

DEBRIS SLIDES AND RELATED FLOOD DAMAGE RESULTING FROM
HURRICANE CAMILLE, 19-20 AUGUST, AND SUBSEQUENT
STORM, 5-6 SEPTEMBER 1969 IN THE SPRING CREEK
DRAINAGE BASIN, GREENBRIER COUNTY,

WEST VIRGINIA

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ABSTRACT

Two storms, the first associated with Hurricane Camille on 19-20 August, the second on 5-6 September 1969, which struck the Spring Creek Drainage Basin of Greenbrier County, West Virginia resulted in 1,534 observed debris slides, the loss of two lives, and extensive property damage.

The debris slide movement is thought to have been initiated by sliding at the head of the scar, with the mass of moving rock, soil, forest debris and water developing into a debris flow as it progressed downslope. The major volume of material was carried entirely out of the area as the debris emptied into the stream channels.

Slide dimensions vary from tens of square feet (1 sq. m) of material removed at the slide scar head to approximately 65,000 square feet (19,820 sq. m). Volume of material removed by an individual slide ranges from less than 10 cubic feet (0.3 cu. m) to approximately 860,500 cubic feet (24,366 cu. m).

Slide scar heads range in elevation from 2,150 feet (655.3 m) to 3,960 feet (1,207 m). They lie at elevations where the amount of precipitation is greatly influenced by orographic lifting. The mean slope on which slides occurred is 34.97 degrees, with a minimum slope of 18.89 degrees on clear land and 16.67 degrees in timberland. The influence of land use is apparent in the frequency of slide

occurrence and also in the thickness of soil removed by individual slides.

Intense summer rainstorms are the major cause of debris slides in the Appalachian Highlands south of the glacial border. Complex cultural and physical factors interact to affect an individual slide location.

Precipitation is a critical localizing factor, as well as the rate of water infiltration which may increase soil pore pressure very rapidly during intense storms, such that soil and regolith fail by sudden reduction in their shearing strength.

Careful field investigation was the method of obtaining detailed data on each slide. All slides were plotted on a large map of the entire area. Two tributary valleys were surveyed and mapped in detail. Evaluation of several types of imagery indicated the Ektachrome Infrared Aero film to be the most useful. The timing of the photographic mission with respect to the recency of slope failure, vegetational foliage, and the altitude at which it is flown are important.

Accumulation of meteorological data for longer time intervals will be of significant value to improve recurrence intervals projections. It is doubtful whether meaningful improvement as to the cause of individual slides can be expected until continuous monitoring of possible debris slides sites and model studies are better established.

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CHAPTER 1

INTRODUCTION

I. STATEMENT OF THE PROBLEM

The remnants of Hurricane Camille moved across extreme southern West Virginia late on the evening of 19 August 1969. In the general area of the southern counties of that state (Nicholas, Greenbrier, and Summers) it produced three to five inches (7.6 to 12.7 cm) of rain. The areas hardest hit had flash flooding along the Greenbrier, Gauley, Meadow, and Cherry Rivers and their tributaries. The Greenbrier River at Alderson, W. Va., crested at 17.1 feet (5.2 m) early on the 20th; 3.1 feet (0.9 m) above flood stage. High water from Spring Creek, a small tributary entering the Greenbrier near Renick, W. Va., resulted in the deaths of two elderly women, and extensive flood and debris slide damage to the area. The National Oceanic and Atmospheric Administration (NOAA) precipitation recording station at Renick, W. Va. recorded 3.95 inches (10 cm) of rain in the period 19 August 1800 hours to 20 August at 0800 hours (DeAngelis and Nelson, 1969). Local unofficial rainfall measurements in the most heavily damaged part of the Spring Creek drainage basin indicate greater amount of rain fell in the study area which is 1,500 to 2,000 feet (457.2 to 609.6 m) higher in elevation, and approximately six air miles (9.7 km) north of Renick.

A partial rebuilding and cleanup had been accomplished after the storm of 19 August when the local area received a second intense rainstorm on the night of 5-6 September 1969, which produced higher flash flood water levels in the streams and greater localized intensity of precipitation than the earlier storm. The NOAA station at Renick, W. Va. reported 2.10 inches (5.3 cm), the station at Jacox Knob, on the eastern boundary of the area reported 2.91 inches (7.4 cm) for the period. An unofficial report of 15 inches (38.1 cm) of rain at Cold Knob, on the western edge of the area, in a three-hour period, appears in reports made to NOAA.

The debris slides which are the major consideration of this study, most frequently occurred toward the end of periods of heavy precipitation, as indicated by observations of local residents. Unlike many mountainous regions of the southeastern United States, this area exhibits very few scars of old debris slides. Conversations with local residents would indicate no extensive debris slide occurrence in the 75 years prior to 1969.

This investigation concentrates on the occurrence of debris slides in the Spring Creek drainage basin as a result of the intense rainstorms of 19-20 August and 5-6 September 1969, and shows the relationship of geology and land use to the extent of rapid mass movement. The study compares the usefulness of USDA aerial photographys and various kinds of airborne remote sensing imagery in

locating and identifying these landscape modifications. The emphasis of this research is to measure the volume of soil and rock material removed by debris slides, and strives to define the causes of rapid mass movement.

Benefits that can be derived from the study of debris slides are both practical and academic. To the geomorphologist it enhances the knowledge of slope processes and the rates at which they shape the topography of an area. To the person responsible for decisions in land use the information gathered here adds to the information on the processes that operate on steep terrain which is subjected to periods of intense rainfall.

II. DATA COLLECTION AND ANALYSIS

Data were collected by detailed field investigation, use of airborne imagery, and interviews with residents of the area.

Field Research Data

The site was selected for three reasons: first, the recent occurrence of the storms would permit detailed observations and accurate identification of the various types of rapid mass movement before they became modified by the passage of time. Second, the availability of ASCS photography which was flown within a month after the storms, would provide documentation of the location and extent of damage. Third, despite the limited number of official

precipitation data collecting locations within the research area, good accounts and some unofficial precipitation data would be available from the residents of the area.

The field data were collected using ASCS aerial photos to aid in locating debris slides. The location of each slide was plotted on a mylar overlay used with the stereo-photo pairs. The measurements and observations for each slide were recorded in a field note book. In addition to the data collected for the entire study area, two tributaries of Spring Creek were selected to be used for producing detailed maps at a scale of one inch to 50 feet (2.54 cm to 15.3 m). These two valleys are representative of many tributaries that suffered extensive debris slide damage and channelway modification. The two valleys were surveyed with a Wild RDS self-reducing tachometer and Philadelphia rod, and sketched planimetrically (Plate III). Longitudinal profiles (Plate IV) were computed from the surveying notes and drawn to a scale of one inch to 50 feet (2.54 cm to 15.3 m). Profiles were constructed with no vertical exaggeration to portray true slope conditions.

Geological mapping involved primarily the Bluefield Formation, of Mississippian age, in these two valleys. Areas where bedrock was newly exposed are shown on the map along with other formational contacts and strike and dip information. Areas of alluvial and colluvial deposits are also shown.

The study site is located in an area that is grazed by livestock and has been cut over for timber. For this reason land use is a parameter that was studied to see how it was related to slope flood damage. Vegetational associations at the site of each slide were noted, along with land use in the area around the slide. The boundaries of clear and timber areas are shown on Plates II and III.

Trees and logs with diameter, greater than six inches (15.2 cm) and length, greater than six feet six inches (2m), which had been dislodged by the debris slides were plotted individually on the planimetric maps. Revegetation in slide and stream flood channels was just starting in the summer of 1971. Observations were recorded on the types of plants initiating the revegetation.

Soil profiles were observed and a record was made of the thickness of each horizon and its subdivisions. Soil drainage, percent of slope, and slope aspect were also recorded. Soil samples for x-ray analysis were collected from five of the debris slide sites. The samples were analyzed to determine the most common clay minerals present. The research area contains some active farms but few of them grow cultivated row crops. The major part of the farm land is used to produce hay and for grazing cattle and sheep. However the greatest part of the study area is in timber, which is also grazed by livestock, and was cut over 30 to 40 years ago and is now being selectively cut.

Airborne Imagery

The major purpose of obtaining airborne imagery of this area was to compare its effectiveness to that based on observations made on the ground.

The University of Tennessee DC-3 research aircraft and the Hasselblad 500 EL quadricamera system were used to obtain simultaneous coverage utilizing four different emulsion/filter combinations. In addition to photographic imagery, thermal imagery was obtained on the same flight.

In the final evaluation, field research data collected by visiting the site of each debris slide on the ground were compared to the results obtained with the airborne imagery.

Historical Records

The present slope damage could not be compared directly with prior damage in the same area because no records of such damage exist. Conversations with long term residents of the study area indicate that only localized flooding had occurred prior to 1969. Field evidence confirms these observations as only 13 recognizable debris slide scars were found which pre-date the 1969 occurrence. It is difficult to determine when these older slides occurred. Earlier ASCS photo coverage taken in 1940 and 1957 is available, but shows no slides. Observations of vegetation growing on the old slide materials or in the slide scar is the most readily available method by which to determine the

approximate time of occurrence, however, based on field observations of the 1969 slides the author considers this method unreliable for the following reason. Many of the larger slides have shrubs and trees up to six inches (15.3 cm) in diameter that have survived for two years after being displaced by slide movement. A smaller number of large slides could possibly sustain even larger trees with little apparent damage. It would be necessary to use some alternate method in order to attempt to establish when these older slides occurred. Climatological records for this area are not detailed enough to be of any value.

CHAPTER II

THE STUDY AREA

I. LOCATION

The study area lies near the junction of two physiographic provinces. According to Price and Heck (1939) the southern part of the Spring Creek drainage basin is in the Valley and Ridge Province and the northern and western portions are in the Appalachian Plateau Province. This arrangement results from the boundary shift (Price and Heck, 1939) between these two provinces to 10 miles (16 km) further west than originally outlined by Fenneman (1930). The reasons cited (Price and Heck, 1939) for the change are: the presence of the Williamsburg anticline, the erosion scarp, the change from trellis to dendritic drainage pattern, and the change from mountains having a general northeast trend to those with no regional trend. Gorman and others, (1972) considered the area east of the Greenbrier River to be in the Ridge and Valley Province and the part west of the river in the Eastern Allegheny Plateau and Mountains. As shown on Plate I, the province boundaries are those of Fenneman (1930). Insert map, Plate II, indicates the part of the Lobelia Quadrangle on the outline map of West Virginia.

II. RELIEF AND DRAINAGE

The Valley and Ridge Province (Price and Heck, 1939) part of the Spring Creek drainage basin generally consists of a series of parallel valleys developed on non-resistant strata. In Greenbrier County the folds are not as well developed as in the Ridge and Valley Province in other areas. The Greenbrier River Valley is the largest valley in the area. In general it parallels the strike of the rocks, but has entrenched itself, with many tortuous meanders, through and over rocks that can be called resistant to erosion. The drainage pattern in this area is a well developed trellis or rectangular type.

The headwaters portion of the drainage basin lies in the eastern edge of the Allegheny Plateau and presents a different drainage pattern as well as different landforms. The streams have been only slightly controlled by the structure of the rocks as evidenced by the development of a dendritic drainage pattern. Here the mountains attain their highest elevation (over 4,000 feet, 1,219.2 m) and their forms are the result of dissection by streams that have cut deep V-shaped gorges into the elevated plateau. Slopes in this type of topography generally have extreme steepness, commonly measuring 45 percent (24.32 Degrees) and more. The general slope of the ridge tops and mountain summits is to the northwest with the regional dip in the same direction.

The highest elevations are at the edges of the research area, at the drainage divides. On the western edge of the area is Cold Knob at an elevation of 4,345 feet (1,324.4 m), and Grassy Knob at an elevation of 4,372 feet (1,332.6 m), Briery Knob on the north at an elevation of 4,518 feet (1,377.1 m), Jacox Knob on the east at an elevation of 4,046 feet (1,233.2 m), with elevations to the south approximately 2,000 feet (609.6 m) lower. At the village of Spring Creek where Spring Creek empties into the Greenbrier River the elevation is approximately 1,855 feet (548.6 m).

