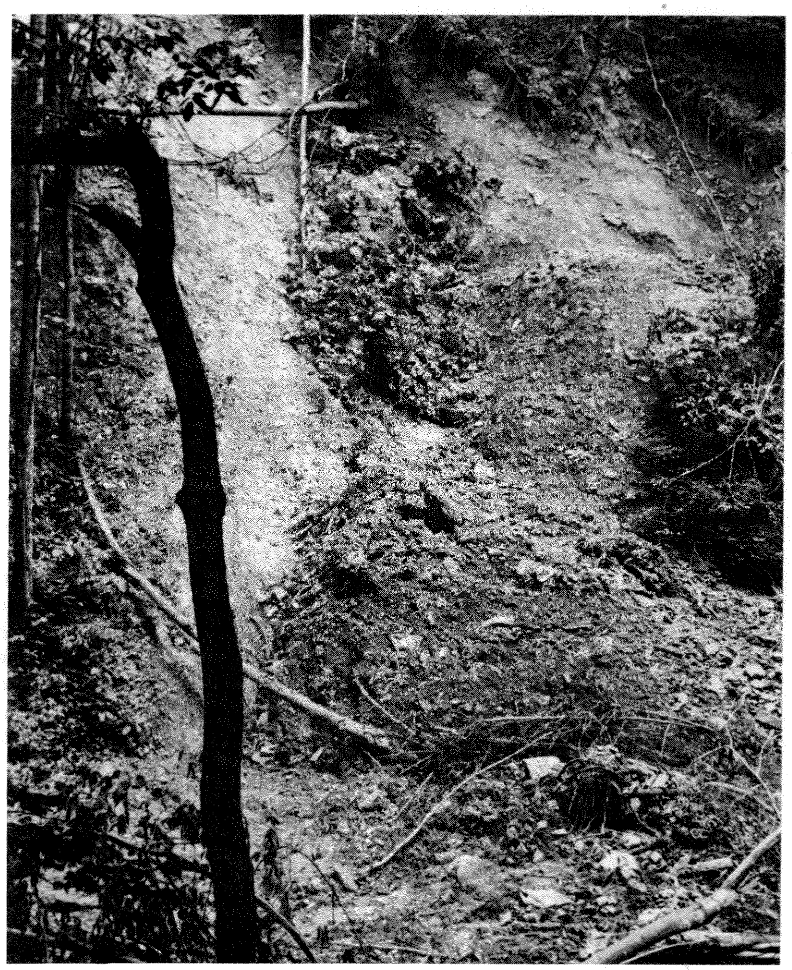
by James H. Patric

Soil-Water Relations of Shallow Forested Soils During Flash Floods in West Virginia



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Abstract

On May 24, 1978, heavy rain caused flash flooding on densely forested land near Parsons, in Tucker County, West Virginia. Poststorm evidences of soil and water behavior were examined in detail on soils related to the Dekalb and Leetonia series. Other flash floods struck seven forested sections of the state in August. Less detailed observation after these storms centered on the Weikert-Berks soil complex. Erosion in perennial channels was severe at all of the storm sites. Ephemeral channels had eroded severely in May but not in August, an effect attributed to higher soil moisture in May. Rain infiltrated completely into most of the forest floor during all of the storms; thus, overland flow occurred only when soils became saturated by infiltrated water draining downslope. Erosion of mineral soil was not apparent on the forest floor, regardless of steepness, even on grazed and cutover land. Neither did logging roads erode seriously. Rain was insufficient to cause widespread erosion by debris avalanching. Sediment production during these rare phenomenal storms was estimated to range from 3 to 10 tons per acre, a rate of loss comparable to the annual losses claimed for farmland. Water relations were similar on all of the soils observed, to the extent that each responded as predicted by the concept of variable source area for the origin of streamflow on forest soil.

INTRODUCTION

MOST HYDROLOGISTS hold to the conventional concept that streamflow is the result of runoff and aquifer discharge (Wadleigh 1966). The Water Resources Committee of the Soil Science Society of America defined runoff as:

> Runoff = (Precipitation)—(Surface Retention)—(Infiltration).
>
> During a major storm, surface retention becomes of very minor consequence so that amount of infiltration becomes the essential determinant of runoff during such a storm.

This is stormflow, or runoff, as usually defined by most engineers and agriculturists. According to this view, stormflow—rain that fails to infiltrate—reaches streams by flowing overland to them. But what if all the rain infiltrates? Does that ever happen? Forest hydrologists think that it does and, furthermore, that overland flow is a rarity in the humid climate forest. They believe that rate of infiltration (the maximum rate at which rain can enter the soil) almost always exceeds rainfall intensities on well-managed forest land throughout the eastern United States (Lull and Reinhart 1972). Miller (1977) concurs:

> Such large volumes of infiltration capacity suggest why many forested slopes in experimental basins, which have been closely observed for many years, have never been seen to produce surface runoff. Never have rates of rainfall exceeded the high rates of infiltration capacity into their upper soil layers.

The concept of variable source area (Hewlett and Troendle 1975) treats infiltration as seldom limiting on forest land. It postulates that headwater (first order) streams rise during intense storms because rain falls directly into their channels; indirectly, infiltrating rain begins to saturate certain of the soil strata and drains into seeps or into ordinarily dry hollows, and water flows within these ephemeral channels to a perennial stream. In effect, these indirect responses to unlimited infiltration cause an upslope expansion by the channel systems of first-order streams, transversely as well as longitudinally.

Infiltration over most of the forest floor continues for as long as the rain continues. Saturated strata (where infiltrated rain exceeds soil pore capacity) respond to increasing hydraulic gradients by flowing within the soil more or less in conformance to its slope. Direction, velocity, and volume of subsurface flows vary with depth of saturation and with the conductivity, steepness, orientation, and depth of soil. Water exfiltrates from the soil when deepening strata of saturation rise to the surface. Exfiltrating water and uninfiltrated rain falling on saturated soil flow overland; these, too, are source areas but often are misinterpreted as runoff as defined by Wadleigh (1966). Source areas expand rapidly during intense rainfall and shrink slowly as rains diminish, draining lower slopes and shallow soils more rapidly and completely than upper slopes with deeper soil. The source area concept, simplified and diagramed in Figure 1, has obvious implications for the erosion of forest soil.

During 1978, I visited seven sites of flash flooding in northern and central West Virginia while the evidences of water behavior and soil erosion were fresh and fully visible on the forest floor. Observation in greatest detail was possible after the storm of May 24 in Tucker County; it skirted just north of the Parsons Timber and Watershed Laboratory. No other storm occurred so conveniently nearby; observation at other sites was limited to from a few hours to a few days. At each site, my purpose was to reconstruct water behavior on and within forest soils, an essential step in interpreting erosion losses from the storm sites.

