Reprinted from Watershed Planning and Analysis in Action
Symposium Proceedings of IR Conference
Watershed Mgt/IR Div/ASCE
Durango, CO/July 9-11, 1990

INFLUENCE OF TILLAGE ON HYDROLOGY IN WESTERN IOWA

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ABSTRACT: USDA Agricultural Research Service has operated four field-sized watersheds in the deep loess soils of western Iowa since 1964. Throughout this time, two watersheds were cropped to corn using conventional tillage. One watershed was in bromegrass pasture with controlled grazing from 1964 to 1971. In 1972, it was converted to corn using a ridge till-plant system. The fourth watershed was cropped to corn using conventional tillage with level terraces from 1964 to 1971. In 1972, the terrace system was changed to parallel terraces with pipe outlets. The revised terraces were spaced at twice the recommended distance, and the field was cropped to corn using ridge tillage.

Total runoff (surface plus base flow) is highly influenced by evapotranspiration. Thus, there was less total runoff from the brome grass than from the corn watersheds, but there was more runoff from the ridge tilled than from the conventionally tilled watersheds due to reduced evaporation from the soil surface. Changing the terraces from level terraces to parallel terraces with pipe outlets resulted is a reduced base-flow and increased surface-flow.

The level terraces watershed exhibited flood hydrographs which were influenced predominantly by the area below the last terrace. Flood hydrographs from the parallel terraced field showed the influence of pipe flow through slightly increased peak discharge rates and greatly extended flow recessions.

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INTRODUCTION

The use of conservation tillage for row-crop production is expected to expand rapidly in the decade of the nineties in response to the 1985 Food Security Act. This act requires greater erosion protection on highly erodible land. Conservation tillage, while useful for reducing erosion, also influences hydrology of both the surface water and ground water. The relative effects of various conservation systems have been documented through studies using simulated rainfall on field plots. Long-term studies are not common, however, on field-sized areas under natural precipitation. This investigation describes the influence of two terrace systems and a conservation tillage system on the surface-water hydrology of field-sized watersheds located in the deep loess region of western Iowa. Ground water hydrology is not investigated explicitly but may be inferred from baseflow observations.

STUDY SITE AND FACILITIES

The Deep Loess Research Station, located near Treynor, Iowa, has been operated by the USDA, Agricultural Research Service since 1964. This research station comprises four field-size watersheds ranging in size from 30.4 ha to 60.8 ha. Two of the fields (WS-1 and WS-2) have been cropped to corn using conventional tillage throughout the study period. Conventional tillage consists of heavy disking in mid-April to incorporate corn residues followed within two weeks with a shallower disking and harrowing for final seed bed preparation. All operations are performed along approximate contours of the steeper side slopes within the watersheds. After planting, one or two cultivations are performed during the growing season for weed control. One field (WS-3) was in brome grass and used as pasture with controlled grazing in the early portion of the study. In 1972 the grass was chemically killed, and since that time the field has been cropped to corn using a ridge-till system. The ridge-till treatment consists of planting in early May in the crop residue of the previous year. One or two cultivations are performed to control weeds and to reconstruct ridges along the corn rows. The fourth field (WS-4) was initially terraced using level bench terraces with permanent sod backslopes and cropped to corn using conventional tillage. In 1972 the terraces were reconstructed to a parallel system with pipe outlets. These terraces are located at twice the recommended spacing. The field was cropped to corn using the ridge tillage system. The cropping and management histories of the watersheds are summarized in Table 1.

The principle soil types are Typic Hapludolls, Typic Udorthents, and Cumulic Hapludolls (Marshall-Monona-Ida

TABLE 1- Management history of Treynor, Iowa, research watersheds

W-shed Number	Size (ha)	1964-1971 Tillage	1964-1971 Crop	1972-1985 Tillage	1972-1985 Crop
WS-1	30.4	Conventional on contour	Corn	Conventional on contour	Corn
WS-2	33.6	Conventional on contour	Corn	Conventional on contour	Corn
WS-3	43.3	None	Grass	Ridge	Corn
WS-4	60.8	Conventional between level terraces	Corn	Ridge between parallel terraces	Corn

and Napier Series). These are well drained soils and areclassified as fine-silty mixed mesics. Ida is also calcareous. The topography is rolling and characterized by gently sloping ridges, steep side slopes, and well defined alluvial valleys with incised channels that usually terminate at an active gully head. Slopes range from 2-4% on the ridges and valleys to 12-18% on the side slopes. The loess overlays a glacial till that is a subdued replica of the land surface. This till layer is relatively impermeable compared to the loess.

