Surface Runoff from Southeastern Oklahoma Forested Watersheds

Barry P. Rochelle* and Parker J. Wigington, Jr.†

Department of Forestry, Oklahoma Agricultural Experiment Station, Oklahoma State University, Stillwater, OK 74078.

The surface runoff component of total storm runoff was monitored on three, forested ephemeral watersheds in the Ouachita Mountains of southeastern Oklahoma from April to June, 1983. Surface runoff was measured from two large runoff plots (25 m^2 to 250 m^2) on each watershed. One of the watersheds was intensively sampled using eighteen smaller (3-m^2) runoff plots to determine the spatial variability of surface runoff among three hypothesized runoff zones. The zones were delineated using the Variable Source Area Concept. Study results indicated that surface runoff in response to precipitation events was a minor contributor to total storm runoff. There were strong correlations between surface runoff and total throughfall amount. However, no significant correlations ($P = 0.10$) were found between surface runoff and throughfall intensity. Mappable runoff zones could not be established based on the small plot (3-m^2) runoff results.

INTRODUCTION

Forests are generally an excellent source of high quality water, with the smallest sediment production levels of any major land use (1-3). However, silvicultural activities have the potential to increase streamflow, surface erosion, and subsequent sediment delivery to streams draining forest landscapes.

In the last decade, intensive forest management and concern about the hydrologic impacts of such management have dramatically increased in southeastern Oklahoma. Although numerous studies in various locations in the United States have examined the relationships between forestry practices and stormflow, data for the Ouachita Mountains of southeastern Oklahoma are limited. An important step in evaluating the water-related influences of any land use activity is the establishment of ambient or natural conditions before land treatments are imposed.

Since 1978, the Forestry Department at Oklahoma State University has monitored three small forested watersheds in the Ouachita Mountains of southeastern Oklahoma for streamflow, sediment, and water chemistry in preparation for the future evaluation of silvicultural treatments to be applied to two of the watersheds. The flashy response of stormflow to precipitation events on these relatively undisturbed catchments led us to ask the question: What is the role of Hortonian overland flow and return flow in the rapid hydrologic response of these catchments?

Hortonian overland flow occurs when rainfall rates exceed soil infiltration capacities. Although fairly common in urban and agricultural settings, overland flow is rarely a dominant streamflow-generating process in forested watersheds because of the very large infiltration capacities of forest soils (4-6).

The Variable Source Area Concept has been presented as an alternative to Horton's model for the explanation of forest streamflow phenomena (4, 7). According to this concept, the sources of stormflow from watersheds with large infiltration capacities primarily include subsurface stormflow, direct precipitation on water surfaces, and return flow. Return flow is caused by water infiltrating into the soil upslope of the location of the return flow, traveling downslope within the soil until it reaches a saturated zone in a depression or near a stream channel, and re-emerging and flowing overland. The source areas or zones of streamflow, for all three forms of runoff typical of forested watersheds, are adjacent to stream

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*Now scientist, Northrop Services, Inc., Corvallis Oregon 97333.

†Now Hydrologist, U.S. Environmental Protection Agency, Corvallis Environmental Research Laboratory, Corvallis, Oregon 97333.

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channels and expand or contract in response to precipitation, evapotranspiration, and other environmental processes. Dunne et al. (8) provided evidence that runoff-producing zones within watersheds could be physically delineated on the basis of topography, soils, vegetation, and related factors.

This paper presents the results of a study that examined the contribution of surface runoff (Hortonian overland flow and return flow) to the total stormflow on forested, ephemeral watersheds in the Ouachita Mountains of southeastern Oklahoma during a spring runoff season. The spatial variability of surface runoff was also examined and is reported.

METHODS

Study area

Data were collected on three ephemeral, forested watersheds (designated as WS-I, WS-II, and WS-III) which are located approximately 13 km southeast of Clayton, Oklahoma (Fig. 1) and ranged in size from 6.1 to 7.9 ha (Table 1). The average slope for all three watersheds was 18 percent; however, slopes as great as 40 percent were common on WS-I. The forest overstory was of oak (*Quercus* sp.) and hickory (*Carya* sp.). Soil parent materials are sandstone and shale, forming predominantly Typic Hapludults, Lithic Dystrochrepts, and Typic Palendults. Armored, ephemeral stream channels are prominent in the lower portions of the catchments. The average annual precipitation is 127 cm with the greatest three-month total of precipitation and runoff occurring from April to June, a period characterized by intense frontal and convective showers. Average daily temperatures range from 6.5 °C in winter to 26.8 °C in summer.

