next the major physical characteristics of the two watersheds (Table 3). They were selected for similarity of soil types and detailed surveys indicate only minor differences; however, in physical dimensions there are differences. Watershed W-1, for example, is larger than watershed Y-2. Ordinarily, unless there is appreciable channel erosion, sediment yield per unit of drainage area decreases as size

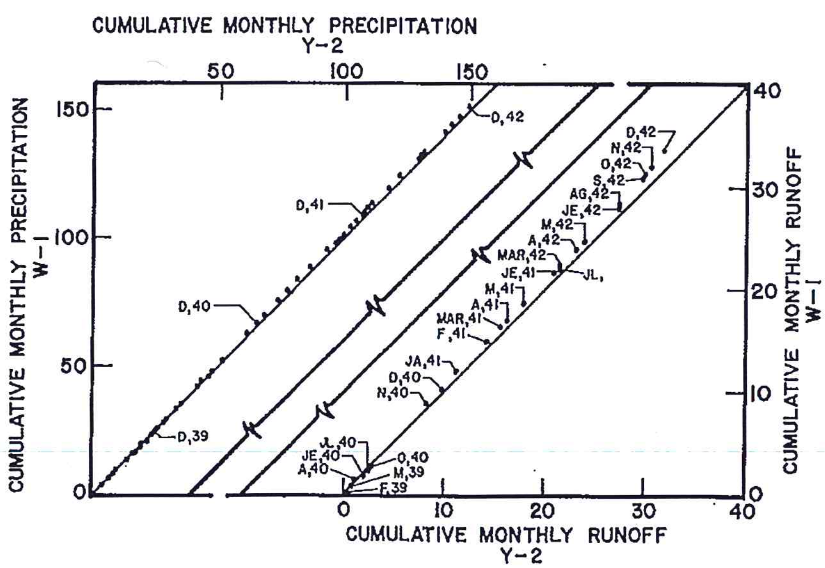

FIG. 4 Cumulative monthly rainfall and runoff amounts on watersheds W-1 and Y-2 when treated alike. Conservation practices including terracing being established September-December 1942.

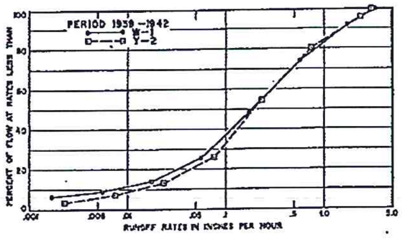

FIG. 5 Distribution of runoff by rate classes for the period 1939-42.

increases (1). In these two watersheds, with broad, flat valleys of uniform soil, no large amounts of channel erosion have occurred and the sizes of these watersheds are not greatly different; therefore, the effect of size should not be great. The longer drainageway, smaller shape factor, and slightly less land slope of watershed W-1 should decrease sediment yield as compared with watershed Y-2.

Estimated soil losses, as outlined by Wischmeier (4, 2), were also used to compare the sediment production potential of the two watersheds and thus provide some test of the validity of the results in Table 2. These soil losses have been estimated by the universal soil-loss-equation method developed by Wischmeier, with the various factors adjusted for local conditions by a soil conservation workshop committee at College Station, Texas, in 1961. Factors considered in this method are rainfall energy and 30-minute intensity, soil, length and steepness of slope, cropping management and conservation practices. These estimated soil losses are the long-term average soil losses.

Assuming identical cropping patterns and practices, this estimating procedure shows that the soil loss from Y-2 would be 114 percent of that from W-1 (upper block of Table 4). This difference of 14 percent may be due to the greater slope of Y-2; the slope lengths are almost the same. This computation provided a verification of the conclusion reached from general consideration of the major physical characteristics; that is, watershed Y-2 when treated in the same manner as watershed W-1 would have a higher sediment-yield potential.

Using the same estimating procedures and the actual cropping and conservation practices for watershed Y-2, the soil loss of the area as a conservation area was 22 percent as much as when considered as a non-conservation area and 26 percent as much as the untreated W-1 (Table 4). If the factor of 0.20 for predicting sediment yield as described by Wischmeier and Smith (5) is applied to those areas where sediment can be deposited in terrace channels, the predicted sediment yield would be 1.76 tons per acre per year as compared to the computed 1.25 tons per acre per year for treated Y-2 (Table 2). Much of the difference between the estimated soil loss and sediment yield is probably due to the deposition of sediment in the terrace channels with some deposition of sediment in the broad, grassed waterways.

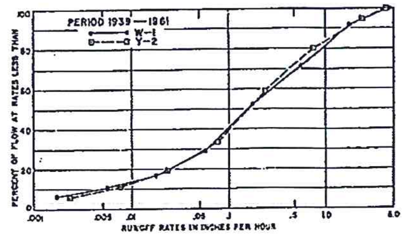

FIG. 6 Distribution of runoff by rate classes for the period 1939-61.

From the foregoing, it seems logical that, when both watersheds were treated alike, the soil losses and sediment yields from watershed Y-2 were slightly greater than those from watershed W-1, and that the differences in the computed sediment yields from these watersheds (which are greater than the differences in the estimated soil losses) are largely the effect of the conservation practices.

Interpretations and Conclusions

This study suggests the order of magnitude of the effect of specific changes in land-use and conservation practices on sediment yield. It also suggests the relations between soil losses and sediment yields under the two treatments. The results apply only to watersheds of the same soils, size, and treatment included in the study. The effect is a large and important one that should be extended to watersheds of larger size. For the Blacklands area the effect is primarily the reduction of sediment concentration with only a limited effect on the amount of runoff or distribution of runoff in various rate classes. For areas where land use has a major effect on amount and rate of runoff or with different soils, effects might be quite different.

TABLE 3. MAJOR PHYSICAL CHARACTERISTICS OF THE WATERSHEDS Y-2 AND W-1

Watershed	Size in acres	Length of principal drainageway, feet	Percent average land slope	Shape factor*	Dominant soil type
W-1	176	5400	2.19	0.262	Houston black clay
Y-2	132	3280	2.57	0.532	Houston black clay

* Area in square miles divided by length in miles.

TABLE 4. ESTIMATED ANNUAL SOIL LOSSES FROM WATERSHEDS W-1 AND Y-2 WITH ASSUMED IDENTICAL LAND USE 1939-42; ACTUAL LAND USE 1943-47

Land Use	Watershed W-1		Watershed Y-2	
	Percent of total area	Soil loss, tons per acre	Percent of total area	Soil loss, tons per acre
1939-42, watersheds treated alike				
Cultivated*	86.4	17.60	86.4	20.15
Permanent grass†	10.6	0.33	10.6	0.38
Farmsteads and roads‡	3.0	33.17	3.0	38.08
Weighted totals		16.24		18.59
1943-47, W-1 no change; Y-2 conservation				
Cultivated	84.8*	17.60	73.3§	4.86
Permanent grass	12.2†	0.33	25.5†	0.38
Farmsteads and roads	3.0‡	33.17	1.2‡	38.08
Weighted totals		15.96		4.10

* Four-year rotation: cotton, corn, cotton, oats with straight rows.
† Native and established pastures, fair condition.
‡ Major portion of farmsteads were livestock holding lots with very little vegetation.
§ Three-year rotation: cotton, grain sorghum, oats with sweet clover, terraced and contour cultivation.

References

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