While working within the constraints of the limited materials available to illustrate the topography and drainage of a small area, the author has chosen to use a description and the general map (Figure 1), taken from Hammond (1964). According to his Classes of Land-Surface Form, the western portion of Greenbrier County has 20 to 50 percent of the area gently sloping, and is classed as open hills and mountains. This is somewhat less stream dissected than the eastern two-thirds of the county which lies near the edge of the Eastern Allegheny Plateau. Local relief is 1,000 to 3,000 feet (304.8 m to 914.4 m) and more than 75 percent of the gentle slope is on upland. The eastern two-thirds of Greenbrier County and the southeastern portion of Pocahontas County have less than 20 percent of the area gently sloping, local relief is 1,000 to 3,000 feet (304.8 m to 914.4 m), and is much more intensely dissected

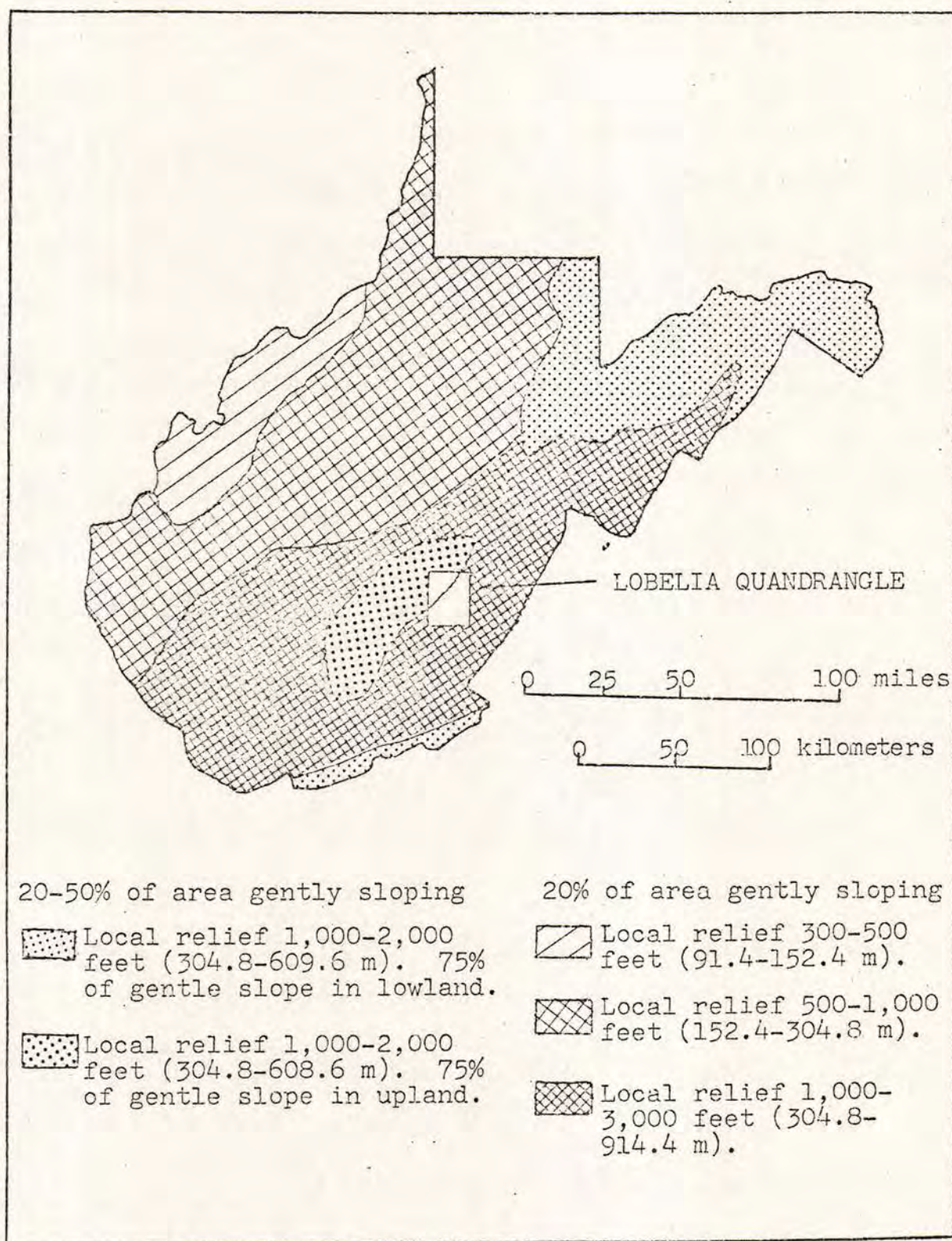


Figure 1. Land-Surface Form of West Virginia.

Source: Edwin H. Hammond, 1964.

by streams. Hammond (1964) classed this portion as hills and mountains.

The Spring Creek drainage basin is well dissected by streams with a pattern that is predominantly dendritic. The stream density is moderately high, due in part to the amount of precipitation (50 to 60 inches, 127 cm to 152.4 cm, annually), and the underlying geologic formations of the Mauch Chunk Group which have very low permeability. The general flow direction is southeast, down the slope of the Eastern Allegheny Plateau. Spring Creek is a fifth order stream when considered by the method of Horton (1945) in which larger streams are given consequently higher numbers based on the nature of their tributaries. The gradient of the first order (or headwater) tributaries, along which the greatest numbers of slides occurred is slightly greater than 1,000 feet (304.8 m) per mile. In the downstream portion, Spring Creek has eroded through the lower most unit of the Mauch Chunk Group, the Bluefield Formation, into the Greenbrier Group of predominantly limestones. At times of low water flows, the drainage is subterranean in this segment of the stream.

III. GEOLOGY

Early geological studies started in Greenbrier County in the very early 1900's. Several economic geology reports were published from 1903 to 1909, with additional work published after that (Price and Heck, 1939, pp. 128-129).

Bedrock Geology

The stratigraphic units that crop out in Greenbrier and Pocahontas Counties (Table I) range in age from Late Ordovician to Early Pennsylvanian (West Virginia Geological and Economic Survey, Geologic Map of West Virginia, 1968). The following formations listed in ascending order with lithologic descriptions including rock physical property terms, from Price and Heck (1939) and Cardwell and others (1968) are given below.

The Upper Union Limestone consists of approximately 100 feet (30.5 m) of gray colored, limestone which is usually colitic. It is somewhat shaly at the top and weathers to a white color. It forms steep bluffs along the downstream portion of Spring Creek and therefore comprises a very small area of the exposed bedrock in the drainage basin. Two slides were found on this unit.

The Greenville Shale is approximately 100 feet (30.5 m) thick, consists of brown to dark green, fissile, calcareous shale with marine fossils and is poorly exposed with only one slide found to occur on it.

The Alderson Limestone is 100 feet (30.5 m) thick and is dark-gray colored and includes an abundance of marine fossils. Thirty-two slides occurred on this formation.

TABLE I

STRATIGRAPHIC UNITS OF GREENBRIER AND POCAHONTAS COUNTY

PENN.	POTTSVILLE GROUP	Kanawha Formation
		New River Formation
		Pocahontas Formation
MISSISSIPPIAN	MAUCH CHUNK GROUP	Bluestone Formation
		Princeton Formation
		Avis Limestone
		Hinton Formation
		Bluefield Formation
	GREENBRIER GROUP	Alderson Limestone
		Greenville Shale
		Upper Union Limestone
		Lower Union Limestone
		Pickaway Limestone
		Taggard Formation
		Patton Limestone
		Sinks Grove Limestone
		Hillsdale Limestone
		Denmar Formation
		Maccrady Formation
		Price-Pocono Formation
DEVONIAN	UPPER	Chemung Formation
		Brallier Formation
		Harrell Shale
	MIDDLE	Mahantango Formation
		Marcellus Formation
	LOWER	Huntersville Chert
		Rocky Gap Sandstone

TABLE I (Continued)

SILURIAN		Helderberg Group
	UPPER	Tonoloway and Wills Creek Formations
		Williamsport Sandstone
		McKenzie Formation
	MIDDLE	Keefer Sandstone
		Rose Hill Formation
	LOWER	Tuscarora-Clinch Sandstone

ORDOVICIAN	UPPER	Juniata Formation

Source: 1968 Geologic Map of West Virginia, West Virginia Geological and Economic Survey.

The Bluefield Formation is approximately 1,400 feet (426.7 m) thick, consisting of red and green shales and sandstone with a few thin limestone lenses such as the Reynolds. It underlies the major area of steep slopes throughout the entire drainage basin. Large numbers of slides originate near the top of the exposed Bluefield, apparently due in part to excess runoff from land surfaces above. This concentration of slides is reduced where Hinton blocks armor this part of the slope. A total of 1,283 slides were found associated with the Bluefield Formation.

The Hinton Formation is approximately 900 feet (274.3 m) thick. It consists of red, green, and medium-gray shale and sandstone, with a few thin limestone units. The total number of slides on this unit is 106.

The Avis Limestone is poorly exposed. It is gray in color, produces a yellowish weathering stain, and contains fossils. Forty slides were found on this unit, which is approximately 50 feet (15.2 m) thick.

The Princeton Formation is the upper most unit on which slides occurred. The lithology is predominantly a sandstone, with some coarser pebbles, cemented and colored by limonite and some plant fossil material. Twenty-two slides occurred on this 40 foot (12.2 m) thick formation.

The Bluestone Formation is 500 feet (152.4 m) thick. The lithology is mostly red, green, and medium-gray shale

and sandstone. This formation represents the upper limit of the Mississippian Mauch Chunk Group, with gentle slopes appearing as benches in many parts of the valley. No slides occurred on these gentle slopes but they appear to have contributed heavy runoff to the steeper slopes below during the intense rainstorms in 1969.

The Pottsville Group of Pennsylvanian age caps the highest elevations in the area. Only the Pocahontas and New River Formations remain in Greenbrier County. The Kanawha Formation is present as the upper most unit in Pocahontas County. There were no slides on these formations, probably because they underlie ridge crests in the area, and have very gentle slopes. They are predominantly sandstones with interbeds of coal and shale. Their involvement appears to be that of a surface on which rainstorm runoff collected to add to the heavy slope flow. Most of the flow from these elevations was concentrated in natural depressions when it reached the steep slopes of the Bluefield Formation, where most of the slides occurred.

Surficial Geology

The mantle of surficial material on the sloping topography ranges from a fraction of an inch (a few cm) on the shale barrens to approximately three feet (91.4 cm) on somewhat more gentle slopes. The general thickness of soil is from one and a half feet to two and a half feet (45.7 cm to 76.2 cm). Where the mantle of material is colluvium the

thickness increases. The thickest observable surficial materials are found in alluvial fans that have been dissected by the present stream systems. They commonly occur at the junction of smaller tributary streams and the streams that occupy the major valleys. The thickness of individual fans varies up to 30 feet (9.1 m). The valley floors of these larger streams also have a cover of alluvial material which ranges from zero to 20 feet thick (6.1 m).

From the many field observations of soil profiles it is evident that soils on the steeper slope pastures are being lost as fast as they are generated. Only the "A" and "C" horizons are present. In forested areas that have not been disturbed the profiles are generally thicker, the upper horizons are thicker and better developed, and they contain much more organic matter.

The colluvial deposits contain a great variety of particle sizes along with the soil. Boulders range to five feet (1.5 m) in diameter while the blocks which are most common in the colluvium were found as large (a axis) as 20 feet (6.1 m) long with a width and thickness of ten feet (2.0 m). Large boulders are common in both the colluvium and alluvial deposits. In some of these colluvial deposits, large boulders are lodged against large trees growing on the deposits. The presence of boulders and blocks in the topographic sites where channelized flow cannot occur indicates the role other processes play in moving materials down these slopes.

IV. CLIMATE

The diversity of climatic conditions in West Virginia can be understood best with some background knowledge of the topography (Figure 1, p. 11). With the exclusion of the northeastern panhandle, the state can be considered to lie in the Allegheny Plateau. It is appropriate to treat this main part of the state in two parts because the Appalachian Mountains are the most pronounced feature of the eastern third of the plateau and contain the highest land in the state. Elevation of the higher peaks in this area range from approximately 2,500 to 4,820 feet (762 m to 1,481.9 m) at Spruce Knob, the highest point in West Virginia. These topographic features and the deep narrow valleys of the stream-dissected plateau, considerably modify the effects of the major climatic controls. For climatic purposes the state can be divided into six parts (Horn and McGuire, 1960). Greenbrier County is in one of these six areas called the Central division. The yearly amounts of precipitation are the greatest in the Central division, ranging from 50 to 60 inches (127 cm to 152.4 cm). Rain and snow producing atmospheric currents generally move across the area on an eastward course. As they approach the mountains, these air currents are subject to orographic lifting, which acts to "trigger" potential precipitation or intensify the rain or snow that may already be falling.

The state has a moderately severe winter climate, accentuated and prolonged in the mountains, with frequent alternations of fair and stormy weather. Summer is marked by hot and showery weather, however the heat is less pronounced in the mountains. The mountains are also more subject to thunderstorms and have fewer clear days the year-round. Marked variations occur in temperatures, precipitations, and the other weather elements, due to the rugged topography, not only between the mountains and plateau but even between different parts of the same county. For example, appreciable differences exist between the bottoms and upper slopes of the numerous valleys that entrench the Allegheny Plateau.