The watersheds are located in pairs with adjacent watersheds, WS-1 and WS-2, about 4 km from adjacent watersheds WS-3, and WS-4. The outlet of each watershed is in a gully which penetrates the zone of saturation, so there is perennial flow from the watersheds. Flow is measured using weirs located in the gullies. The gullies penetrate nearly to the till surface. The weirs are founded on sheet piling which is intended to limit seepage around the gaging station. Rainfall is measured using a network of three recording rain gages per watershed.

WATER YIELD

The influence of the various management systems on hydrologic response is most easily established by comparing the response of WS-3 and WS-4 to the response of the conventionally tilled watersheds, WS-1 and WS-2. Water yield can be compared using double-mass curves. In this analysis, the accumulated flow from WS-3 or WS-4 is compared to the average accumulated flow from WS-1 and WS-2, Fig.1. Recall that the gully cuts into the saturated ground water zone so that base flow from that zone is contributing to the total flow. The slope of a line on this diagram represents the ratio of the flow

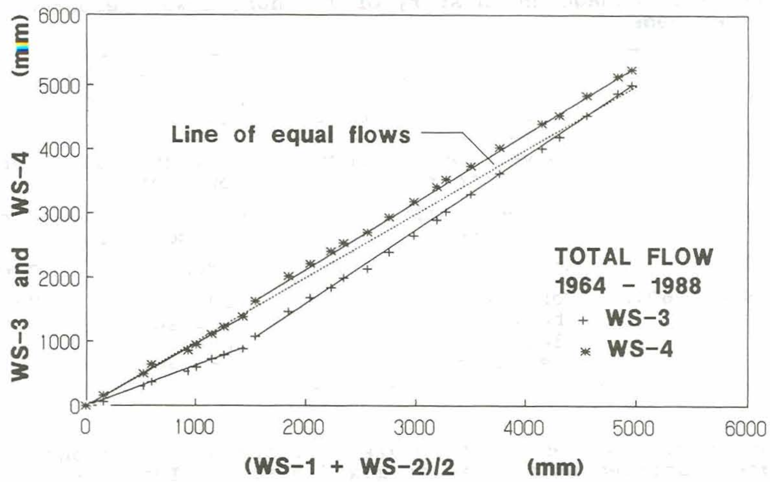

FIG. 1. Accumulated annual total flow.

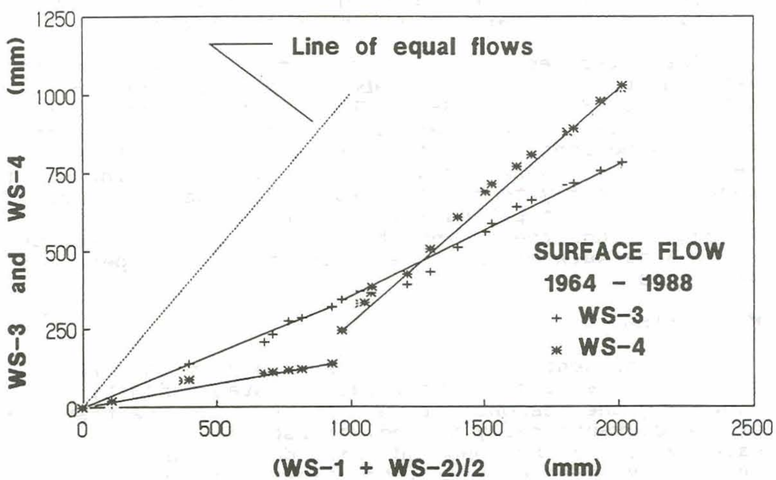

FIG. 2. Accumulated annual surface flow.