THE SPRINGTIME STORM

On May 24, 1978, an intense rainstorm caused flash flooding and associated damages across Tucker County, West Virginia. The radar at Pittsburgh Airport, about 75 miles north-northwest, detected only light to moderate rain, with clouds to 18,000 feet, during the hours 9 a.m. to 3 p.m.[1] The

[1] Personal communication from Sterling Yeager, National Oceanic and Atmospheric Administration, Eklins, West Virginia.

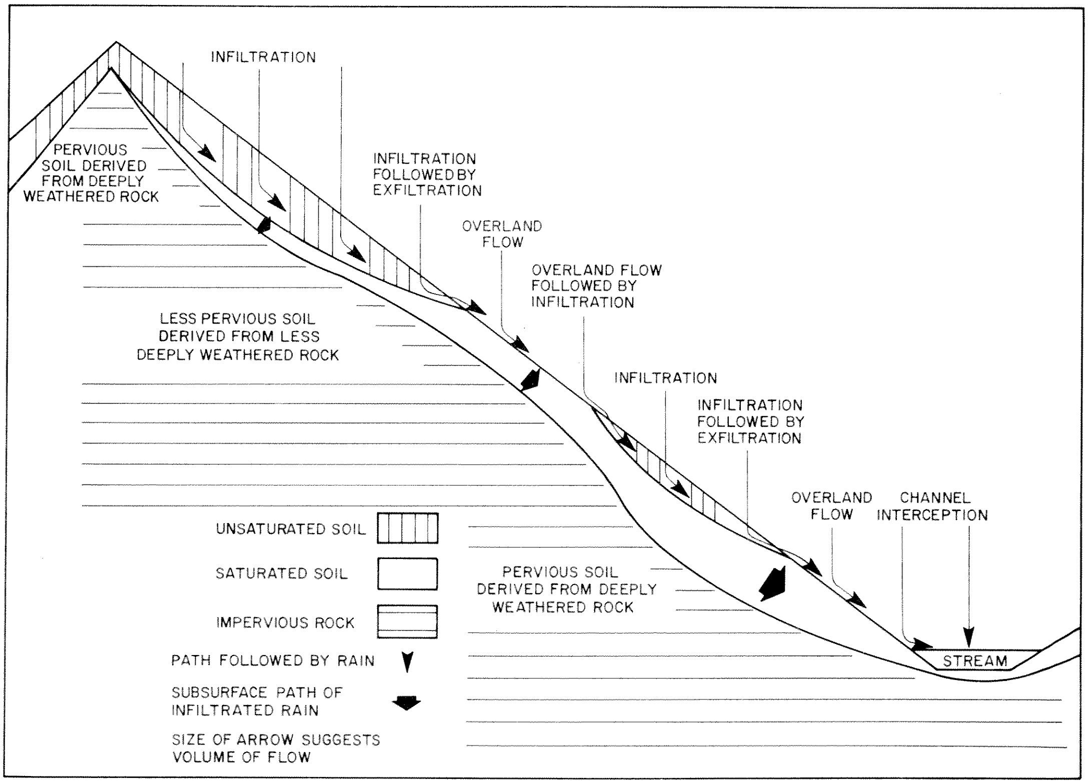


Figure 1.—Two-dimensional representation of rainfall disposition on a shallow forested soil.

Figure 2.—Highway workers were pressed to keep Route 38 open to traffic as debris poured from this unnamed draw near St. George. At this elevation (1,700 feet) tree foliage had almost fully emerged.
PHOTOGRAPH BY KENNETH SMITH, PARSONS ADVOCATE.

Figure 3.—Stormflow far exceeded the capacity of this ephemeral flow channel on Route 219. At this elevation (2,800 feet) tree foliage had only begun to emerge. Note small stones being washed along the road pavement.

report in the Parson Advocate of May 31 suggests that radar is not infallible:

> A cloudburst last Wednesday afternoon tore through a strip between Rt. 38 area, Sugarlands, US 219 near Mackeyville and Backbone Mountain, and in an area in Canaan Valley causing extensive damages . . .On Route 38 from the Barbour County line to St. George enormous amounts of rock and dirt were washed out of the hollows onto the roads and culverts were closed.

Fortunately, the proximity of this storm permitted a closer look at water behavior along its path. Water and debris had indeed poured in unprecedented volumes from normally dry hollows (Fig. 2). and ephermeral channels (Fig. 3), as well as from perennial headwater streams (Fig. 4). (Except where noted, photographs are by Forest Service personnel.)

My paramount concern was to establish the amount, timing, and extent of heaviest rainfall. A notice in the Parsons Advocate led to particularly useful information from the following respondents:

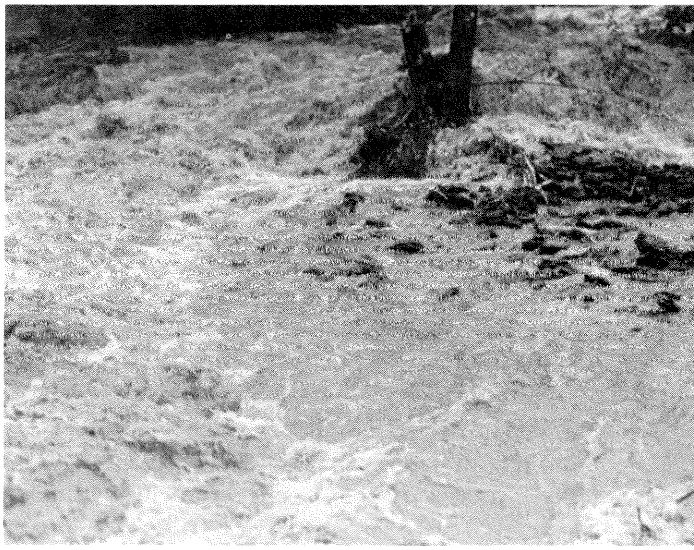


Figure 4.—Debris-laden stormflow in Jonathan Run at Route 72. The flooded stream is about 30 feet across and perhaps 4 feet deep. One can step across this stream during non-storm flow.
PHOTOGRAPH BY KENNETH SMITH, PARSONS ADVOCATE.