Sampling layout

Each watershed was equipped with a 1.2-m H-flume and a FW-1 water level recorder for continuous measurement of stormflow. The flumes were anchored in clayey B-horizons, thereby allowing the possibility of some deep seepage below the flumes. Precipitation data were collected with one weighing-bucket recording rain gauge at each watershed.

Surface runoff phenomena were studied on two sizes of runoff plots. Large (25-m^2 to 250-m^2) plots were established to determine the occurrence of surface runoff. These plots were large enough to ensure that natural hydrologic processes could occur. In each watershed, two large plots were located in areas such as depressions or shallow swales where the potential for surface runoff production was the highest. Plot boundaries were defined by natural topographic divides or with sheet metal flashing. A 1.5-m gutter was installed at the base of each plot to collect surface runoff. Special care provided for minimal soil disturbance in the installation of the gutters. Surface runoff was measured after each precipitation event during April, May, and June, 1983. Throughfall reaching each plot was measured with a series of five collectors on the forest floor.

The second type of surface runoff plot was smaller to allow a relatively large number of plots to be randomly established on one of the watersheds (WS-I). The hypothesis underlying small-plot location was that all portions of the watershed do not produce equal amounts of overland or return flow, but that regions or zones within the watershed could be delineated, within which hydrologic similarities (e.g., the relative amount of surface runoff) exist.

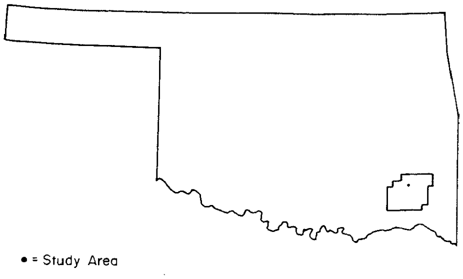

FIGURE 1. Location of Clayton Lake Watersheds Research in Oklahoma.

Three surface runoff-producing zones were identified based on topography and field observation (Fig. 2). Zone I was composed of areas immediately adjacent to the stream channels. Zone II comprised ridges and upper side slopes between the stream channels, and Zone III was the upper part of the watershed, an area with gentle slopes and no armored stream channels. Eighteen 3-m^2 (1-m x 3-m defined by wooden frames with metal flashing penetrating the soil surface) surface runoff plots were placed randomly in the watershed with seven plots each in Zones I and II and four plots in Zone III (Fig. 2). Fewer plots were used in Zone III because of the relatively homogeneous slopes and topography. Surface runoff was measured for eleven storms during April, May, and June, 1983, the most notable of which delivered 55.7 mm of precipitation with an average intensity of 12.2 mm/hr (Fig. 3). Throughfall was measured at each of the small runoff plots.

In addition to throughfall and surface runoff, soil moisture of the upper 20 cm of soil was measured at each small plot every seven to ten days. Five or six samples were collected in areas immediately adjacent to each plot with a soil punch tube and composited, and the moisture content was determined gravimetrically (9).

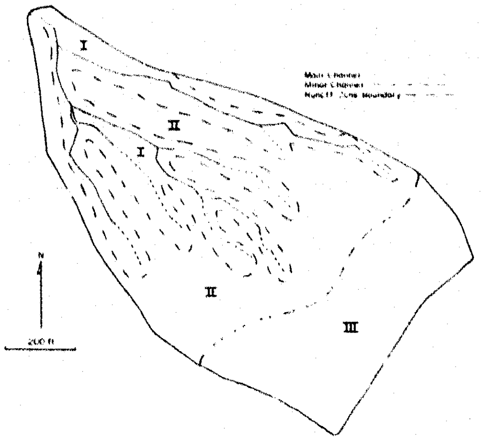

FIGURE 2. Delineation of hypothesized runoff zones for WS–I.

Data analysis

Data were tested to determine if there were any significant differences in surface runoff and percent soil moisture among the three identified zones using a split-plot design analysis of variance and Duncan's multiple comparison procedure (10). Each runoff event was a block, with differences in surface runoff or soil moisture among zones tested with plots nested within zones. Ranks of the data were used in the test to account for possible non-normality of the data (11).

Pearson's correlation procedure was used to determine possible associations between a) average surface runoff and average throughfall intensity, b) average surface runoff and average total throughfall and c) average surface runoff and maximum throughfall intensity for both the large plot and zone study (12). Randomized block analysis of variance was used to evaluate differences in total surface runoff among the six large plots (13, 14).