from WS-3 or WS-4 to the average flow from WS-1 and WS-2. A line indicating equal flows from the watersheds is shown for reference. Consider the values for WS-3. In the first eight years, when WS-3 was in grass, total flow was considerably (39%) less than for the conventionally tilled watersheds. Runoff from WS-3 averaged 112 mm/yr compared to a mean of 178 mm/yr for WS-1 and WS-2. This is indicative of the increased evapotranspiration of grass over corn. In 1972, WS-3 was converted to ridge-tillage corn, and there is a break in the trend. The new slope is greater than the equal flow reference. Total runoff averaged 242 mm/yr for WS-3 during the 17 year period 1972-1988. This is 17% greater than the annual mean total runoff from WS-1 and WS-2. The corn yields of the ridge tillage and conventional tillage watersheds were quite similar, so the transpiration can be expected to be quite similar. The increased residue left on the surface with ridge-tillage causes a reduction in the evaporation from the soil surface or a decrease in the combined evapotranspiration. This is the hydrologic explanation of the observation that reduced tillage fields often remain wet longer in the spring causing a delay in planting.

The total runoff from WS-4 in the early eight year study period was very close to the equal flow reference, averaging 174 mm/yr compared to 178 mm/yr mean for WS-1 and WS-2. This is to be expected as corn was grown on WS-4 using the same system as on WS-1 and WS-2. In 1972, the terrace system was changed and the ridge tillage system used on WS-3 instituted. The total flow from WS-4 in the later years (average of 227 mm/yr) is 10% greater than that from WS-1 and WS-2 (average 207 mm/yr).

Total flow is composed of both surface flow and base flow. The two types of flow were separated using a linear separation rule. In general, however, runoff events are short in duration and base flow is a small portion of the event hydrograph, so that separation technique used does not materially influence the result. Surface runoff is compared using a double-mass curve in Fig. 2. The surface runoff from WS-3 is much less than from WS-1 and WS-2 in the early years when in grass. Surface runoff averaged 40 mm/yr from WS-3 but 122 and 112 mm/yr from WS-1 and WS-2, respectively. After 1972, with the conversion to ridge tillage, the surface runoff averaged 27 mm/yr, less than half the surface runoff from the conventionally tilled fields WS-1 and WS-2, which averaged 67 and 61 mm/yr, respectively. During the level terrace years, surface runoff from WS-4 was only 17 mm/yr compared to 122 and 112 mm/yr for conventionally tilled watersheds, WS-1 and WS-2. Surface runoff on WS-4 was predominantly from the region below the lowest terrace. Surface runoff was about 15% that of the conventionally tilled fields, and the area below the last terrace was about 17% of the total area of WS-4. Conversion to parallel terraces with pipe outlets in 1972 resulted in a dramatic increase in the surface runoff. The slope of the line is more nearly parallel to the equal flow reference. Average flow from WS-4 was 52 mm/yr, whereas WS-1 and WS-2 averaged 67 and 61 mm/yr, respectively.

The double-mass curve for base flow is shown in Fig. 3. Base flow from WS-3 in the early years was slightly greater than that from the conventionally tilled watersheds (72 mm/yr for WS-3 and 62 and 63 mm/yr for WS-1 and WS-2, respectively). Conversion of this watershed to a ridge tillage system resulted in an increase in baseflow to an average of 214 mm/yr compared to 135 and 152 mm/yr for WS-1 and WS-2, respectively. The ridge tillage system resulted in increased infiltration and, as a result, reduced surface runoff. The evaporation from the soil is also reduced by the residue which leads to increased baseflow. When WS-4 was in level terraces, infiltration was the predominant means for removing surface water trapped by the terrace berms. The evapotranspiration from WS-4 was very similar to that from WS-1 and WS-2, so base flow was very high, averaging 156 mm/yr compared to 62 and 63 mm/yr for WS-1 and WS-2, respectively. Conversion to parallel terraces with pipe outlets provided a flow route for the water trapped by the terraces. The baseflow, which averaged 175 mm/yr compares to the conventional field baseflow of 135 and 152 mm/yr. The baseflow in these later years is 1.2 times that of the conventionally tilled watersheds, whereas in the level terrace configuration the baseflow was 2.5 times that of the conventionally tilled fields.