1. Mrs. Lana Oaster, Texas Mountain, elevation 2,750 feet. The rain began just as Mrs. Oaster delivered her daughter to the school bus at 7:15 a.m. The storm approached from west of their mountaintop home. The hardest rain fell between 9 a.m. and 11 a.m., and the storm ended at 1:30 p.m. On the previous evening, Mr. Oaster had left an empty 5-gallon bucket in the garden. It contained just under 6 inches of water after the storm. Water spurted upward when Mrs. Oaster walked on the waterlogged ground, where dense sod near the garden was raised several inches by water trapped between it and the underlying soil.
2. Mr. Miles Kochenderfer, Holly Meadows, elevation 1,740 feet. The rain began in midmorning and was heaviest during midday. At about 1 p.m., Mr. Kochenderfer recalled that grass on his lawn was covered by standing water. The grass was neatly mowed, perhaps 2 inches high, on a lawn sloping about 5 percent away from the house. Apparently, rain fell at the height of the storm faster than it could infiltrate into or flow across the grass-covered surface. A glass gage contained 4.20 inches of rain.
3. Mr. Ben Thompson, Canaan Valley, elevation 3,300 feet. Mr. Thompson is a longtime weather observer for NOAA. His official gage recorded 3.10 inches of rain. His notes record light rain from 6 a.m. to 11:30 a.m., heaviest rain from noon until 3 p.m. Several inches of water were pumped from Mr. Thompson's basement, never flooded before this storm.

From measurements and eyewitness accounts, it seems that rain fell at intensities close to 1-1/2 inches per hour for 3 hours near the western edge of Tucker County, for 2 hours near its eastern edge. Furthermore, rain at these intensities fell on fully wetted soil. Winter snow had melted early in April, more than 4 inches of rain had fallen earlier in May, and tree foliage had emerged too recently to draw down soil moisture by transpiration.

Distribution of high-intensity rain was determined by recording its poststorm evidences on a highway map of Tucker County. Every road in the storm vicinity was traveled in search of evidences such as deeply scoured streambeds and road ditches, slipouts along roads and streams, and debris deposits below hollows. A storm track about 30 miles long, about 3 miles wide at its western end, and less than 2 miles wide at its eastern end was thus defined (Fig. 5).

Reported amounts of rainfall, with roads and locations referred to in this report, were plotted on the storm track. Only one catch of heavy rainfall was reported outside the storm track; rain in a small glass gage, mounted on the flat side of a board, probably had been augmented by in-splash from the board. There were neither reports nor evidence of flash flooding at this location and an official standard gage less than 1 mile away had caught only 1.15 inches of rain.

SOIL-WATER RELATIONS AND EROSION ON THE DEKALB-CALVIN SOIL ASSOCIATION

The largest roadside debris deposits lay beneath outlets of hollows on Dekalb soil (Losche and Beverage 1967), near St. George on Routes 38 and 72. Here, the mountains are low but steep, ranging in elevation from 2,500 to 3,200 feet, in slope from 40 to 70 percent. The forest, predominantly oak and maple, had not been cut in many years.

After the storm, I walked into the forest above some of the larger debris deposits which were composed mostly of sandstone fragments, but contained much soil and organic detritus. Upslope, the bedrock was interbedded shale and fine-grained sandstone, with the shallowest soil usually overlying the shale. Sandstone fragments on the forest floor were flat, seldom thicker than 2 inches or wider than 12 inches. There was little or no surface rock were soils where underlain by shale.

My first concern was to search for evidences of overland flow. Hardwood litter blanketed most of the forest floor, usually 1 to 3 inches deep. Rearranged litter was interpreted as evidence of overland flow. Litter closest to channels often had washed away.

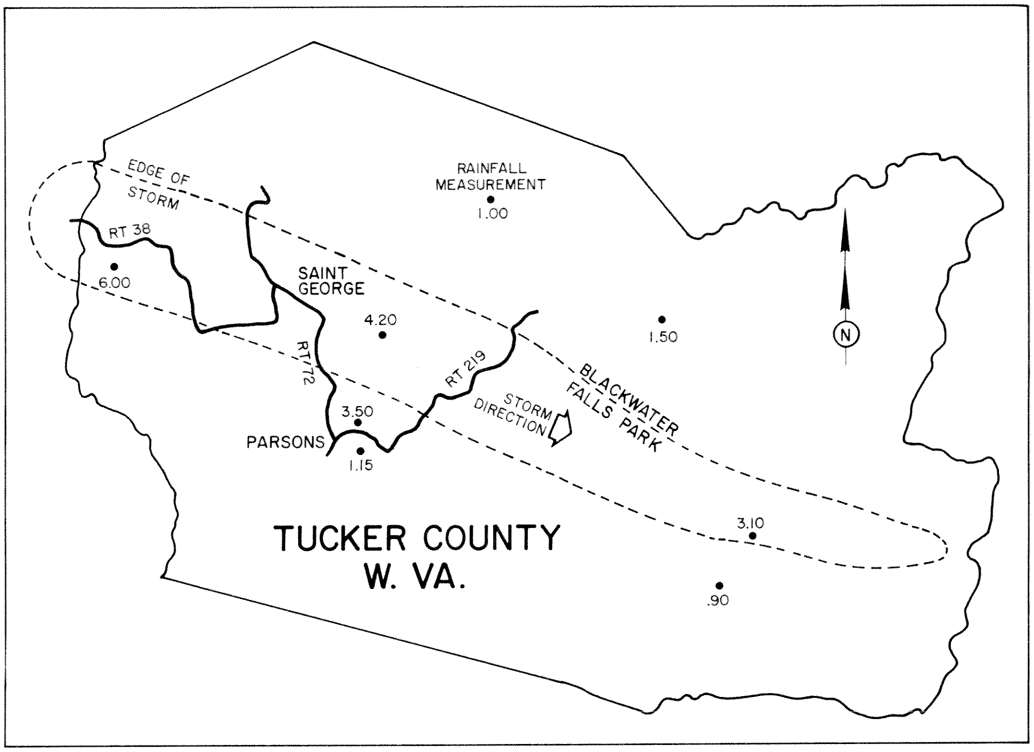


Figure 5.—The storm track.

Farther from the channels, dead leaves had been carried a few inches or even a few feet downslope, then redeposited in low cross-slope ridges behind stones or woody debris. Smaller fragments of litter often had been reoriented by overland flow with long axes downslope, giving the forest floor a "combed" appearance. This exposed the L and H layers of the soil but, apparently, overland flow had moved too slowly to tear them apart because they were bound firmly in place by roots and mycelia. Mineral soil was exposed here and there, but only in the small patches likely to be found in any steep woodland.