RESULTS

Large plot surface runoff

Surface runoff was observed on all plots (Table 2). However, there was no significant difference (*P* = 0.10) in surface runoff among the six plots. Large-plot surface runoff amounts ranged from 0.1 to 5.0 percent of total catchment stormflow amount, with most of the surface runoff amounts less than 1.0 percent of total stormflow. The maximum surface runoff percentage measured was 11.0. Surface runoff amounts tended to increase with larger (volume) rainfall events at each site.

Surface runoff zones

There was no significant difference in surface runoff production among the three hypothesized zones (*P* = 0.10), but there was a large variation in surface runoff amounts ranging from 0.0 to 1.3 cm, among all plots for any given storm (Fig. 4). The zones as delineated, however, did not reflect any specific trends. Conversely, soil moisture was found to be significantly different among the three zones (*P* = 0.10). Based on the Duncan's Multiple Comparison results, Zone III, the area highest in the catchment, had significantly greater soil moisture than Zones I and II. The median soil moisture percentages for Zones I, II, and III were

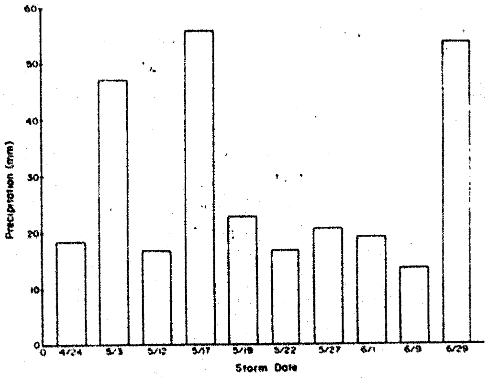

FIGURE 3. Total precipitation for spring sampling events.

TABLE 1. Study watershed characteristics[a].

Parameter	Unit of Measure	Watershed 1	Watershed 2	Watershed 3
Area	ha	7.86	6.07	7.71
Elevation	ft (m)			
Maximum		1370 (418)	1320 (402)	1240 (378)
Minimum		1140 (348)	1140 (348)	900 (274)
Aspect		NW	SW	SW
Slope (avg.)	%	14	18	21
Crown cover[b]	%	90	86	88
Surface conditions	%			
Litter		86	81	76
Rock		3	8	6
Tree		6	5	6
Erosion		1	0	1
Stream channel		4	6	11
Drainage density	km/km^2	24.8	18.8	22.2

[a] Data were collected from sample points at 20–m intervals on a random grid (from Vowell, unpublished master's thesis, Oklahoma State University) and boundary survey completed 1983.

[b] Percent crown cover was estimated from aerial photographs.

TABLE 2. Surface runoff depth as a percentage of total stormflow depth for large plot study.

	Watershed 1		Watershed 2		Watershed 3	
Date (1983)	Plot 1	Plot 2	Plot 1	Plot 2	Plot 1	Plot 2
4/24	0.1	---[a]	0.4	0.4	0.1	---
5/3	---	---	0.04	0.1	0.1	0.1
5/12	0.2	0.3	5.6	6.0	8.1	---
5/17	1.7	0.2	0.4	1.6	0.2	0.3
5/19	0.1	0.6	0.3	0.7	0.2	0.3
5/22	0.1	0.3	0.2	0.3	0.4	0.2
5/27	0.4	0.7	1.0	11.0	6.6	3.2
6/1	0.6	1.3	1.7	5.6	---	---
6/9	0.7	2.4	---	---	---	---
6/29	0.4	2.4	8.6	4.2	1.4	5.0

[a] Data missing.

24.4, 24.2, and 26.9, respectively.

Average surface runoff per zone was well correlated with total throughfall amount, with correlation coefficients equal to or greater than 0.91 whereas correlations between surface runoff per zone and average throughfall intensity were not significant (P = 0.10) [Table 3]. Additionally, there was not a significant correlation (P = 0.10) between surface runoff and maximum throughfall intensity. Similar trends were observed for the large runoff plots (Table 4). Correlations between surface runoff and average throughfall amount for the small plots tended to be higher than those for the large plots.

DISCUSSION

On the basis of the described experiments, surface runoff comprised a small portion of the total stormflow from the experimental watersheds. The large runoff plots were of sufficient size to include rock outcrops, downed logs, and other features that might contribute to surface runoff but be too large to fit within the boundaries of small, fixed-geometry runoff plots. Nevertheless, surface runoff depth rarely exceeded five percent of total stormflow depth. Although differences in surface runoff

TABLE 3. Correlation results for surface runoff, total precipitation, and average precipitation intensity per zone.