FLOOD FLOWS

The double-mass curve comparisons describe annual conditions but do not illustrate response to individual events. It is seldom that the storms impacting the pairs of watersheds have identical hyetographs due to the 4 km separation. The results of two events that were quite similar are shown in Figs. 4 and 5. Note that the discharge scale is logarithmic to permit displaying of the hydrographs from all watersheds on a common graph. Figure 4 depicts an event during the period in which WS-3 was in grass and WS-4 was in level terraces. WS-1 and WS-2 received 16.8 mm of rainfall in 21 min for this event, whereas WS-3 and WS-4 received 17.3 mm in 23 min. In Fig. 4, the hydrograph for the terraced watershed, WS-4, appears to be a scaled version of the hydrographs for WS-1 and WS-2. The predominant source for this flow is the region below the last terrace. This region is cultivated in the same manner as WS-1 and WS-2. The hydrograph for the grass watershed, WS-3, shows a lower peak discharge and a longer time-to-peak than WS-1 and WS-2, as would be expected. This hydrograph is also more regular than those from WS-1 and WS-2. That is, the slower response attenuates the influence of rapid changes

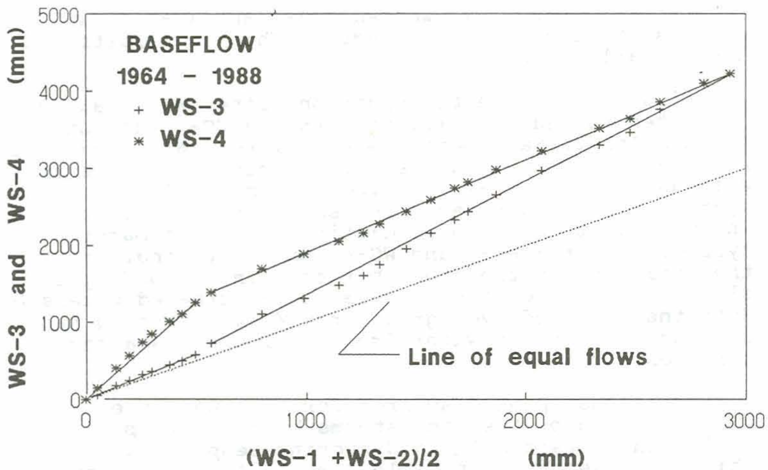

FIG. 3. Accumulated annual base flow.

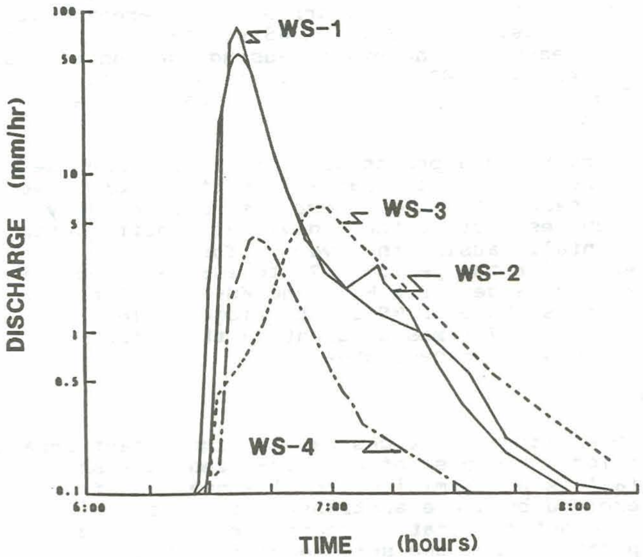

FIG. 4. Runoff hydrographs for watersheds WS-1, WS-2, WS-3, and WS-4 for the storm event of June 14, 1967.

in rainfall intensity, whereas WS-1 and WS-2 show response to those rapid changes. This is illustrated more clearly in Fig. 5.