Most of the overland flow had originated on shallow shale soils, then drained downslope where it often reinfiltrated the deeper, more previous sandstone soils. At least 25 percent of the forest floor evidenced overland flow. Slope gradient had little relation to overland flow except that the steepest slopes often had the shallowest soil.

In general, two kinds of drainages predominated on these mountainsides. Sharply incised basins, V-shaped in cross section, evidenced most overland flow and soil erosion. Broad, gently concave basins evidenced some overland flow, but only on cross-slope belts of shallow soil, and little or no accelerated erosion was evident. So pervasive was this contrasting drainage that two typical sites were examined in detail.

A V-shaped basin

A debris deposit over a blocked culvert on Route 72 drew my attention to some severe erosion. The deposit lay beneath a vertical sandstone face about 15 feet high. I climbed the debris, only then discerning an east-facing, V-shaped basin extending upslope at a gradient close to 60 percent. Side slopes of about 70 percent extended perhaps 75 or 100 feet to sharp-crested ridges paralleling the channel. Freshet flow almost 3 feet deep had detached but left behind some sandstone slabs as large as 4 inches thick and 24 inches across (Fig. 6). The channel was freshly eroded about a foot into the underlying bedrock. Overland flow had occurred on at least 50 percent of the side slopes.

About 300 feet up-channel, a mottled subsoil had been newly bared by erosion, but no bedrock. Here, the freshet had flowed about 2 feet deep, depositing sandstone fragments up to 2 inches thick and 8 or 10 inches across. Upslope, large plugs of soil and organic debris had lodged in the channel. Clearly, the erosive power of the freshet decreased substantially over short distances upslope. If the side slopes had eroded at all, the losses were restricted to litter carried into the channel by overland flow.

At 625 feet upslope, the channel gradient was 55 percent, with side slopes about 50 percent. The basin was no longer V-shaped, but somewhat rounded in cross section. A longitudinal band of forest floor about 2 feet wide had washed away, leaving a shallow channel of exposed mineral soil. Overland flow had occurred on perhaps 25 percent of the nearby side slopes. There, cavities in the

Figure 6.—The channel of the V-shaped basin, about 50 feet above Route 38, looking downslope. The freshly scoured bedrock is partly covered with sandstone fragments too large to be carried farther downslope. Note the scant cover of litter on channel sides. It is not possible to convey the steepness of this channel in photographs.

Figure 7.—This photographic field is about 1 square foot and shows nine piping cavities.

L and H layers (Fig. 7) suggested piping during the storm. Extending a few to several inches upslope between the organic and mineral soil horizons, were cavities 1/2 to 1 inch in diameter—probably animal burrows, which were found wherever overland flow had swept away the litter.

At 730 feet above the highway, the land still sloped 55 percent to the east but there was no clearly defined channel. Overland flow had swept away about half of the litter along a diffuse pathway about 30 feet wide, exposing mineral soil in some places.

Bedrock lay 6 to 12 inches beneath the soil surface at 850 to 980 feet above Route 72. There was no evidence of channelized flow. Here, the ground was almost planar in cross section but sloped about 70 percent to the east. Overland flow had occurred on perhaps half of the forest floor, redistributing the litter but carrying it no great distance. These evidences of overland flow were found as far upslope as 50 feet from the ridgetop.

Stereoscopic examination of large-scale aerial photographs showed that the V-shaped basin was 1,030 feet long and about 160 feet wide, almost 4 acres in extent.

A gently concave basin

From the crest of the V-shaped basin, I walked south along the ridge for 200 or more yards. Below me lay another steep east-facing basin, this one broad and gently rounded in cross section. I paced downslope, walking in its lowest discernable "channel."

There was no evidence of overland flow for the first 100 feet downslope, despite frequent outcroppings of sandstone on the 70 percent slope. Virginia creeper and poison ivy formed a dense ground cover. Along the next 100 feet downslope, shale bedrock underlaid the shallow soil; here, tiny "deltas" of soil up to 6 inches long were everywhere. Perhaps they had been caused by overland flow, but there was little evidence of litter displacement. More extensive soil disturbance may have been prevented by the dense ground cover of jewel weed and nettles. For the next 250 feet downslope, the slope moderated to about 50 percent and was thickly covered with loose sandstone talus. Herbaceous ground and litter cover were scanty but there was no evidence of overland flow or soil disturbance. The basin narrowed gradually and its sides steepened for the next 250 feet. Loose rock covered much of the soil surface. At a point about 300 feet upslope from the highway there had been some overland flow in a shallow channel. For the last 200 feet to Route 72, stormflow had scoured away a longitudinal band of litter about 4 feet wide. The slope of this channel was about 50 percent but stormflow in it hardly could have exceeded 4 or 5 inches in depth.

Photographs taken in this basin show nothing but ordinary forest floor. There was no evidence of accelerated soil erosion. Overland flow had occurred on perhaps 25 percent of the basin surface, but most of it reinfiltrated within short distances downslope. The 18-inch culvert under Route 72 had carried the entire stormflow without plugging (Fig. 8).

Measurements on aerial photographs indicated an area of 12 acres with a length of 1,155 feet for the gently concave basin.

Recently logged land

Facing west from the ridge above the gently concave basin was a woodlot logged in 1977. Most of the trees larger than 10 inches in diameter had been cut; smaller trees remained standing. Considerable slash reinforced the soil-protective role of the forest floor, only minimally disturbed by logging during the previous year. Topography, the forest floor, and soil erosion differed little from the gently concave basin.

A truck road led downslope on 8-percent grade from a log landing about 100 yards below the ridge. There was no gullying or other evidence of severe soil loss from the

Figure 8.—Outlet of the gently concave drainage. The culvert headwall is visible at the lower center of the picture.

landing (Fig. 9) or from any logging road. Most of the finer soil particles probably had washed away during the previous winter. In any case, an existing erosion pavement of small stones and woody detritus had prevented serious soil loss during the storm of May 24.

Figure 9.—View across a log landing, downslope along a logging road with an 8-percent grade. This road had not been regraded after the storm and presented no obstacle to safe driving.

Grazed woodland

Also facing west, but from the ridge above the V-shaped basin, was a heavily grazed woodlot. Oak and maple trees of 5 to 16 inches in diameter formed a complete tree canopy but cattle had eliminated the understory. Most of the litter had been trampled into the mineral soil, creating a pocked surface irregularly covered with muddy organic matter. Here, too, topography and soil erosion differed little from that described for the gently concave basin.