Warm-season thunderstorms, mostly those of June and July, often yield intense local rainfall and cause flash flooding in the narrow valleys that cut through the plateau and mountain districts. Greatest precipitation amounts recorded in 24 hours or less at officially recognized precipitation measuring stations have exceeded five inches (12.7 cm) in all six climatological divisions. Precipitation records up to 1960 illustrate some localized severe rainfall records that have been accepted by the criteria of Horn and McGuire, 1960). An outstanding example of intense local rainfall due to thunderstorm activity was 19 inches (48.3 cm) in 2 hours and 10 minutes at Rockport in Wood County on 18 July 1889. Thirty-one fatalities and damage exceeding 10 million dollars resulted

from flash flooding caused by heavy thunderstorm rainfall (amounts up to 14 inches, 35.6 cm) on the night of 24-25 June 1950, in parts of Doddridge, Gilmer, Harrison, Lewis, Pleasants, Ritchie, Tyler, and Upshur Counties. The Petersburg-Moorefield area was hit by flash floods on the night of 17-18 June 1949, when up to 12 inches (30.5 cm) of rain fell in 24 hours. No such records appear for Greenbrier County prior to 1960. Climatological records for the past 25 years show that this kind of severe local flooding caused by thunderstorms occurs in some part of the state every year.

The study area in Greenbrier County lies on the eastern edge of the Allegheny Plateau. The climate is considered humid-continental, and is characterized by strong seasonal temperature changes. In the southern and eastern parts of the county, the average annual air temperature is 50°F (10°C), the annual precipitation is about 39 inches (99.1 cm), and the rainfall during the growing season is about 18 inches (45.7 cm). Long term temperature extremes at Lewisburg in Greenbrier County, range from near or over 100°F to -37°F (37.8°C to -38.3°C). In the high and mountainous parts of the county, the precipitation ranges from 50 to 60 inches (127 cm to 152.4 cm) and the rainfall during the growing season is nearly 25 inches (63.3 cm) (Gorman, and others, 1972). The northwestern part of Greenbrier County has some of the highest elevations in the state. These high elevations surround the Spring Creek

drainage basin on the west, north, and east, as described earlier in the section on relief and drainage (Figure 1, p. 11) and Plate II). These high elevations have considerable effect on the climate and especially local summer rainstorm activity. These marked variations in mesoclimate between valley bottoms and ridgetops must be considered when applying standard weather data to the climate of the area.

Thunderstorms occur on 40 to 50 days in an average year, more frequently at higher elevations, especially in June and July. The remnants of hurricanes over land areas sometimes cause extensive damage when large moisture laden air masses are involved. More frequently there are flash floods caused by wide spread heavy rain or severe thunderstorms. Light winds prevail in the lulls between storms, which are most frequent in late summer and fall, especially in the valleys (Weedfall, 1972).

V. SOILS

The Soil Survey of Greenbrier County, West Virginia (Gorman, and others, 1972) was issued in April 1972. The major field work for this report was completed by soil scientists in 1965. As classified by the report the major part of the soils in the central part of the research area are placed in the Teas Series. Soils in the headwaters area of Spring Creek, near the western boundary of the area belong to the Dekalb Series. Soils in the northeastern portion of the drainage basin, in Pocahontas County are

listed as: Upshur silt loam, rough stony land, Upshur stony silt loam, and Leetonia stony loam (Williams and Fridley, 1938).

The Teas Series is described as:

. . .moderately deep, well-drained, gently sloping to very steep, reddish-brown soils. These soils occur extensively on the dissected uplands in the western part of the county. They formed in residuum weathered from reddish shale and siltstone, some of which is weakly calcareous. In most places slope is more than 15 percent, but it ranges from 3 to 65 percent.

In a typical profile in a wooded area, a thin mat of dark-colored organic matter covers the surface. The surface layer, below this mat, is mainly reddish-brown, friable light silty clay loam. The lower part is reddish-brown, friable, very channery silty clay loam that has a high proportion of siltstone fragments. Reddish siltstone bedrock begins at a depth of 22 inches.

Permeability is moderate, and the available moisture capacity and natural fertility are low to moderate.

In many areas these soils are used for pasture and general crops. The steeper areas are used for pasture and woodland. The erosion hazard is moderately severe, and severe erosion is fairly widespread. The use of these soils for cropland is limited by slope, shallowness, and erodibility.

The Dekalb Series is described as:

. . .moderately deep, gently sloping to very steep, well-drained soils that contain many small rock fragments. These soils are widely distributed on uplands and mountain slopes throughout the county. They formed in residuum weathered from gray, acid sandstone and some interbedded shale. In most of the acreage the slope is very steep, but it ranges from 5 to 65 percent. Stones are on the surface in most places.

In a typical profile in a wooded area, a thin mat of black organic matter covers the surface. The surface layer, below this mat, consists of very dark grayish-brown loam in the uppermost

2 inches and brown channery loam in the next 8 inches. The subsoil extends to a depth of 27 inches. It is yellowish-brown, friable channery and very channery fine sandy loam. Sandstone fragments are numerous and increase in number and size with increasing depth. Below the subsoil is yellowish-brown very channery sandy loam. This layer is nearly 75 percent sandstone fragments. Sandstone bedrock begins at a depth of 33 inches.

Permeability is moderately rapid, and the available moisture capacity and natural fertility are low to moderate.

The Upshur silt loam is described as:

. . . derived from Indian-red shales that contain considerable lime. Surface drainage is generally not excessive, as the land occupies the smoother rounded ridge tops, the benchlike middle slopes, and the less steep lower slopes near small streams. Its friable subsoil allows good internal drainage.

The surface soil to a depth of 6 or 8 inches is chocolate-brown or dark reddish-brown friable silt loam which changes abruptly to Indian-red heavy silt loam or silty clay loam that extends down to about 30 inches or more. Below is loose partly weathered Indian red shale which overlies bed shale at a depth ranging from 3 to 5 feet below the surface. Some of the included soils have a small amount of shale chips and small rock fragments scattered over the surface.

The Upshur stony silt loam is described as:

. . . Most of the soil is on steep upper and middle mountain slopes; the rest is on somewhat flat benchlike areas 100 or more acres in extent and on rounded knobs and ridge tops. A considerable portion of it lies at elevations of 4,000 to 4,500 feet above sea level, and nearly all of it is at elevations greater than those of Lowell and Hagerstown stony silty clay loam, with which it is associated.

In pastures the surface soil to a depth of 5 or 6 inches is dark chocolate-brown or reddish-brown friable silt loam which passes abruptly into

Indian-red heavy friable silt loam. This material gradually becomes heavier with depth and at a depth ranging from 10 to 15 inches it passes into Indian-red granular or friable silty clay loam. This rests on partly weathered Indian-red shale or brownish red and gray limestone at a depth ranging from 2 to 4 feet. Numerous red shale chips, fragments, and large blocks of red and brown sandstone are scattered over the surface and embedded in the soil.

The Leetonia stony loam is included in forest soil and miscellaneous land types and described as follows:

. . . Podzol development has advanced further in Leetonia stony loam than in Leetonia stony silt loam; that is, the topmost inch or two of the mineral soil is definitely a leached gray layer underlain by the well-defined coffee-brown layer. . . . Beneath the topmost 3 or 4 inches of partly weathered duff is a 1- to 1½-inch layer of gray or brownish-gray leached friable or loose loam. This is underlain by light coffee-brown friable loam to a depth of 5 or 7 inches. Below is brownish-yellow friable loam, which at a depth of about 15 inches abruptly passes into yellow friable loam extending downward to bedrock lying at a depth ranging from 30 to 40 inches below the surface.

The rough stony land is also included in forest soil and miscellaneous land types and described as follows:

. . . is an undifferentiated classification, largely Leetonia material. It occupies nearly all of the high plateau area in the extreme western part of the county. . . .

The high plateau sections constitute some of the more gentle relief of the uplands but are the most stony. The surface is literally strewn with boulders of sandstone and large blocks of conglomerate, some of which weigh hundreds of tons. The escarpments and steep slopes along the plateau rim are a mass of rockslides and massive blocks of stone that have broken from the cap rock that forms the plateau level. The widely scattered smaller areas are largely on the steeper and higher ridge and

mountain slopes or on the scarplike slopes adjacent to streams. These areas have numerous heavy outcropping ledges of underlying rock and an abundance of loose rock and boulders scattered over the surface.

VI. VEGETATION

West Virginia, before settlement by Europeans, was covered by a practically unbroken forest, mainly of hardwood trees except in more elevated areas where conifers were locally predominant (Price, Tucker, and Haught, 1938). This mixed hardwood forest containing many canopy species was a portion of the belt of temperate zone woodland which has classically been called the Appalachian Hardwood Forest.

Among the many kinds of flowering shrubs growing in this forest are the azaleas (wild honeysuckle), rhododendrons (big laurel), Kalmias (laurel), and the American wisteria.

About 78 percent of Greenbrier County, or approximately 513,000 acres (207,608.3 hectares), is woodland. Nearly 20 percent of the woodland or 99,000 acres (40,064.8 hectares) is in the Monongahela National Forest. About 5,400 acres (2,185.4 hectares) is in Greenbrier State Forest, near White Sulphur Springs.

The most common forest types, or natural associations of trees, are the oak-hickory type, which makes up about 70 percent of the forested area; the beech-birch-maple type, which makes up about 20 percent; other hardwoods,

which make up about five percent; and white pine, pitch pine, Virginia pine, Table-mountain pine, and other pines, which make up about five percent (Gorman, and others, 1972).

VII. SETTLEMENT AND ECONOMY

Greenbrier County, the second largest in the state, was established by Act of the Virginia General Assembly, passed 12 January 1778, from parts of Montgomery and Botetourt Counties. The county takes its name from the river which flows across it (Price and Heck, 1939).

The county has a total area of 1,026 square miles (2,647.1 sq. km). Livestock raising became important in the central part of the county not long after permanent settlements had been established. Lumbering became important with the building of a railroad in 1872. Coal mining was begun at the western edge of the county about 1907 and became an important industry by 1922.

In 1960 the population was 34,446 in the county, 2,257 at Lewisburg, and 2,676 at White Sulphur Springs. At present there are several small mining communities in the western part of the county. The central part is largely rural, and farmsteads are dispersed throughout the area. The northern and eastern parts are mostly wooded and sparsely populated.

CHAPTER III

MASS MOVEMENT

I. INTRODUCTION

The study of slopes is essential not only for understanding landscapes and the manner in which mass movements contribute to the denudation of the landscape, but also as a practical means of reducing erosion, sedimentation, and rapid mass movement due to gravity induced processes which result when man modifies the landscape through agriculture, forestry, and construction of all types. These considerations take on increasing importance as man extends his land utilization activities to more remote regions where he encounters increasingly steep slopes. The study of downslope movement of rock, regolith, and soil under the influence of gravity necessitates extensive sampling of materials and observation of slope processes which range from extremely slow, such as creep, or infrequent, to extremely fast movement such as a debris slides or rock fall. For these reasons gravity induced erosion has not received its proper consideration until relatively recently.

II. CLASSIFICATION

It is understandable that efforts to classify slope processes are difficult, given the complex and transitional nature of the manner in which materials move downslope. The term "mass wasting" refers to the direct response of materials to gravity without the immediate influence of transporting agents such as running water, glaciers, and wind. In this group of processes are mass movements with velocities that range from free fall of rock and soil to slow creep of material on very gentle slopes.

Our understanding of the nature of instability in soil masses has been greatly enhanced by the efforts of soils engineers; the works by Ward (1945), Skempton (1953), and Terzaghi (1950) in particular, mark the first real progress (Carson and Kirkby, 1972).

Most early classifications by European geologists dealt with catastrophic movement but neglected slow movement. C. F. S. Sharpe (1938) devised the first English language classification which received wide usage. The major recent classifications cited by Young (1972, p. 75) are those of Heim (1882, 1932), Sharpe (1938; with bibliography of earlier classifications), Ward (1945), Varnes (1958), and Hutchinson (1968). The two most commonly cited are Sharpe (1938) shown in Table II and Varnes (1958) shown in Table III.

TABLE II

MASS MOVEMENT CLASSIFICATION BY C. F. STEWART SHARPE

I. Slow Flowage - usually imperceptible

Creep

Soil Creep

Talus Creep

Rock Creep

Rock-Glacier Creep

Solifluction

II. Rapid Flowage - relatively wet

Earthflow

Mudflow

Debris Avalanche

III. Landslide - relatively dry

Slump

Debris Slide

Debris Fall

Rockslide

Rockfall

IV. Subsidence - surface material displaced vertically
downward

Source: C. F. Stewart Sharpe, Landslides and Related Phenomena (New York: Columbia University Press, 1938).