Parameter	Surface Runoff by Zone		
	I	II	III
Total precipitation	0.98[a]	0.99[a]	0.91[a]
Average precipitation intensity	0.22	0.22	0.22

[a] P value < 0.005

TABLE 4. Correlations between surface runoff and precipitation for the large plot study.

Variable	Total Precipitation	Average Precipitation Intensity
Watershed One		
Plot One		
Surface runoff	0.97[a]	-0.06
Plot Two		
Surface runoff	0.10	0.47
Watershed Two		
Plot One		
Surface runoff	0.76[a]	0.47
Plot Two		
Surface runoff	-0.34	0.14
Watershed Three		
Plot One		
Surface runoff	0.79[a]	0.06
Plot Two		
Surface runoff	0.79[a]	0.06

[a] P value < 0.005

among the large plots were not found to be statistically significant, examination of the data reveals that surface runoff production from large plots within the same watershed was not uniform. Several factors could contribute to the variability in surface runoff between the two plots within a watershed. Plot size varied significantly among the plots. Microtopographic features within the plots may have affected surface runoff volume. The plots were located in areas where surface runoff would be concentrated, such as swales or slight depressions. A plot with a slightly more defined depression site may tend to produce larger volumes of surface runoff than sites with more poorly defined depressions. Plot location may also have affected surface runoff with one plot located in the upper part of the watershed and one plot in the lower part of the watershed on all three watersheds. Further examination of the plots may aid in identifying specific factors affecting the variability in surface runoff.

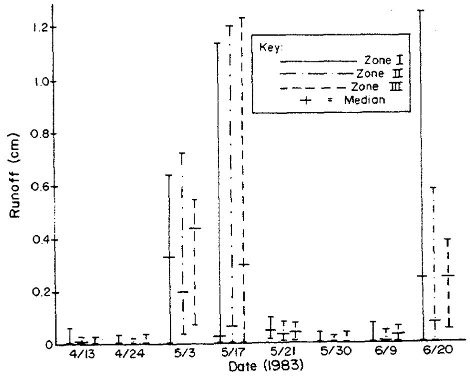

FIGURE 4. Range and median value of surface runoff per zone for the variable source study.

The small runoff plot study failed to establish a series of mappable zones of surface runoff such as had been demonstrated by Dunne et al. (8). On the basis of the Variable Source Area Concept, the depressions and slopes immediately adjacent to active stream channels were expected to produce the most surface runoff (primarily return flow). However, Dunne and Leopold (4) noted that for small catchments with steep topography and rapid drainage, saturated zones adjacent to streams are likely to be of small areal extent and short lived. This may have been the case for the watershed examined in the small plot study. The rapid movement of water through a coarse-textured A horizon that was over a clayey B horizon and the water's reemergence into stream channels as subsurface stormflow seems to be the most likely explanation for the flashy hydrologic response of the watersheds. The presence of expanding runoff source areas in the catchments is demonstrated by rapid channel expansion that occurs during rainstorms. However, the water probably leaves the source areas so quickly that widespread saturated areas are not developed. In the type of systems studied, microtopography, the location of small swales and depressions throughout the watershed, may be more important to surface runoff processes than larger zones. Of course in extremely large events (e.g., 100-year return-period) the importance of surface runoff, especially return flow, and the formation of definable source areas may be much greater.

At first glance, the small plot soil moisture results seem puzzling. The largest soil moisture values were found in the upper portion of the catchment, away from the stream channels. Two factors may be responsible for the observed phenomenon. First, the soil moisture sampling was conducted on a seven-to-ten-day basis, too infrequently to pick up soil moisture changes of expanding source areas during rainstorms. Instead the small soil moisture differences were probably more representative of general seasonal trends. Secondly, the area corresponding to Zone III, the uppermost in the watershed, had different soils than the lower two zones.

The question of which type of surface runoff, Hortonian overland or return flow, was more important on the watersheds may have been answered by the correlation analysis results. For both small and large plots, surface runoff was well correlated with total throughfall amount but not with average throughfall intensity. Additionally, surface runoff did not correlate with maximum throughfall intensity. This implies that the infiltration process was not the factor controlling the surface runoff processes and Hortonian overland flow was probably not very important during the storms monitored on the study watersheds.

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