Trampling since the storm may have eliminated the more subtle evidences of overland flow, but I found no evidence of accelerated erosion on nonchannel parts of the grazed woodlot. Apparently rain had infiltrated as fast as it fell. Where drainageways narrowed and deepened to define a channel, there was the same evidence of severe channel scour described for the V-shaped basin. There was no evidence that scour had been worsened by grazing. As in the V-shaped basin, erosion of soil and rock increased greatly over short reaches of deeply incised channel.

Landsliding

Slope failures above roads and streams were common, but only one landslide (Fig. 10) was found on the storm track. It was on a 58-percent slope between Routes 38 and 72. Almost 100 feet wide and perhaps twice as long, it dumped nearly 1,500 cubic yards of debris into Clover Run. Monongahela National Forest personnel believe that road

Figure 10.—Landslide on the Right Fork of Clover Run. The lightest colored surfaces are bedrock. For scale, note workmen at the top of the photograph.

construction caused this landslide. Loss of slope support from bank undercutting by Clover Run seems as likely a cause. Upstream a short distance, another landslide of similar size had occurred long before the forest was roaded.

An estimate of debris production

Heavy rain caused stream channels to extend far upslope, often into land showing no previous overland flow (Fig. 11). Here, the erosive action probably was like that described for the V-shaped basin. Scour was severe, too, in small headwater hollows (Fig. 12), the origin of mere trickles during ordinary wet weather. Bank undercutting was ubiquitous, with several slope failures per mile common along perennially flowing, first-order headwater streams (Fig. 13). Huge stormflows had widened and deepened the second- and third-order stream channels (Fig. 14). Debris from all of these upstream

Figure 11.—Overland flow on shallow Dekalb soil cut this channel on a 40 percent slope where no channel had existed.

Figure 12.—This ephemeral channel near Route 38 was scoured to bedrock and greatly widened.

Figure 13.—Water had flowed at least 4 feet deep far up the headwaters of Clover Run. Several slipouts of this size or larger occurred per mile along its streambanks.

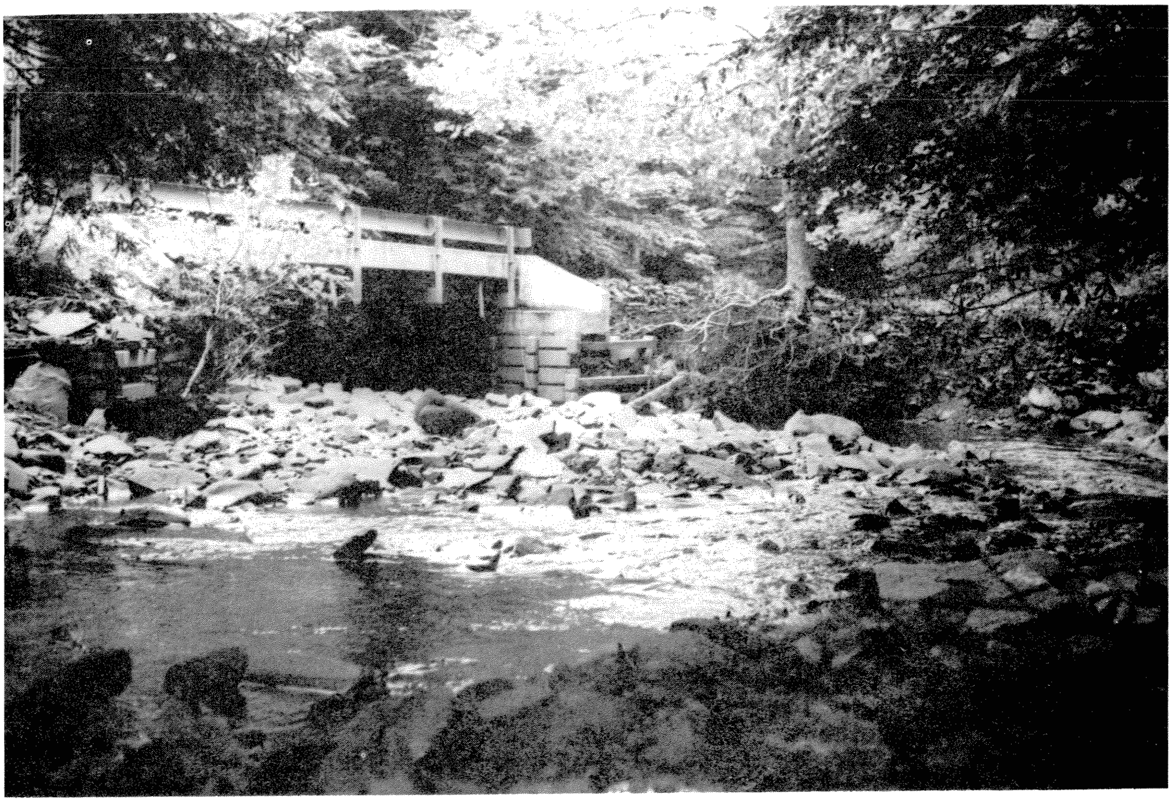


Figure 14.—Stormflow in Mill Run rose to the guardrail on this bridge. The large sycamore tree to the right of the bridge was undermined by bank undercutting. Note the size of rocks carried downstream by the flood waters.

sources was deposited downstream where channels widened and flattened (Fig. 15), or where tributaries joined larger streams (Fig. 16).

Debris at the mouths of Wolf Run (Fig. 15), Jonathan Run (Fig. 16), and an unnamed hollow near St. George (Fig. 2) had been deposited in discrete, easily measured piles. Tonnage of these piles was estimated by multiplying their volume in cubic yards by 1.4, a factor recommended as realistic by a local stone and gravel company.

Based on its modal profile description (Losche and Beverage 1967), Dekalb soil is about one-third rock fragments. I assumed that two-thirds of the nonrock particles eroded from the channels of Wolf and Jonathan Runs had been flushed into the Cheat River. A higher proportion of soil and organic matter remained in the deposit below the unnamed hollow; here I assumed that only half of the nonrock particles had been flushed into Clover Run. These assumptions provided a basis for estimating debris production from these drainages (Table 1).

Table 1.—Estimates of debris production from forested watersheds during the storm of May 24, 1978

Watershed	Area[a]	Eroded Material	Debris per acre of	
			Watershed	Channel
	acres	- - - - - - - - - - *tons*	- - - - - - - - - -	
Wolf Run	1,000	2,766	2.8	56
Jonathan Run	980	2,987	3.1	62
Unnamed hollow	33	318	9.6	192

[a]Planimetered from U.S. Geological Survey quadrangle maps.