TABLE III

MASS MOVEMENT CLASIFICATION BY DAVID J. VARNES

I.	Falls	
	Bedrock	
		Rockfall
	Soils	
		Soilfall
II.	Slides	
	Bedrock	
		Few Units
		Rotational Slump
		Planar Glide
		Many Units
		Rockslide
	Soils	
		Planar Block Glide
		Rotational Block Slump
		Debris Slide
		Failure by Lateral Spreading
III.	Flows	
	All Unconsolidated Material	
	Dry	
		Rock Fragment Flow
		Sand Run
		Loess Flow
		Rapid Earth Flow
		Debris Avalanche
		Slow Earth flow
	Wet	
		Sand or Silt Flow
		Debris Flow
		Mud Flow
IV.	Complex	
	Combinations of Material or type of movement	

Source: David J. Varnes, "Landslide Types and Processes," Landslides in Engineering Practice, Highway Research Board Special Report 29, E. B. Eckel, editor (Washington: Highway Research Board, 1958).

III. TERMINOLOGY

The two types of mass wasting that best describe the majority of slope processes in the area the author investigated are debris avalanche and debris slide/debris flow. Sharpe (1938, p. 61) describes a typical debris avalanche as having a long, relatively narrow track, occurring on a steep mountain slope or hillside in a humid climate, and is almost invariably preceded by heavy rains which increase the weight of the unadjusted material and aid in its lubrication. Initial movement and progress on the upper part of the course is related to slippage, sometimes on a smooth underlying rock surface and sometimes within the loose debris. Sharpe's (1938, p. 74) description of debris slides includes all cases of rapid downward movement of predominantly unconsolidated and incoherent earth and debris in which the mass does not show backward rotation but slides or rolls forward, forming an irregular hummocky deposit which may resemble morainal topography.

According to Varnes (1958, pp. 29, 36, 37), debris slides and less commonly, debris avalanches may have slump blocks at their heads. In debris slides, the moving mass breaks up into smaller and smaller parts as it advances toward the foot, and the movement is usually slow. In debris avalanches, progressive failure is more rapid and the whole mass, either because it is quite wet or is on a steep slope, flows and tumbles downward, commonly along a

stream channel, and advances well beyond the foot of the slope. Debris avalanches are generally long and narrow and often leave a serrate or V-shaped scar tapering uphill at the head, in contrast to the heel print shaped scarp of a slump. With increase in water content or with increasing velocity, debris slides grade into the flowing movement of debris flows (Johnson, 1970, p. 433-459). Johnson (1970) has also indicated that in arid regions debris flow is laminar. In West Virginia, Debris flows that originate in timberland are much more turbulent because of the large timber component moving with the flow. This is illustrated by log jams, debris piles, and large tree covered slump blocks, held together by roots, which are shown on Plate III. One of the larger tree covered blocks (approximately 25 by 30 feet, 7 by 9 m) can be seen on the southwest corner of Plate III A.

This author's field observations agree generally with the definition of terms and comments by Clark (1973) in his FINAL REPORT on PROJECT THEMIS Task II, as follows:

. . .A varied group of terms and definitions utilized by many writers has evolved to describe the processes and landforms studied in this research. One major goal of the work was to gather field data on the nature of this class of mass movements. With the information gained, some tentative inferences can be made concerning the processes involved in material erosion, transport and deposition. The author now suggests that a preference may be given to terminology that most closely describes the inferred complex processes. Accordingly, the following terms are defined below and certain of them are schematically illustrated in Figure 2.

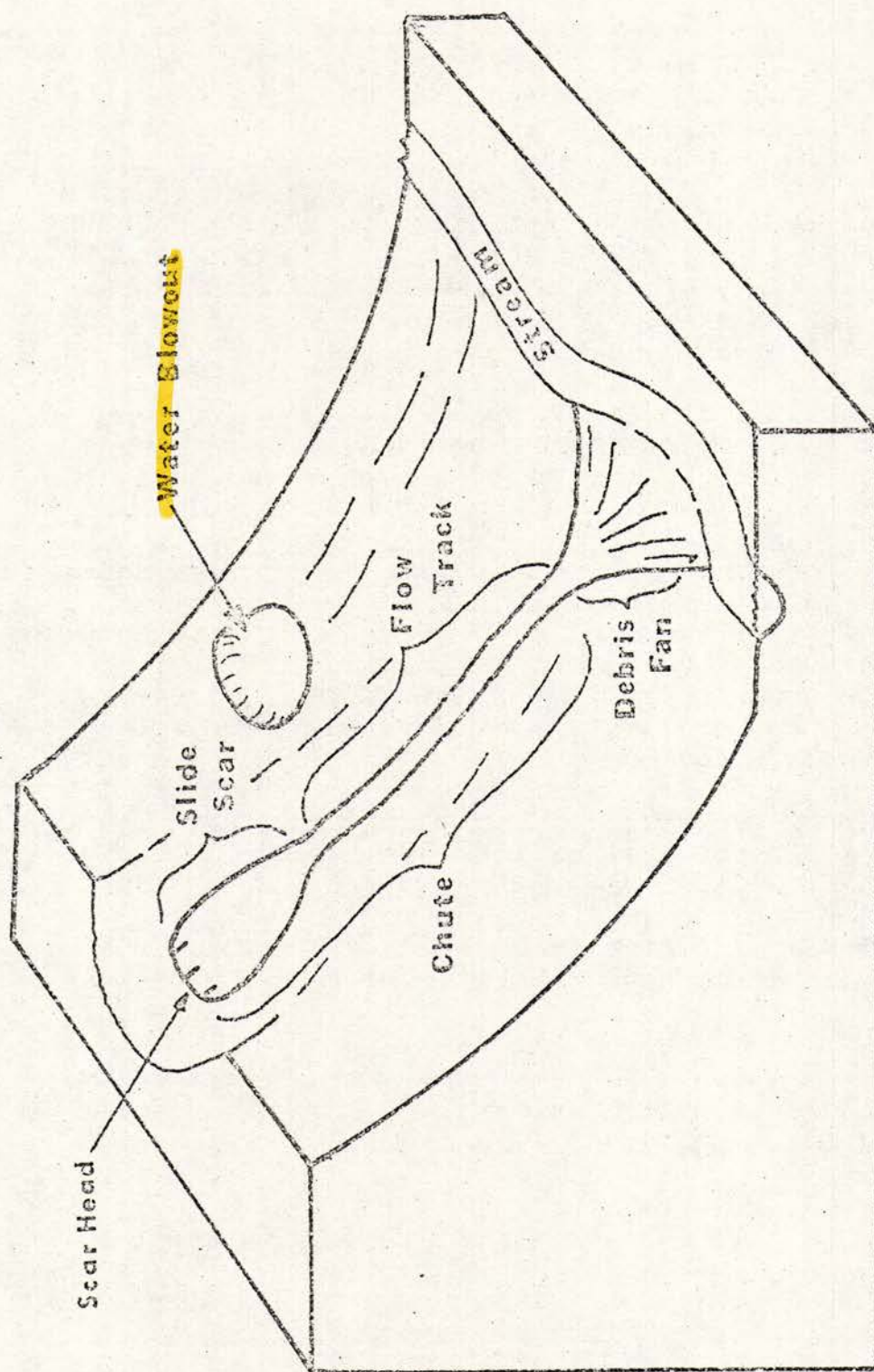


Figure 2. Schematic Block Diagram Illustrating the Terminology used for Features Produced by Rapid Mass Movements.

Source: D. J. Bogucki, 1970, and G. M. Clark, 1973.

Chute - A general term for hillslope areas where vegetation and soil mantle have been partially or completely removed by the processes of debris slides/debris flows. Chutes often extend from short distances below ridge crests downslope to debris fans or to channelways if fans are absent. (See Hack and Goodlett, 1960, p. 43-44).

Water Blowout - Erosional holes in hillslope debris mantle that show no evidence of ground cover breaks above or below the depression. (See Hack and Goodlett, 1960, p. 45-47).

Debris Fan - Fan or cone-shaped accumulations of predominantly water laid debris, mainly stones and gravel, some fines, and vegetational remains. Debris fans are the depositional termini of chutes in locations where chutes do not directly enter channelways; some debris fans, however, may be transitional to high-energy alluvial fans. (See Hack and Goodlett, 1960, p. 53).

Debris Slides - Rapid mass movements initiating along one to many regular to irregular, surfaces of discrete movement that primarily involve soil and vegetation but occasionally also upper bedrock layers. Initial movement may be rotational or translational in nature, or may involve elements of both. Multiple occurrences within the study region were related to intense precipitation events on relatively steep slopes possessing a soil mantle. (See Rapp, 1963, p. 196-197).

Slide Scar - The erosional depressions produced on hillslopes by debris slide activity. Slide scars are often transitional downslope to flow tracks.

Debris Flows - Rapid mass movements involving rapid debris flowage, containing coarse-grained materials, and resulting almost invariably from intense precipitation. (See American Geological Institute, 1972, p. 181-182).

Flow Track - That portion of the chute modified by debris flow activity accompanied by fluvial erosion, transportation and deposition.

Log Jams - Large deposits predominantly composed of tree trunks that are commonly emplaced on the outsides of chute bends and on debris piles. (See Bogucki, 1970, p. 53).

Debris Piles - Accumulations of vegetational remains, especially stems and roots, soil and rock on the upslope sides of standing trees bordering chutes and downslope from water blowouts. (See Hack and Goodlett, 1960, p. 45 and Figure 24, p. 46; of Debris Dams, see Bogucki, 1970, p. 80-81).

Perhaps the major break with common usage in this research is the abandonment of the popular term Debris Avalanche in favor of the terms Debris Slide/Debris Flow. Although much remains to be known, especially from the rheological standpoint, of specific forces and the nature of movements, the field evidence accumulated in this work suggests that these terms better describe the gross mass movements involved in chute formation.

In the above reference to abandonment of the term debris avalanche, it is noted that 31 out of the total of 1,534 slides in this investigation agree very well with Sharpe's (1938) classification. They do not qualify as debris avalanches in the classification of Varnes (1958) on the basis of water volume involved.

Plate II illustrates the part of Lobelia, West Virginia 15-minute U. S. G. S. Quadrangle map on which the field investigations were conducted. The boundary on the south-east consists of the wide stippled band, while the remainder of the boundary which follows the drainage divide, is illustrated by large solid dots. The total designated area is approximately 36 square miles (94 sq. km), of which 28 square miles (73 sq. km) are timberland, and eight square miles (21 sq. km) are clear land. A total of 1,534 landslide sites were visited to record measurements. The location of each slide is shown as a dot on this Plate. The clear land is designated by the stippled areas outlined in yellow. The

locations of the two valleys (Taylor Place Valley and Beard Place Valley) which were surveyed and sketched planimetrically (Plate III) are labeled and outlined on the north central part of this map. The upper and lower contacts of the Bluefield Formation are outlined by the heavy dashed lines.

IV. THE SYSTEM: DEBRIS SLIDES/DEBRIS FLOWS

Because no one observed the movement of these natural slides a subjective judgement is made on the mechanism of movement, based on field evidence. Residents describe the sounds of the slides in a manner that would indicate the velocities were high. The greatest number of slides occurred near the end of a period of heavy rainfall and are located on the Bluefield Formation, a very impermeable rock unit that is also very slick when wet. The heads of most slide scars (Figure 2, p. 34) are shaped like a heel print, which would indicate they originated as a debris slide with the transition to debris flows taking place part way down the chute, as more water became available, and the velocity increased. Additional evidence of the water content and velocity are provided by observations in the chute. Downslope from the head, where the initial mass of debris was removed to bedrock, the unchannelized segments of the flow track commonly show very little additional material removed, as illustrated by the fact that small trees and bushes are not uprooted but have their leaves and some

branches stripped. Occasional scour depressions and/or water blowouts occur in these portions of the chutes. In some pasture areas the grass mat, over which the debris slide moved, has not been disturbed nor has it been covered by a veneer of sediment. The deposits associated with this activity range from levees along the margins of the chutes, some consisting of shingled rocks, to log jams caught in large trees, and alluvial fans with large amounts of vegetative debris mixed soil and rock.

Active erosion within the flow tracks and slide scar head area has continued at a high rate since the initial event in 1969. During the field investigations numerous examples of high volume sediment transport from slide-damaged drainage basins were observed. Even small rain storms produced heavy sediment loads in streams. In winter, needle ice or mush frost was extremely active on the steep barren surfaces. Small secondary slumping and sliding were observed taking place in the original slide scars. Debris jams in stream channels with small diameter wood material were dissected as the woody material decayed and weakened. Livestock frequent the slide scars and use them as resting places, probably because they are less steep; they thereby churn the barren surfaces with their hooves. Revegetation, however, starts quickly. The small trees and brush with leaves and branches stripped, frequently recover and revegetate the chutes. In the depression created by the slide

scars, weed plants appeared a year after the sliding took place. Revegetation on the slide scarps, the headward surface along which the slide occurred, will take many years, because of the active erosion going on there now.