Figure 5 represents conditions after WS-3 had been converted to reduced tillage corn and WS-4 was converted to parallel terraces with pipe outlets. WS-1 and WS-2 received 41.1 mm of rainfall in 56 min for this event, whereas WS-3 and WS-4 received 40.6 mm in 56 min. The hydrographs for WS-1 and WS-2 show three distinct peaks. These correspond to three distinct rainfall bursts. The hydrographs from WS-3 and WS-4 show only single peaks, the influence of the other bursts being damped by the slower response of these conservation treated watersheds. Note the extended hydrograph from WS-4 resulting from drainage of surface water from the low spots along the terraces.

The annual peak discharge for each watershed is not always caused by the same storms because of spatial variation of rainfall and differing response patterns. This is illustrated in Table 2 which lists the annual peak discharges. For WS-1 and WS-2 the annual floods occurred on the same day, except in 1974 and 1981 when the events occurred near midnight and in 1977. In 1977, two events produced floods of nearly equal magnitude. The larger of the two events occurred on different days for the two watersheds. For WS-3 and WS-4, however, in less than half of the years was the event causing the annual peak discharge coincident with WS-1 or WS-2. As a result, comparisons of annual peak discharges on a year-by-year basis are meaningless.

A frequency based approach was used to compare the response of the watersheds. Partial duration curves were developed for each watershed. Comparisons made apply only to the curves, not to the individual runoff events or to the rainfall causing the event. The partial duration series for the period 1972 to 1985 are shown in Fig. 6. Peak discharges from WS-1 and WS-2 are 3 to 5 times as great as those of WS-3, the ridge tilled watershed, and 5 to 7 times as great as those from the parallel terraced watershed, WS-4.

CONCLUSIONS

Soil conservation practices have a significant impact on the hydrologic response of a field-sized watershed. Where rainfall is not limiting, total annual runoff is mainly determined by the evapotranspiration of the vegetation. Practices that increase surface residue also reduce evaporation from the soil resulting in a slight increase in total runoff. The major influence of conservation practice on hydrology is in partitioning between surface and base flow. Both the ridge-till system and the terrace systems result in a substantial

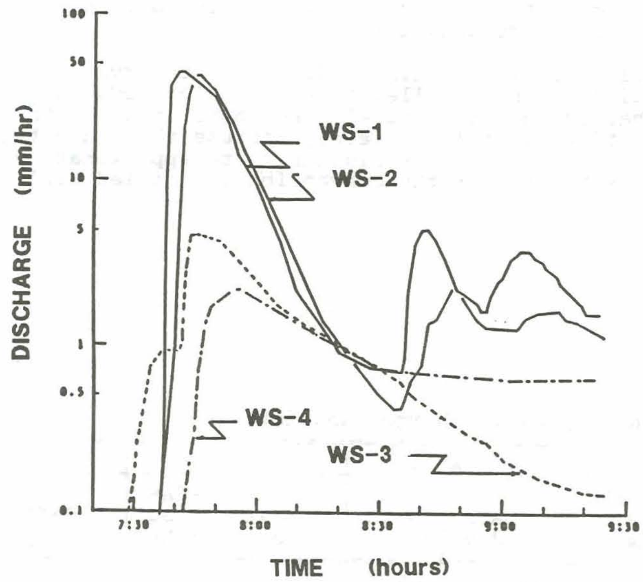

FIG. 5. Runoff hydrographs for watersheds WS-1, WS-2, WS-3, and WS-4 for the storm event of May 8, 1977.