Although overland flow had been common around St. George, only organic matter was carried across the forest floor in appreciable amounts. Even the logging roads showed only slight soil losses. Freshet flows had scoured

Figure 15.—Huge amounts of gravel were deposited near Wolf Run's confluence with the Cheat River. Note road pavement swept away.

Figure 16.—Debris from Jonathan Run at its confluence with the Cheat River. The largest object found in this deposit, a concrete block of about 2 cubic feet, indicated the carrying power of the flash-flood waters.

far more rock, soil, and organic matter from the channels of perennial and ephemeral streams.

Expressing debris production as loss per acre of watershed is customary but misleading because acres never erode equally. It seems more realistic to express debris as amount per acre of stream channel. Assuming that 5 percent of each watershed had been subject to freshet flow at the height of the storm, debris production also was expressed as loss per acre of freshet channel (Table 1)

SOIL-WATER RELATIONS ON THE LEETONIA-BRINKERTON SOIL ASSOCIATION

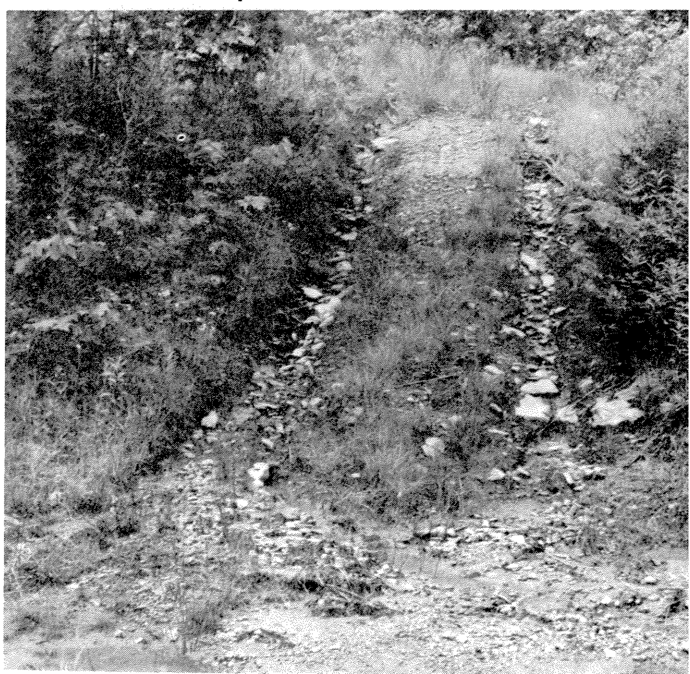
These soil-water relations were observed east of Route 219, near Blackwater Falls State Park. Here, a nearly flat plateau of sandy soil overlies coarse-textured sandstone and conglomerate (Losche and Beverage 1967). Elevation is about 3,500 feet. Young northern hardwoods are mixed with hemlock and red spruce, with few trees exceeding 12 inches in diameter. This area had regrown slowly since it was logged and burned about 60 years ago. Mountain-Laurel, rhododendron, and blueberry form an understory of variable density. Litter was 2 to 3 inches deep.

Evidences of overland flow were less common here than on Dekalb soils, possibly because of sandier soil, flatter slopes, thicker litter, and somewhat less rainfall. Most commonly found were bands or low ridges of litter, mostly spruce and hemlock needles, that marked high water levels parallel to ephemeral as well as perennial channels. The bands were an inch or two wide, about half as high, and a few feet to many feet long. Perhaps 20 or 25 percent of the land surface had been subject to some sort of gentle inundation, seldom having greater erosional effect than the formation of litter bands along the periphery of inundated areas.

Given the flatter topography of this plateau, there was no high-velocity overland flow and associated erosion on the forest floor. Only the stream channels eroded severely, often as severely as channels in the St. George vicinity. Here too, erosion damage to logging roads was minimal (Fig. 17 and 18). Most of these roads had been little used

Figure 17.—Erosion pavement on a logging road with an 8-percent grade near Canyon Rim Road, Blackwater Falls Park. This was the most severely eroded road found and most of the soil loss probably occurred before the storm of May 24.

Figure 18.—Erosion on a logging road with a 15 percent grade near Tub Run. Note accumulation of eroded material at slope change, a common deposition site.



for years; probably an erosion pavement had formed on them long before the storm of May 24. Grazing, too, had little effect on soil-water relations.

TWO SUMMER STORMS ON THE WEIKERT-BERKS SOIL ASSOCIATION

The summer of 1978 was rainier than usual over much of West Virginia (U.S. NOAA 1978). Moreover, several flash floods were reported during the first 2 weeks of August, but they occurred too far from Parsons for detailed poststorm observation. I was fortunate, however, to visit all of the sites once and the Weikert-Berks sites twice, the second time accompanied by John Gorman, West Virginia's Woodland Conservationist for the U.S. Soil Conservation Service.

Baker Run, Hardy County, storm of August 3

An account of this storm is in the August 6 issue of the Moorefield Examiner. An unusually good unofficial record of rainfall was obtained by four amateur observers in the Needmore area, at the headwaters of Baker Run. One of them, Mr. Gordon Combs, collected 4.1 inches of rain between 7:30 and 8:15 p.m., with hard rain stopping at 9 p.m. At least 5 inches of rain fell within 2 hours, at a maximum intensity exceeding 4 inches per hour. Three miles downstream from the Combs residence, Baker Run flowed 15 feet deep and 295 feet across at the height of the storm. This was the only flash flood causing loss of human life.

Our most detailed observations were on the Ewing farm, adjacent to the Combs property. Soils of the Weikert-Berks series (Curry 1978) are 20 to 40 inches deep over shale bedrock. Both woodland and pasture were heavily grazed by cattle and sheep, but neither showed accelerated soil erosion. There was no evidence of erosion on a woodlot clearcut in 1971, even on a logging road with a 25-percent grade. Localized overland flow may have occurred in grazed woodland, where slopes seldom exceeded 40 percent, but there was no accelerated erosion. Leaves, mud, and stones up to 2 inches in diameter formed scattered alluvial deposits in a headwater stream draining the Ewing farm. Channel scour was not nearly as severe in any headwater stream as in Baker Run itself.

About 1 acre of grazed woodland had been remarkably scoured by overland flow (Fig. 19). There, slopes of 35 to 40 percent had been heavily grazed, leaving a complete tree canopy but no understory. If overland flow occurred frequently on grazed land, these downslope belts, swept clear of litter, would be commonplace. They are unique to my long experience in forest hydrology.