In a geomorphic sense the slides increase the headward extent and depth of first order streams and also expose additional rock surfaces to surface processes (Hack and Goodlett, 1960). They also affect the downstream portions of channels, at least in a temporary sense, by disruption of the former gradient due to channel modification, whether it is by deepening the channel in the case of scouring and water blowouts or log jam debris dams which temporarily block and or divert the channel. One case of a "U"-shaped valley was found where a large steep drainage basin empties into the main valley through an erosional resistant sequence of lithologies within the Bluefield Formation. It is impossible to say how much of this modification was due to the 1969 activity. The volume of material carried from this drainage basin was extremely large, with a large amount of boulder and block size material moving through a laterally-restricted valley at a very high velocity. The evaluation of the long term importance of these processes depends on the ability to get a better estimate of the recurrence interval of these events, and also on comparisons of volumes of material removed by sliding as opposed to volumes involved in chemical/organic denudation, and mechanical creep.

V. KNOWN DISTRIBUTION OF DEBRIS SLIDE/ DEBRIS FLOW OCCURRENCES

Shown in Plate I are the individual topographic quadrangles in which one or in a few cases, more than one major debris slide/debris flow producing storm is reported to have occurred. Data for map construction were from published and unpublished sources documented whenever possible by aerial photographic interpretation and field checking. (See Clark 1973 for examples). A general conclusion that can be drawn from Plate I is that debris slides/debris flows and the storms that produce them are probably common events in the last 100 years in the Appalachians south of the glacial border. Thus knowledge gained in the study of this class of features will probably find wide application elsewhere in the region.

CHAPTER IV

CLIMATOLOGICAL AND GEOMORPHIC EVENTS ON THE NIGHTS OF 19-20 AUGUST AND 5-6 SEPTEMBER 1969

I. INTRODUCTION

The first of two periods of excessive, intense rainfall which occurred in the Renick area was the result of Hurricane Camille, which after intensifying in the Gulf of Mexico, made landfall on the Mississippi coast at 10:30 P. M. on 17 August. It traveled eastward through extreme southern West Virginia and southern Virginia. A combination of factors interacted on 19 August to produce several areas of concentrated torrential rainfall which caused devastating flash floods and landslides in this study area (Plate II) and along the eastern slopes of the Blue Ridge Mountains and record flooding along the James River.

The Storms

The remainder of Camille's dying circulation moved into the Spring Creek area, which was already occupied by a large, moist, maritime tropical air mass, with some existing rain areas. Northwest of the area of maximum rainfall in Virginia a narrow valley surrounded by steep ridges suggested that orographic effects on the cyclonic flow aided in producing the torrential rain. This report, not located specifically by DeAngelis and Nelson (1969) may be in reference to the Spring Creek area. Thunderstorm activity ahead of a

slowly approaching cold front may also have accentuated the rain. In combination these meteorological factors (and perhaps others not yet ascertained) produced torrential rains in these two states which rank with other record rainfalls throughout the world. Several reports of more than 25 inches (63.5 cm) were noted (DeAngelis and Nelson, 1969) on later examination in the Virginia area and amounts in excess of four inches (10.2 cm) fell over an area 30 to 40 miles (48.3 to 64.4 km) wide and 120 miles (193.1 km) long. Most of the rain fell in a period of eight hours. There were no rain gauges or bucket surveys in the Spring Creek drainage basin. The nearest bucket surveys were conducted in Nelson and Albermarle Counties, Virginia, and indicated 12 to 14 inches (30.5 cm to 35.6 cm) of rain to be common (DeAngelis and Nelson, 1969).

Local residents in this study area described this storm as having been a steady rain during the daylight hours of 19 August with an increase in intensity as it became dark. The sounds of slides crashing down the slopes were reported to have occurred at approximately midnight. There are accounts of the noise of rocks colliding in the slide chutes ranging in sound from a heavy clatter to dynamite explosions. Wind velocities are described as having been moderate, never the velocities required to uproot trees or damage buildings.

The second storm occurred on the night of 5-6 September. It appears to have been a localized heavy thunderstorm. The

major descriptions of this storm consist of newspaper accounts, ESSA flood damage reports, and accounts by area residents. Intense black clouds directly over the mountains were visible from a distance of six miles. During the storm, lightning appeared to run parallel to the horizon, rather than as vertical flashes. Because of the localized nature of the storm official precipitation records are non-existent. The ESSA Flood Report (Van Metre, 1969), indicates local stream levels a foot higher than the earlier storm. This is confirmed by comments of residents. Also several homes damaged by flood water in August were washed from their foundations and demolished in September.

The Floods

The major intensity of the two flash floods that resulted from storms in Greenbrier County were in the tributaries flowing into the Greenbrier River. These tributaries have no stream gauging stations. The Greenbrier, Gauley, Meadow, and Cherry Rivers were affected by high levels of flow from tributaries. Two women drowned during the first storm, when they were swept away by the rapid flooding water in Spring Creek. Thirty homes were destroyed 30 miles (48.3 km) to the north by flood water of Little Clear Creek in Anjean, West Virginia. A dozen cars and trucks, two house trailers, four homes, a herd of sheep and some hogs were lost along Spring Creek.

The flash flooding during the night of 5-6 September produced water levels a foot (30.5 cm) higher than the earlier storm on Spring Creek, resulting in severe damage to farm land on the flood plain. Reports indicate 1,254 acres (507.5 hectares) with crops destroyed or severely eroded. Much of the land was damaged beyond economic reclamation. Three additional houses were washed away including the one in which two women drowned during the earlier flood, and 12 homes were damaged. Ten local bridges and five miles (8 km) of road were washed out. Local reports of a surge of water 45 feet (13.7 m) high moving down the narrow Spring Creek Valley certainly gains credibility when surveys of the damage were evaluated. Mr. James W. Van Metre, Greenbrier County Agent, listed a damage total of \$281,200 in the Flood Damage Report to the U. S. Weather Bureau (16 September 1969). There are no reports of buildings lost due to landslides and none of the reports included damage due to landslides on the hillslopes. Damage done by slides was not included unless the slide blocked a road or railroad. The damage caused by slides on agricultural land consists of damage to the land surface and the resulting sedimentation of slide debris on fields or fence rows. Slides originating in timberland destroyed some marketable timber and killed or damaged many young trees. An additional factor that is impossible to estimate is the increased damage resulting from the large floating timber component (at least in part produced by

debris slides/debris flows) of the flood waters and their impact in destroying bridges, buildings, and fences where they became lodged and increased the destruction by the flood water.

Slide Dimensions-Regolith Volumes Involved

In the course of this research 1,534 slide sites were investigated and the following data items recorded.

1. Length of the slide scar head.
2. Maximum width of the slide scar head.
3. Average depth of removal of material from the slide scar head.
4. Percent of slope at the site.
5. Azimuth of slide movement.
6. Geologic formation and lithology.
7. Vegetation on the slide or immediate area.
8. Classification as to the type of slope failure.
 - a. Debris slump when rotated as a unit and not removed.
 - b. Debris slide when entirely clear of head scar.
 - c. Water blowouts when erosional holes are present with surrounding area not disturbed.
9. Total soil thickness.
10. Soil horizons and their individual thicknesses.
11. Soil color.
12. Soil texture and stone content.
13. General soil drainage and/or presence of seep or spring.
14. Geometry of the slide scar.

In order to analyze the large volume of field data, it was quantized and tabulated for computer processing.

Preliminary analysis of the data provides some insight into the degree of damage. The total land-surface removed as slide scar heads is slightly more than 46 acres (18.6 hectares). The total volume of material removed was 5,215,466 cubic feet (147,684.2 cu. m). This does not include additional material removed from the slide chutes, where the thickness of material removed is not great, however the surface area is relatively large. The tributary channels into which the slide flow material moved were also altered, however with no pre-storm channel form and pattern information it is impossible to evaluate the volumes affected.

General Slide Characteristics

Some general characteristics of the slides obtained by summarizing the data are presented in Table IV. The average width of the slide scar heads is greater than their length, the average thickness of regolith removed is slightly less than average total soil thickness. The average slope percent agrees with the value Flaccus (1958) determined for landslides in the White Mountains. The azimuth of slide movement is strongly influenced by the predominance of small drainage basins which drain eastward. The azimuth value in Table IV results from considering each azimuth reading separately. The results of grouping all azimuth values into 72 categories of five degrees each, gives South 85 Degrees East as the commonest orientation.

TABLE IV
SUMMARY MEASURES OF 1,534 DEBRIS SLIDES

VARIABLE	MEAN	STANDARD DEVIATION
Length of slide scar heads	30.15 ft. (9.2 m)	21.96
Maximum width of slide scar heads	36.35 ft. (11.1 m)	32.80
Depth of removal of material from the slide scar head	21.14 in. (53.7 cm)	11.65
Percent of slope at the site	62.95 (34.97 Degrees)	14.30
Azimuth of slide movement, from North	131.38	82.82
Total soil thickness	21.56 in. (54.8 cm)	11.02

Debris slump blocks, defined as masses of regolith which have rotated as a coherent unit, with downslope displacement generally limited to a distance roughly equal to the regolith thickness, illustrate how most of the debris slides were initiated. The rotation appears to have released sufficient soil-water thereby reducing pore pressure such that the coefficient of friction between the slump block and the underlying surface is great enough to stop movement. The author is aware that this phenomena may be unique to these particular storms because other evidence such as slide debris lodged as a unit in stream channels at the base of the slopes and accounts of debris slides occurring approximately at the termination of the periods of intense rainfall would also permit these slump blocks to cease movement. Small slump blocks which were initially part of a larger slide that continued downslope are relatively common, as illustrated on Plate III. The dominant surface outline of the large slump blocks is similar to the heel print of a shoe, with the convex curve upslope. The small slump blocks are more irregular in surface outline. A total of 24 of the large slump blocks representing 1.6 percent of the entire number of slope modifying features were recorded.

The most common of the heel shaped features described above are the debris slides with a total of 1,105 of this surface outline recorded, comprising 72 percent of the 1,534 features. The agreement in the surface outline of these

two types of features further substantiates their origin as a coherent mass. In general these two shapes include the slides and slumps which have the greatest surface area and largest volume of displaced material. Two modifications of the geometry common to slump blocks and debris slides are found to apply to the debris slide. Debris slides commonly narrow toward the mouth as illustrated on Plate III and when this modification occurs the thickness of removed regolith increases toward the mouth. When debris slides are so modified they are closely comparable to water blowouts described by Hack and Goodlett (1960, p. 45-47) and the bottle slides reported from Tanzania by Temple (1972). They differ from water blowouts in the fact that some ground cover breaks commonly occur above and below the slide scar. Further modification of the slump and slide surface form consist of compound head scars observed in 304 slides representing 19.8 percent of the total and some combinations of these forms (Plate III). Slumps and slides tend to move parallel to the line of maximum slope, as opposed to the last two types, debris avalanches and a surface shape modification of the debris avalanche which here will be called a "trapezoid" shape. The author observed that in the initial 10 to 20 feet (3.1 to 6.1 m) of travel these latter types do not move parallel to the direction of maximum slope but diagonal to it at an angle of two to three degrees, which suggests that the initial velocity is so great that it controls the

direction of travel. A second possibility that appears more probable is that slope sheet flow turbulence steers the initial travel direction. Further downslope the chutes of these avalanche types move parallel to the direction of maximum slope. A total of 56 of the trapezoid shapes and 30 of the debris avalanche types, representing 3.7 percent and 1.9 percent respectively, were observed. The long narrow track of the debris avalanche is moderately well illustrated by some examples on Plate III, however the trapezoid surface outline is not well represented in these valleys.

Water blowouts constitute the most limited group in this classification if the requirement of no evidence of ground cover breaks above or below the depression (Hack and Goodlett, 1960) is rigorously observed. One ideal example occurred in clear pasture land and almost none in timberland would qualify because of the disturbed forest floor litter. Admittedly the leaf cover of the forest floor was removed in many large areas because of sheet flow and therefore it is difficult to determine whether the associated slides could be classified as water blowouts.

The following general comments on floor profiles are based on detailed measurement of one slide and general measurements and field observations of 1,533 sites. The geometry of floor profile lines is generally slightly concave in the debris slide, both for profiles from scar head to mouth and for profile lines at right angles to the

hillslope. From other comparisons this situation is probably also true for slump blocks. The floor of the debris slide commonly resembles that of an early state of a cirque, with a slight rise in the floor toward the mouth. Temple and Rapp (1972) report. . .The long profiles of the flows are convex both in section and length. . .for bottle slides in Tanzania. Bottle slides were not selected for observation of specific features in this investigation.