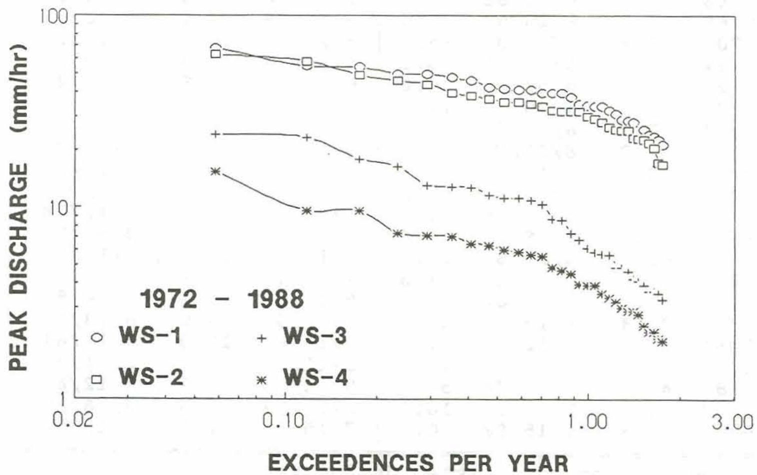

FIG. 6. Partial duration series for peak discharges from the four Western Iowa watersheds.

decrease in the surface runoff. This implies an accretion to groundwater.

Flood flows are also reduced by conservation practices. The parallel terrace system reduced the peak discharges to approximately one-third those of the conventionally tilled fields, whereas the ridge-tilled field reduced the peak discharges to approximately one-sixth those of the conventionally tilled fields.

TABLE 2- Annual peak discharges and dates.

WS-1		WS-2		WS-3		WS-4	
DATE m/d/y	PEAK DISC mm/hr	DATE m/d/y	PEAK DISC mm/hr	DATE m/d/y	PEAK DISC mm/hr	DATE m/d/y	PEAK DISC mm/hr
6/22/64	71.7	6/22/64	65.7	(a)		(a)	
6/29/65	105.5	6/29/65	47.8	4/4/65	7.8	6/29/65	3.0
6/26/66	49.7	6/26/66	46.5	6/25/66	4.5	6/25/66	7.5
6/20/67	148.1	6/20/67	123.5	6/20/67	51.1	6/20/67	7.1
6/13/68	22.7	6/13/68	28.6	10/8/68	6.8	6/13/68	3.9
8/20/69	22.7	8/20/69	11.2	8/20/69	3.3	8/20/69	0.9
8/2/70	132.2	8/2/70	85.9	8/2/70	2.4	5/12/70	1.7
5/18/71	80.8	5/18/71	65.1	5/10/71	7.3	5/10/71	6.1
5/5/72	50.0	5/5/72	36.8	6/7/72	12.8	6/7/72	15.4
9/26/73	14.5	9/26/73	13.3	7/3/73	2.9	7/3/73	4.9
5/18/74	8.2	8/17/74	7.1	5/19/74	1.0	5/19/74	1.7
8/29/75	19.2	8/29/75	16.5	6/18/75	0.2	6/18/75	1.1
6/17/76	0.9	6/17/76	1.3	6/26/76	23.2	6/26/76	7.2
5/27/77	50.0	5/8/77	44.2	5/8/77	4.8	5/8/77	2.2
5/19/78	68.3	5/19/78	25.6	5/31/78	8.7	5/19/78	6.5
5/18/79	5.6	5/18/79	5.2	5/17/79	4.1	9/6/79	1.6
6/15/80	41.6	6/15/80	63.0	6/15/80	18.0	6/1/80	6.3
6/2/81	33.8	6/1/81	31.6	7/8/81	24.2	7/8/81	9.6
6/14/82	54.8	6/14/82	45.9	6/14/82	3.3	6/14/82	1.1
6/13/83	28.4	6/13/83	31.6	6/13/83	8.6	6/13/83	2.8
6/12/84	54.1	6/12/84	31.6	6/14/84	13.0	6/14/84	5.6
5/14/85	14.2	5/14/85	10.8	2/21/85	0.8	2/21/85	0.7
4/27/86	42.6	4/27/86	58.1	8/12/86	11.7	8/12/86	5.9
5/26/87	39.9	5/26/87	16.9	5/26/87	4.6	5/26/87	2.3
6/15/88	1.8	6/15/88	0.9	7/15/88	11.1	7/15/88	2.9

(a) Gaging station established during year.