North of the Ewing residence, a debris avalanche (Fig. 20) had occurred on a 55-percent slope in grazed woodland. The avalanche scar was about 20 feet wide, 50 feet long, and 2 feet deep to bedrock. The debris slid about 700 feet to the base of a 40- to 45-percent slope. It must have flowed as a semiliquid mass because grass and small trees were bent over but not uprooted by its passage. Five smaller (200 to 300 square feet) landslips were found close to the base of a 40-percent grassy slope nearby.

Johnson's Run, Grant County, storm of August 5

An account of this storm is carried in the August 9 issue of the Grant County Press. East of Johnson's Run, Mr. Raymond Armentrout (NOAA observer) measured 2.80 inches of rain falling between 3:30 and 4:30 p.m. Mr. J. A. Graham, a farmer west of Johnson's Run, measured 3.6 inches in a glass gage. The superintendent of the Petersburg trout hatchery confirmed the storm timing but had no rainfall measurement.

Johnson's Run gives a first impression of severe channel scour (Fig. 21). Debris strewn about the channel area is nearly all sandstone but this watershed is underlain with calcareous shale. Most of the debris came from Buchanan soil, a sandstone-derived series to the east that overlies the shale. The road east of Johnson's Run cuts into this sandstone and had been rebuilt several times, most recently since the storm of August 5 (Fig. 22). Several large gullies on 30 to 40 percent slopes have

Figure 19.—Overland flow paths on grazed woodland. The largest path is 3 to 4 feet wide, litter ridges on each side about 1 foot high. The H layer was not disrupted and mineral soil was not exposed.

Figure 20.—About 70 cubic yards of soil and rock were dislodged from this debris avalanche scar.

Figure 21.—The main channel of Johnson's Run, downstream from the outlets of gullies caused by road drainage.

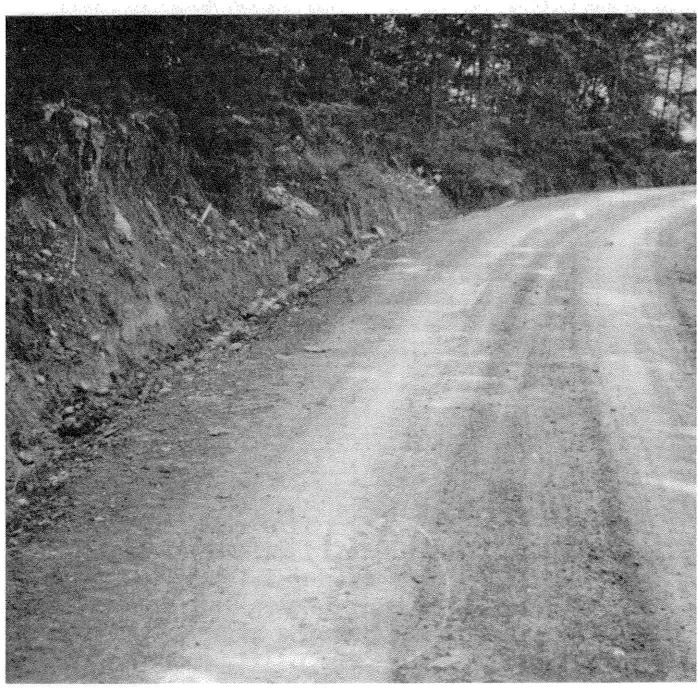


Figure 22.—These road banks are 8 feet high, the ditches 2 feet deep, the traveled road surface 24 feet wide. The roadbed is on sandstone bedrock at a grade of 9 percent. The road was completely washed out by the flash flood.

carried road debris into Johnson's Run for years (Fig. 23). Surely, this road and its associated gullies are the sources of sandstone debris strewn about the stream channel. The streambed of Johnson's Run had scoured to its shale bedrock but there had been only minor loss of soil and organic matter from its tributary channels.

Cattle have grazed for years on the forested Weikert-Berks soil of this watershed. In 1972, a 50- to 60-percent slope was clearcut and it too, has been grazed since. There were no signs of accelerated erosion on the clearcut or on skid roads ascending its steepest slopes. Nor was there accelerated erosion on steep (up to 70 percent) pastured woodland adjacent to the channel of Johnson's Run. Overland flow had occurred on not more than 5 percent of the forest floor.

Figure 23.—Tons of debris from the road shown in Figure 22 poured down this 35-percent pastured slope. Johnson Run is about 200 yards downslope from the fence.

OTHER FLASH-FLOOD SITES VISITED

At least six other flash floods were reported in West Virginia during those first 2 weeks of August. I visited five of the sites (Table 2). Some notes on conversations with residents, a few photographs, and some hasty field observations constitute my meager record. Nevertheless, findings there conform closely to those reported for the Weikert-Berks complex.

1. There was no evidence that rainfall intensities ever exceeded infiltration capacity of the forest floor. In other words, overland flow played an insignificant role in whatever soil erosion occurred.
2. Harvest of wood products and grazing had no visible effect on soil erosion.
3. Flash floods did not materially accelerate soil erosion on logging roads.
4. Scouring in headwater (first order) channels removed little more than organic matter and some soil.
5. For a given flash-flooded watershed, scouring and overflow were severe only in the channels of larger (second- and third-order) streams.

Flash-flooding had similar effects in May and August with respect to infiltration, woodland grazing, and logging roads. Channel overflow and scour in large, perennial streams were similar, too (Fig. 24). Only in the tiny, ephemerally flowing, first-order channels was there contrasting behavior. Most of these had carried damaging freshet flows in May and were deeply eroded; in August, flows and erosion were negligible in all of them (Fig. 25).

Table 2.—Location and characteristics of August 1978 flash floods in West Virginia

Storm site	County	Date	Storm characteristics		
			Rainfall	Duration	Intensity
			inches	*hours*	*in/hr*
Watershed of Dumplin' Run	Grant	8/6	5.00	2.5	2.0
Village of Mathias	Hardy	8/6	3.78	6.5	0.6
Watershed of Hizer Creek	Putnam	8/10	3.50	2.0	1.8
Town of Moorefield	Hardy	8/11	2.65	2.0	1.3
Watershed of Sugar Creek	Kanawha	8/11	3.50	1.0	3.5

Figure 24.—This 4-foot culvert had provided access to a small farm on the right. Dumplin' Run washed away the newly repaired gravel road on the left.

Figure 25.—This tributary of Dumplin' Run has a channel gradient of 25 percent. Litter was flushed out but there had been no heavier scour. There was no evidence of overland flow on the 70-percent channel banks.

ARE THESE SOIL-WATER RELATIONS TYPICAL?