Slope Steepness

The slope inclinations were divided into 15 groups of five percent units, starting with 26 percent (14.56 Degrees), the lowest slope on which any slides occurred. Slides in timberland were separated from slides in clear land. Three values in Table V show the same tendency in both timber and clear land.

First, the greatest thickness removed occurs at the low slope angle because these slides generally occur in alluvium and colluvium deposits along streams. The probable causes of slope failure here are undercutting and a very heavy sheet flow. The number of slides involved is small in both cases. Second, comparison of the remainder of the values indicates the 46 to 50 percent slope (25.00 to 27.02 Degrees) in both types of land use has the greatest thickness (other than the 26 to 30 percent interval) of material removed. Finally the slope at which the greatest numbers of slides occur is 56 to 60 percent (29.32 to 30.93 Degrees) in both cases. These

TABLE V

REGOLITH THICKNESS REMOVED WITH RESPECT TO SLOPE STEEPNESS

SLOPE INTERVAL		TIMBERLAND		CLEAR LAND	
PERCENT	DEGREES	MEAN INCHES REMOVED	NUMBER OF SLIDES	MEAN INCHES REMOVED	NUMBER OF SLIDES
1. 26-30	14.56- 16.66	61.89 (157.20 cm)	9	46.50 (118.11 cm)	2
2. 31-35	17.22- 19.34	0.00 (0.00 cm)	0	18.00 (45.72 cm)	9
3. 36-40	20.11- 21.74	24.50 (62.23 cm)	6	19.16 (48.67 cm)	32
4. 41-45	22.28- 24.32	27.27 (69.27 cm)	11	19.58 (49.73 cm)	31
5. 46-50	25.00- 27.02	30.71 (78.00 cm)	24	19.64 (49.89 cm)	110
6. 51-55	27.57- 28.80	25.24 (64.11 cm)	70	18.20 (46.23 cm)	147

TABLE V (Continued)

SLOPE INTERVAL		TIMBERLAND		CLEAR LAND	
PERCENT	DEGREES	MEAN INCHES REMOVED	NUMBER OF SLIDES	MEAN INCHES REMOVED	NUMBER OF SLIDES
7. 56-60	29.32- 30.93	27.75 (70.49 cm)	126	17.24 (43.79 cm)	180
8. 61-65	31.44- 32.99	23.66 (60.10 cm)	116	18.91 (48.03 cm)	118
9. 66-70	33.50- 35.00	23.79 (60.43 cm)	100	15.95 (40.51 cm)	82
10. 71-75	35.50- 36.76	24.68 (61.16 cm)	73	18.68 (47.45 cm)	41
11. 76-80	37.25- 38.46	22.94 (58.27 cm)	93	16.27 (41.33 cm)	33
12. 81-85	39.00- 40.48	25.33 (64.34 cm)	24	12.39 (31.47 cm)	13

TABLE V (Continued)

SLOPE INTERVAL		TIMBERLAND		CLEAR LAND	
PERCENT	DEGREES	MEAN INCHES REMOVED	NUMBER OF SLIDES	MEAN INCHES REMOVED	NUMBER OF SLIDES
13. 86-90	40.57- 42.00	22.71 (57.68 cm)	14	9.88 (25.10 cm)	8
14. 91-95	42.52- 43.18	21.54 (54.71 cm)	13	14.40 (36.58 cm)	5
15. 96-100	43.64- 45.00	17.88 (45.42 cm)	33	14.46 (36.73 cm)	11

results indicate the steepness of the slope is more important than land use. The general tendency for thickness of removed material to become less with increasing slope steepness is no doubt influenced by the trend of soil thickness reduction with increasing slope steepness.

Lithologic Influence

The distribution of slides with respect to the various rock units is influenced by several factors. The Bluefield Formation underlies approximately 65 percent of the total area and contains 83 percent of the total slides. The reason for this high percentage of slides includes the fact that the Bluefield underlies the majority of the steeply sloping land, has a somewhat higher clay content in the soils, is very impermeable, and is extremely slick when wet.

The Hinton Formation, Avis Limestone, and Princeton Formation are the remaining units which lie above the Bluefield and on which slides occurred. These units comprise approximately 19 percent of the total area with 11 percent of the slides. Generally these formations constitute the upper parts of the slopes, and have extensive areas of the surface armored by large blocks of Hinton material, which reduces the numbers of slides.

The three formations below the Bluefield (Alderson Limestone, Greenville Shale, and Upper Union Limestone) comprise approximately 0.1 percent of the area and contain 0.2 percent of the total slides. The fact that they occupy

the lower portions of the slopes and underlie the stream valleys accounts for the small percentage of slides.

Impact of Land Use

A comparison of occurrence of slides in timber and on clear land indicates 712 slides or 47 percent in timber and 822 or 53 percent on clear land. The timberland constitutes 77.5 percent of the total area with the remaining 22.5 percent clear land. This would indicate a greater tendency for clear land to fail by sliding than timber. This agrees with the findings of Pain (1969) in a study of environmental factors effecting slopes in New Zealand.

Pain (1969) reports slides in timber tend to remove all soil horizons and the loose bedrock while soils in clear land tend to fail at well developed soil horizon boundaries, especially the "C" horizon. This behavior was investigated for the slides in this study and found to be true. There is a noteworthy difference in the completeness of soil removal in timber as opposed to clear land. In timber 532 slides or 75 percent had a thickness of removal greater than the total soil thickness. Slides in timber with less than the total soil thickness removed number 180 or 25 percent of the total. In clear land 490 slides or approximately 60 percent had a thickness of removal greater than the total soil thickness, explained by the fact that the upper portion of the weathered bedrock (extreme base of the "C" horizon) was removed with the soil. The "R" horizon or bedrock, rarely moves with the debris slide. The number of slides in clear land with less

than the total soil thickness removed is 332, which is 40 percent of the total slides in that category, and 15 percent more than occurred in the same category for timber.

Table VI provides additional information on soil characteristics in both timber and clear land. The major differences in the soil in the two land use categories is the distribution of the O_1 and O_2 soil horizons. The smaller number of clear land sites with O_1 and O_2 soil horizons reflects the soil modification during the time interval since the land was cleared. The "A" horizons are represented in almost identical percentages in both land use categories. The smaller number of recognized "C" horizons for clear land is due to the fact that the clear land soils tend to fail just above the "C" horizon and therefore it is not exposed as frequently. The "B" horizon is so weakly developed in these soils, that it can rarely be recognized in the field. Rapp (1963) found slide shear planes originating in the "B" horizon in Norway soils which he describes as having a well developed podzol profile, with a rust-colored B-layer, 30 to 40 cm (11.8 to 15.8 inches) thick, resting on gray, fine-grained compact substratum of till. The base of the "A" horizon in the soils of the Spring Creek drainage basin may provide a surface of weakness, for shearing, although it is not nearly as pronounced as that described by Rapp (1963).

TABLE VI
GENERAL SOIL CHARACTERISTICS

SOIL CHARACTERISTICS AT SLIDE	NUMBER OF SLIDES	
	TIMBERLAND	CLEAR LAND
Horizons		
O ₁	295	37
O ₂	416	102
A	707	819
C	75	56
Stoniness		
Class 0	527	610
Class 1	19	14
Class 4	68	91
Class 5	98	107
Drainage		
Well drained	666	791
Imperfectly drained	8	1
Seep or Spring present	38	30

The stoniness of the soils in the two land use categories is not significantly different. When stoniness percentages are calculated and compared, the Class I category, which has the greatest difference, is slightly less than one percent variation. The parent material for the soils on which the majority of the slides in both timber and clear land occurred is the Bluefield Formation a unit that consistently produces similar soil stoniness.

The greatest variation in soil drainage is in the imperfectly drained category, and probably is related to land use to a greater degree than any other factor. The clear land permits faster surface evaporation and has a slower infiltration rate (Sherman and Musgrave, 1949) than forest floor soils. The above two factors tend to limit the area of imperfectly drained land. The springs and seeps are primarily due to geologic conditions, and therefore less affected by localized land use on the scale of areas involved in this investigation. The soil characteristics appear to play a minor role in localizing slides.

Taylor Place Valley

The Taylor Place Valley (Plate III A) is one of two tributary valleys of Spring Creek which was surveyed and sketched planimetrically to a scale of one inch representing 50 feet (2.54 cm representing 15.24 m). A total of 47 slides removed 131,066 cubic feet (3,711.3 cu. m) of soil and regolith from a land area of approximately 31 acres

(12.5 hectares). The greatest concentration of slides is near the crest of this drainage basin, with many slides originating within 75 to 150 feet (22.9 to 45.7 m) of the drainage divide. The slope in this part of the valley is 65 percent (33 Degrees). The greatest amount of headward channel extension occurred in this topographic position. Many of the slides moved directly down slope without flowing into existing channels. When this occurred large boulders and the uprooted timber became lodged on the slope. The regolith material was carried off the slope by the extensive sheet wash. The slides which emptied into existing channels, appear to have had all their material except for some of the timber which became lodged in debris dams, carried into Robbins Run tributary of Spring Creek at the mouth of the valley. The amount of material lodged in and along the channel is very small compared to the total volume removed. Channel modification does not appear to have been extensive.

Beard Place Valley

The Beard Place Valley (Plate III B) is the smaller of the two valleys. In both valleys the slides originate at the Bluefield-Hinton Formation contact. Fifteen slides removed 66,694 cubic feet (138.5 cu. m) of soil and regolith from approximately 24 acres (9.7 hectares) of drainage basin. This pattern is typical throughout the entire area. The pattern of slope failure is very similar in both valleys. The slides at the head of this valley start

on slopes of 65 percent (33 Degrees) which is identical to the situation in Taylor Place Valley. There is somewhat more material, especially timber deposited as debris dams in this valley. There is more pre-1969 alluvium deposited in this valley, which permits useful comparisons of the present day depositional patterns and slope activities with much earlier activity. All of the material transported to the mouth of this valley has been swept away by Robbins Run, a tributary of Spring Creek.

The preceding two valleys were selected to be surveyed and sketched planimetrically partly because of their accessibility, both for the surveying and for observations of modifications which will take place as the area recovers from the storm effects and because they were rather typical of the modification in small tributary valleys to Spring Creek. Additionally these two valleys appeared to be representative of the much larger area in a manner that would aid in understanding the mechanism of debris slide initiation and transport of material down the slide chutes. The standing trees and stumps with brush or log debris dams on their upslope sides aid in outlining the extent of flooding and the water depth on these surfaces. Trees up to 18 inches (45.7 cm) in diameter were sheared off by the rapid moving material in the chutes. In parts of the chutes, the downed trees are aligned with the flow, with many of the stump ends upslope. Where log jams occurred there is

no preferred alignment, indicating the turbulent tumbling nature of the debris flow. Many of the deposits of coarse rock material, ranging from cobble size to boulders are aligned along the chutes and channels. The smaller sizes of these materials record transport activity in the late stages of flooding. Only small amounts of material smaller than cobble size remains anywhere in the channels and chutes. The vast majority of the materials that slid from these tributary valleys were carried away by the major stream at the mouth of the tributaries.

An attempt was made to apply the statistical tests to these two small areas in order to compare them to the entire study area, however inspection revealed the timberland to clear land ratios were not in agreement with the total area and therefore the tests would not be valid. This characteristic of the two valleys was not obvious at the time they were selected. It would be difficult to select two valleys with the land use ratios, characteristic of the entire research area.

Statistical Tests for Significance of Debris Slide Distribution with Respect to Land Use

A study of the distribution curves (Figure 3) of slides with respect to slope suggests that the central tendency characteristics of these distributions are similar. For example it is noted that the largest number of slides in both timber and clear land occur in the 56 to 60 percent

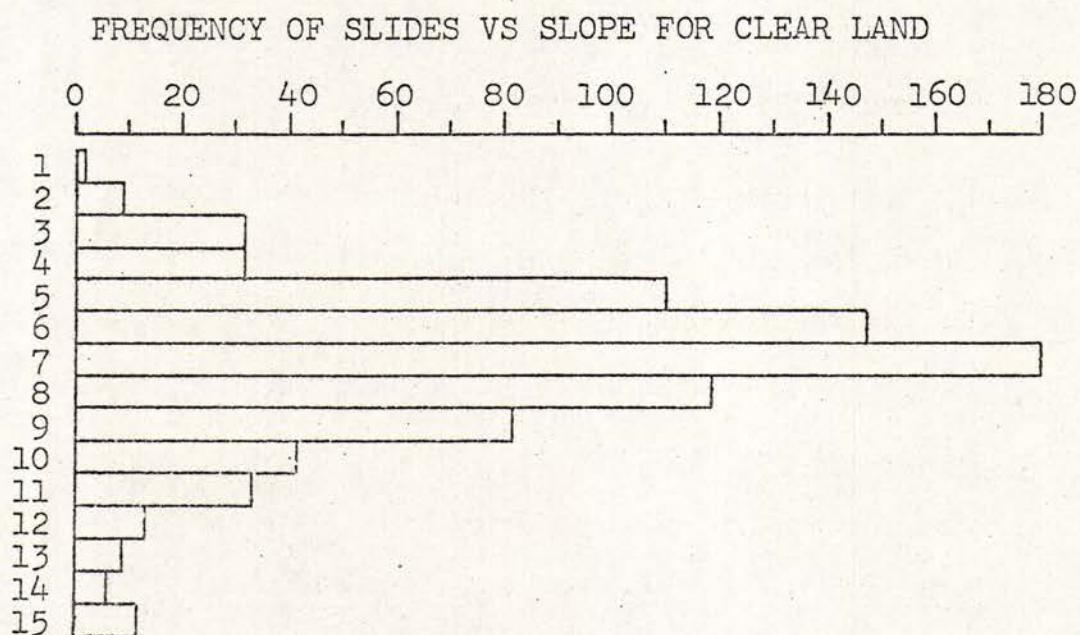
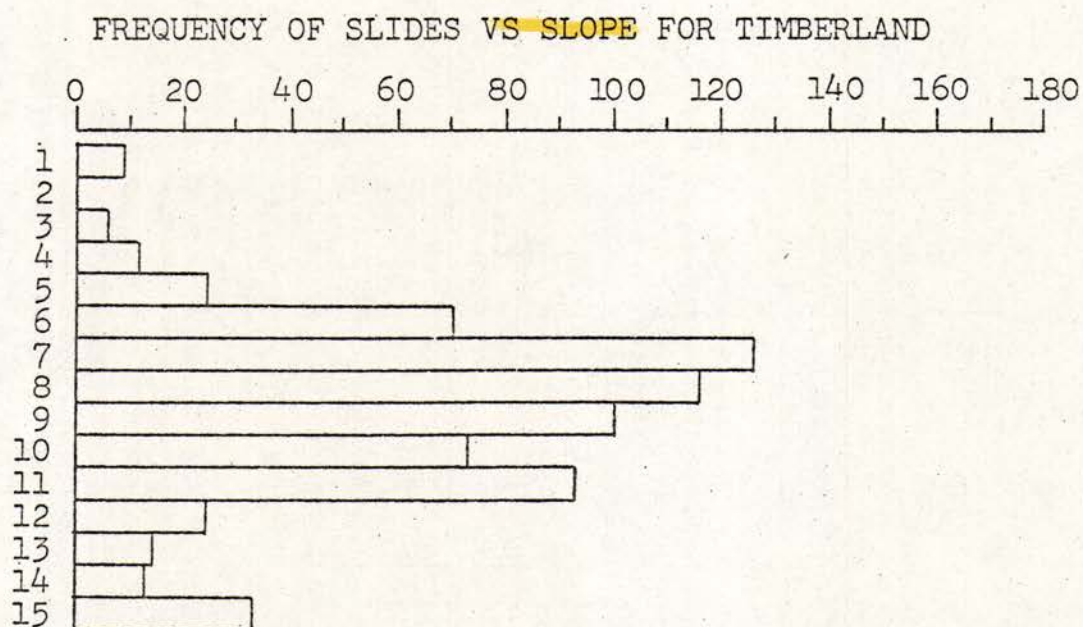


Figure 3. Frequency of Slides vs Slope for Timberland and for Clear Land.

Source: Table V.

slope (29.32 to 30.93 Degrees) category. The means of these distributions (mean slope for slide occurrence) falls within category nine for timberland and category seven for clear land. An application of a Mann-Whitney U Test (Figure 4) for the significance of differences between means shows that the two means are not significantly different at a level $\alpha = .05$.

$$n_1 = n_2 = 15$$

$$\mu_{R_1} = \frac{n_1(n_1 + n_2 + 1)}{2} = \frac{15(31)}{2} = 232.5$$

$$R_1 = 229$$

$$Z = \frac{R_1 - \mu_{R_1}}{\sqrt{\frac{n_1 n_2 (n_1 + n_2 + 1)}{12}}} = \frac{-3.5}{24.11} = -.14$$

Since $-1.96 < -.14 < 1.96$ we accept the null hypothesis of equality of means at $\alpha = .05$.

The fact that from a total of 1,534 slides, 822 occur in clear land which occupies only 22.5 percent of the total area suggested that a study of the density characteristics of slides in timberland verses clear land should be undertaken. For this purpose the measure of density or relative frequency of slides is defined as the number of slides per unit area. Since the ratio of clear land to the total area is approximately $r_1 = .225$ and the ratio of timberland to the total area is approximately $r_2 = .775$, it is possible

Rank:	6.5,	1,	4,	8.5,	13.5,	20,	28,	26,	24,	21,	23,	13.5,	12,	10.5,	17.5	$R_1=229$
T:	9	0	6	11	24	70	126	116	100	73	93	24	14	13	33	
Rank:	2	6.5,	16,	15	25	29,	30,	27,	22,	19,	17.5,	10.5,	5,	3	8.5	$R_2=236$
C:	2	9	32	31	110	147	180	118	82	41	33	13	8	5	11	

Figure 4. Mann-Whitney U Test; Data for Debris Slides in Timberland and Clear Land.

Source: Table V.

to obtain relative frequency distribution curves by multiplying the frequency distribution curves (Figure 3, p. 63) by $\frac{1}{\bar{r}_1}$ and $\frac{1}{\bar{r}_2}$ respectively. Inspection of these relative frequency curves (Figure 5) indicated that the mean density for timber is much lower than the mean density for clear land, that is, fewer slides occur per unit area of timberland than per unit area of clear land.

Reflection on the above observation initiated a study to investigate the statistical significance of the difference between these two mean densities. A discriminating orthogonal grid was constructed as an overlay for a map on which all debris slides, clear land, and timberland were designated. Each square grid element covered approximately 90.7 acres (36.7 hectares) on the map. For each grid element the proportion of timber area to the total area of the element (T-Ratio, Appendix A), as well as the number of slides in timberland (T-Slides), and the number of slides in clear land (C-Slides), were recorded. The resulting data consisting of 212 data points were accessed by an APL computer program. The program calculated upon demand a t-statistic, on the basis of random samples of sizes n_1 , n_2 , respectively, and on the basis of the null hypothesis that $\mu_C = \mu_T$ (i.e. that the mean density for "C" equals the mean density for "T"). The statistic was calculated as:

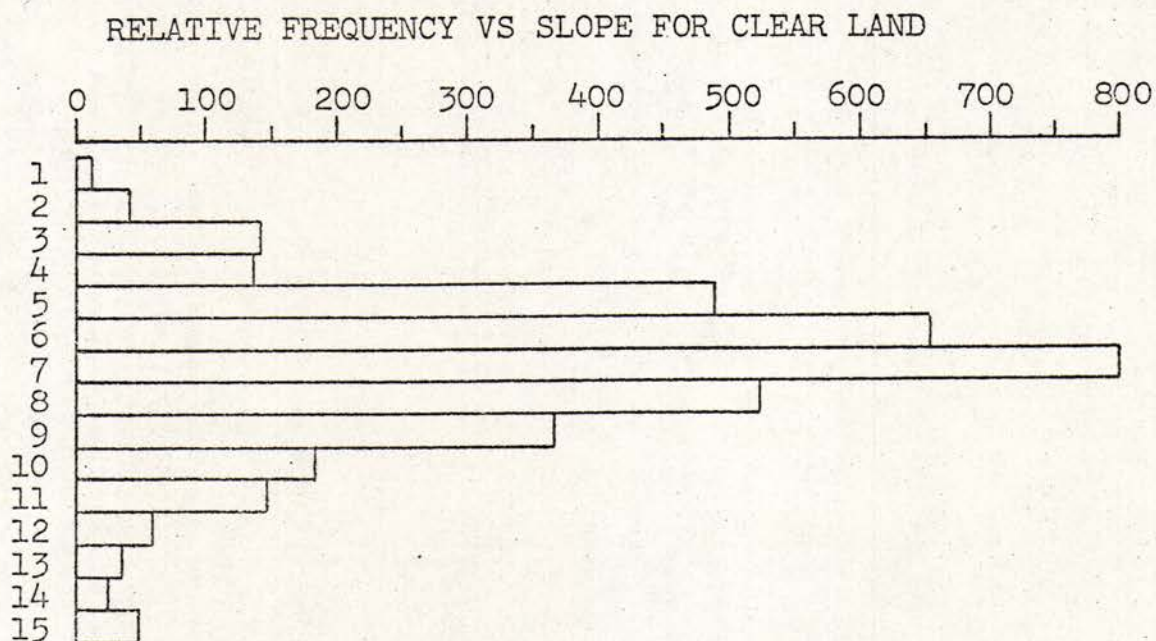
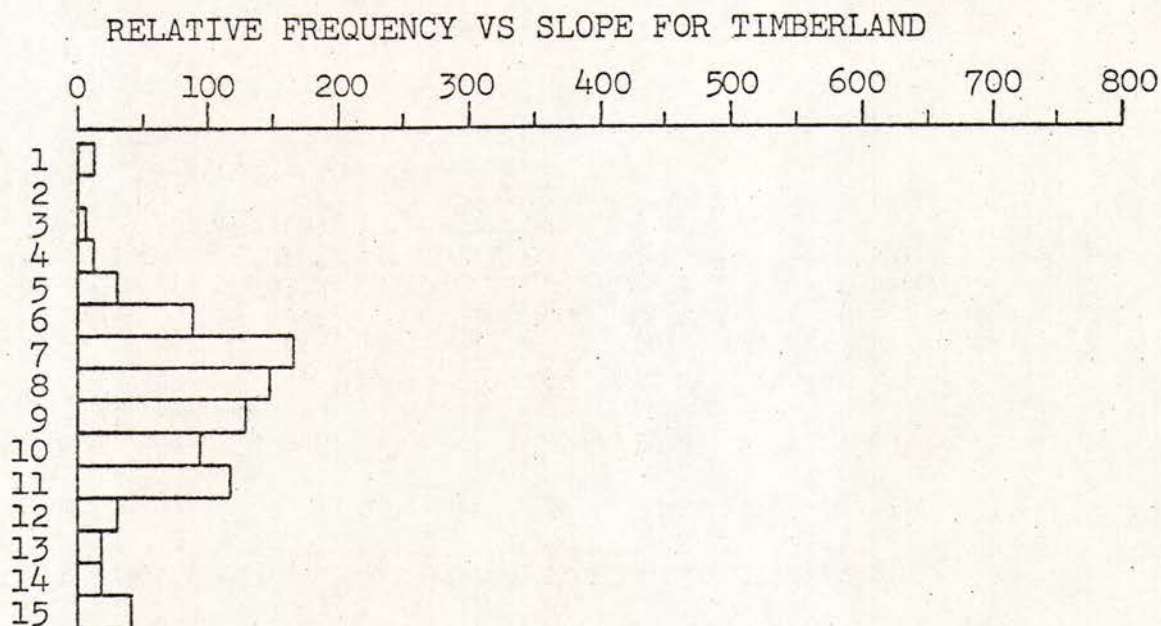


Figure 5. Relative Frequency vs Slope for Timberland and for Clear Land.

Source: Table V.

$$t = \frac{\bar{X}_C - \bar{X}_T}{\sqrt{\frac{S_C^2}{n_1} + \frac{S_T^2}{n_2}}}$$

where $\bar{X}_C$ is the mean density of slides for the random sample of n_1 clear elements. The symbol S_C stands for the standard deviation among the densities of the n_1 "clear" sample elements (Fischer, 1973) and where $\bar{X}_T$, S_T , n_2 are analogous parameters for the timberland sample.

A number of program runs for large sample sizes were made (Appendix B) and although the t 's calculated were usually large and positive, indicating a greater density of slides on the clear land, they were not large enough for the rejection of the null hypothesis $\mu_C = \mu_T$, hence we cannot substantiate statistically that the observed difference in mean density is significant. Apparently, the reason for the somewhat unexpected result is that the sample density variances are large, contributing to a large standard error (equivalently diminishing the t -statistic).