The storms that caused these flash floods are atypical. Rainfall intensity data for the Middle Atlantic Region (U.S. Department of Commerce 1958) show that storms ranging from 2.3 to 3.4 inches in 1 hour, and storms ranging from 3.8 to 5.4 inches in 6 hours, are likely to occur only once per century in this part of West Virginia. All of the flash-flood sites were subject to storms of these or greater intensities. Even at these phenomenal intensities, most of the rain infiltrated as fast as it fell. Surely, no less infiltration can be expected during lesser storms. To this extent, soil-water relations were typical.

Dekalb-Calvin, Leetonia-Brinkerton, and Weikert-Berks soil complexes are widespread in northeastern West Virginia, and they are taxonomically similar in many respects. All range from 20 to 40 inches to bedrock. Coarse fragment content is high in subsoil; from 15 to 75 percent in B horizons, from 60 to 90 percent in C horizons. This stoniness causes high soil densities, ranging from 1.5 to 1.9. Dekalb has about 50 percent greater waterholding capacity than other soils, the only difference of obvious hydrologic significance in their profile descriptions.

Had rains been even heavier, I suspect that channels in the V-notch basins would have eroded even more severely. The erosion mechanisms (overland flow and channel scour) would be unchanged from the storm of May 24, but greater volumes of overland and channel flow would greatly increase losses of soil and rock. Short ridge-to-channel distances provide highly efficient drainage across and within soils on such rough topography.

Forest soil-water relations during flash flooding probably differ little on any of these soils when the surface configurations of the soil and bedrock are similar. But similar configurations are rarely found, even on a given slope. They came closest to being similar on the gently concave basin. There, with minor exceptions, erosion was minimal because water was contained in and drained rapidly through a relatively deep soil on a relatively uniform slope. Far more complex soil-water relations prevailed in the V-shaped basin. There, in effect, the deeply incised channel greatly shortened slope lengths. Poststorm evidence suggested exfiltration all along its channel margins. Rain falling on exfiltrated water was transformed instantly to overland flow; in effect, causing channel interception on an enormously lengthened and widened channel. So much water flowing so rapidly eroded the V-notch severely. Water yield per acre probably was identical from the V-shaped and gently concave basins but, from the erosion standpoint, the timing of the flows was more critical than their total amount.

More rain falling on the gently concave basin would have thickened the strata of saturated soil, forcing water to exfiltrate farther upslope. The resulting overland flow might have eroded the soil, but landsliding would have been a more serious threat. Thickened strata of saturation would have increased soil-pore water pressure, increased soil buoyancy, and decreased soil shear strength (Swanston 1969). These are effects of complete infiltration during heavy rain that unavoidably lead to debris avalanching, a condition only verged upon in the 1978 flash floods. Landsliding was severe during a 12-inch storm at Petersburg, West Virginia (Allard 1951) and disastrous in a 28-inch storm in nearby Nelson County, Virginia (Woodruff 1971). Thus, nearly unlimited infiltration coupled with efficient internal drainage minimizes erosion by overland flow but poses the greater erosion threat of debris avalanching on smooth topography.

Erosion thus related to topography has been observed on shallow forest soils in southeast Alaska (Bishop and Stevens 1964). There too, the channels of V-shaped basins were severely eroded but relatively smooth slopes were more prone to debris avalanching.

Given similar capability of all soils to infiltrate and drain phenomenal rains, why were overland flow and soil erosion so much greater in May? At that season, Dekalb and Leetonia soils probably were near capacity in water content. There are only clues as to how much less water the other forest soils may have contained in August. Our best clues are from the Fernow Experimental Forest, near Parsons, where abundant data are available concerning the soil-water relations of Calvin silt loam. It is wettest in springtime, containing as much as 15 inches of water in the upper 4 feet of soil. Transpiration by trees is most rapid in June and July, lowering midsummer moisture content to about 10 inches of water (Patric 1973). Thus, Calvin soil has retention capacity for about 5 more inches of rain in midsummer than in early spring. Presumably, the Weikert-Berks series, too, had greater rain-retention capability in August. The drier the soil at the onset of a storm, the more rain is needed to start the sequence of saturation, exfiltration, overland flow, and soil erosion.

These results are important because the soils, vegetation, topography, and land use on the flash flooded sites typify much forested land not only in West Virginia but in most of the central Appalachian region. But atypical indeed are the rates of debris production caused by these storms. Their atypicality is important in itself, partly because it implies rare occurrence, but mostly because it defines a ceiling—an amount highly unlikely to be exceeded during ordinary weather. A floor, 0.05 to 0.10 ton per acre per year (Patric 1976), is generally accepted as the usual erosion rate of forest land in the Eastern United States. Hewlett (1979), too, estimates about 0.05 ton of soil loss per acre per year between cutting cycles on the more erodible soils of the Georgia piedmont, about 1 to 2 tons during and immediately after clearcutting and pine planting. Hewlett's data, falling well within the preceding floor and ceiling values, suggest that these lower and upper limits of soil loss may hold for forest land even beyond the Appalachian region.

The U.S. Soil Conservation Service (1979) estimates a national soil-loss rate averaging 4.8 tons per acre per year from cropland, and 10.6 tons for the Appalachian states. Whether my estimates of debris production and their estimates of soil loss are comparable is unclear. It is clear, however, for the central Appalachian region, that only rare phenomenal rates of debris production from forest land even approach the average rates of soil loss said to occur annually on cropland. These contrasting rates alone provide a useful perspective for evaluating the relative significance of erosion from farm and forest as a conservation problem.

The limited infiltration cited by Wadleigh (1966) unquestionably determines runoff and soil erosion from such relatively impervious land surfaces as highways, cities, and fields. People familiar with such land surfaces but unfamiliar with forest soil-water relations erroneously attribute overland flow and soil erosion in forests to limited infiltration capability.

From these observations, I conclude that the soil-water relations described here are implicit in the original description of the variable source area. (Southeastern Forest Experiment Station 1961). More fully described and modeled by Hewlett and Troendle (1975), the concept embodies current understanding of soil-water relations on forest land. The key is complete infiltration. Under prolonged rainfall, zones of exfiltration expand upslope, in effect lengthening and widening stream channels. When rain stops, exfiltration diminishes and channels shrink to prestorm dimensions. Overland flow and piping contribute to the drainage process, but only as the soil saturation that is prerequisite to their functioning develops. Differences in stormflow and erosion occurred not because the behavior of water in the soils differed, but because infiltrated water performed the same way in forest-soil-bedrock complexes of differing configuration and antecedent wetness.

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