The total volume of debris slide transported material was 5,215,466 cubic feet (147,634.2 cu. m). The volume of debris removed in timberland totals 3,789,928 cubic feet (107,317.8 cu.m) which is 73 percent of the total material removed from the area. The 1,425,538 cubic feet (40,366.4 cu. m) removed from clear land is 27 percent of

the total volume removed. Despite the greater number of slides recorded in clear land, their average volume of 1,734.2 cubic feet (49.1 cu. m) is approximately one-third the average volume of 5,322.9 cubic feet (150.7 cu. m) of the slides in timberland. The volume of regolith removed per unit area in timberland is only slightly less than that for clear land. Simonett and Rogers (1970) report similar findings with respect to slide numbers and their volumes, for clear land and timberland in New Guinea. They also report no difference in "depth of material removed", in high forest and regrowth gardens, after excluding 13 excessively large bedrock slides.

Interpretation and Evaluation of Airborne Imagery

The most useful imagery was ASCS black and white photography at a scale of 1:20,000, taken on three dates in October 1969. The first was taken on 9 October when almost no leaf fall had occurred. The next date was 19 October at which time approximately 50 percent of the leaves had fallen at higher elevations, with almost no leaf fall at low elevations. The last of the three dates was 23 October when 60 to 70 percent leaf fall had taken place at high elevations. Approximately 73 percent of the total slides were visible on this photography. It was not possible to distinguish between slides and shale barrens, or slide chutes and eroded channels in small streams. The foliage on the dense timber combined with the steep slopes

account for the rather high percentage of slides which were not visible (Figure 6). For this reason extensive field work was necessary to insure a high degree of accuracy in locating the total number of slides and to properly identify what appeared to be slides on the photos, but in fact were not.

One mission was flown at approximately noon on 20 March 1971 with the University of Tennessee DC-3 research aircraft equipped with a Daedalus Thermal Infrared Line Scanner System and the Hasselblad 500 EL quadricamera system utilizing four different emulsion/filter combinations to obtain simultaneous coverage with the two systems. The mission was flown at an altitude of 8,000 feet (2,438 m) to determine the capability of these systems to detect slides rather than its usefulness as a quantitative tool. The problem of accurate navigation in remote areas with few good land marks, resulted in gaps in both types of imagery. The quality of the thermal imagery is considerably reduced by problems of scale, created by improper tape speed with respect to aircraft speed, and processing difficulties which combined to make it unusable. The resolution and image clarity (Figure 7) are sufficient to identify the larger features such as streams, roads, and topography but not adequate to identify slides. The results of the photography obtained on the mission are illustrated in figures 8 and 9. The Kodak Ektachrome Infrared Aero film was

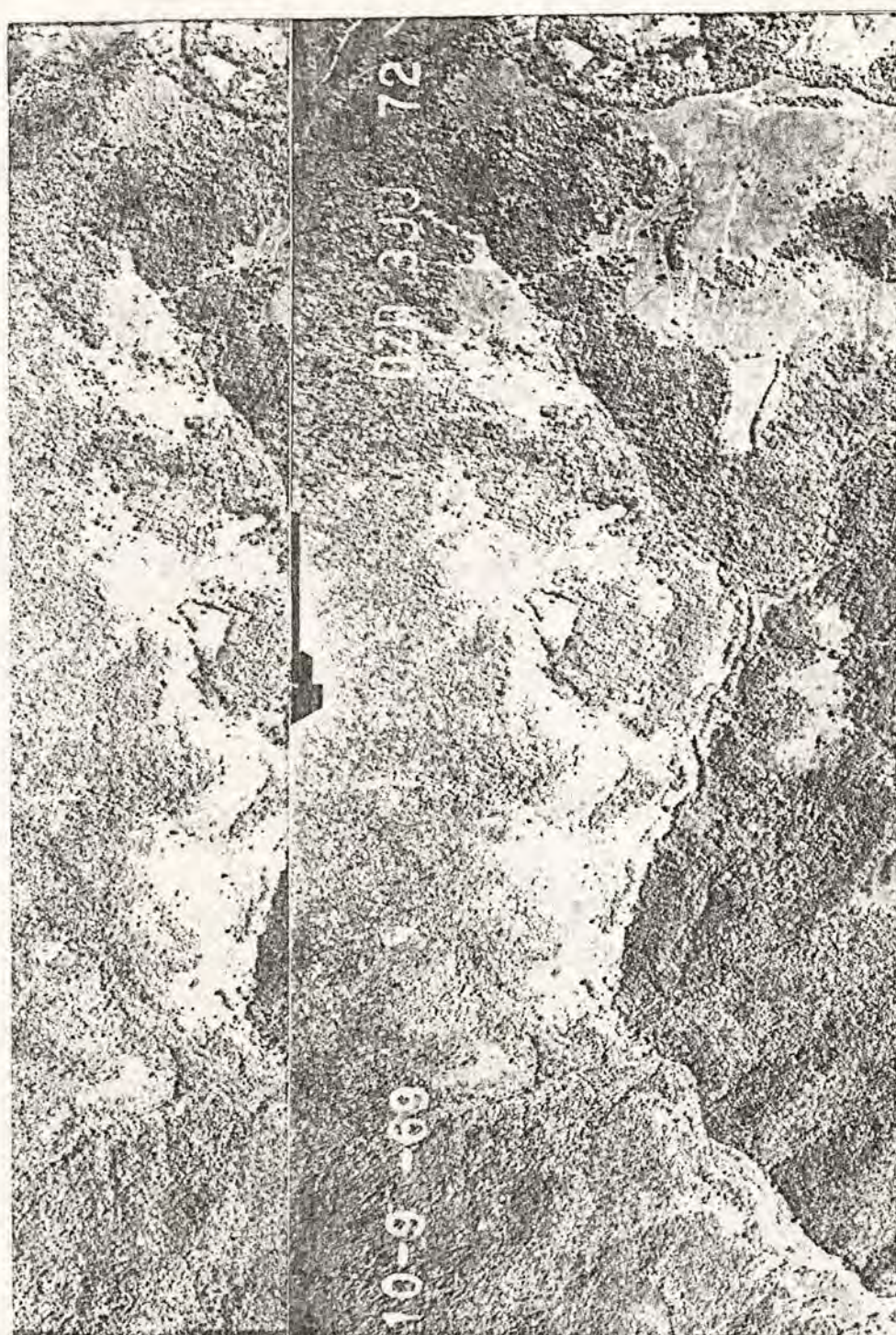


Figure 6. ASCS Stereophotograph Pair, northeast part of Research Area, containing Beard Place Valley. Nominal Photograph Scale is 1:20,000.

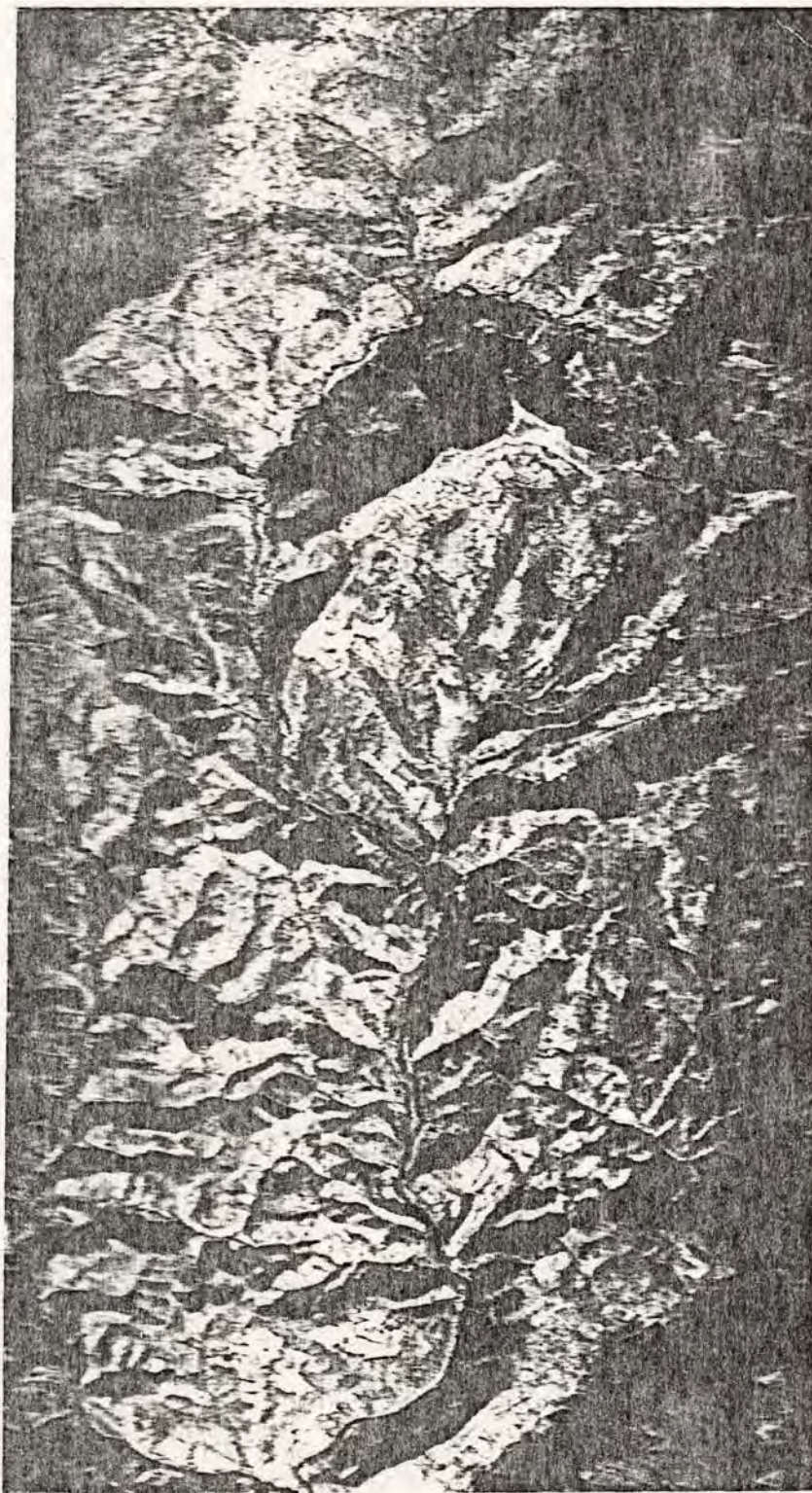


Figure 7. Noon 8-14 Micron Band Thermal Imagery of Robbins Run Tributary, 20 March 1971, Mission, Scale not constant in this 70 mm enlargement.



A.



B.

Figure 8. Vertical Aerial 70mm Hasselblad Quadri-camera System Black and White Photographic Imagery; Contact Prints of Identical Frames, north at top, Approximate Scale 1:60,000. "A" Kodak Plus-X Aerocon Film, Type 8401. "B" Kodak Infrared Aerographic Film, Type 5424, Wratten 25 Filter.



A.



B.

Figure 9. Vertical Aerial 70mm Hasselblad Quadri-camera System Color Photographic Imagery, Contact Prints of Identical Frames, north at the top, Approximate Scale 1:45,000, for comparison with Black and White Imagery see Figure 8. "A" Kodak Ektachrome MS Film, Type 2448. "B" Kodak Ektachrome Infrared Aero Film, Type 8443, Wratten 15.

the most effective for detecting unvegetated land surfaces. The scale of the photography does not permit identification of the smaller slides, but some of the larger slides and slide chutes are visible.



CHAPTER V

PLAUSTELE SLIDE LOCALIZING FACTORS

I. INTRODUCTION

The variation in debris slide distribution, even within a relatively small area of steep terrain, illustrates the difficulty of isolating the specific causes of debris slides. The processes are related to the interaction of a complex group of factors which contribute to slope instability, such as meteorological, climatological, slope, hydrological, geological, pedological, vegetational, and cultural. The primary factors associated with debris slide activity appear to be intense and/or prolonged precipitation, steep slopes, and presence of a soil mantle; however other factors must also be investigated. Varnes (1958) states that the origin of a slide can seldom be attributed to a single definite cause.

II. METEOROLOGICAL AND CLIMATOLOGICAL FACTORS

Meteorological factors are important in their role of localizing debris slide-producing conditions both in the frequency of severe storms and the size and character of the storms. Locally intense cells may occur independently as thunderstorms which limits the area of damage, larger areas may also be similarly affected by convectional activity associated with frontogenesis, or such precipitation

may occur within a larger pattern associated with a hurricane.

It is not possible to arrive at a definite recurrence interval for slide-producing storms in this part of the Eastern Allegheny Plateau and Mountains for several reasons. Two major reasons are immediately obvious. First, there are limited precipitation data for these remote areas and the time span of frequency of occurrence data is too short to be considered accurate. Second, the rate and amount of precipitation necessary to cause debris slides probably varies considerably because of the numerous factors that may be involved and therefore is not known with any degree of certainty. The critical values for precipitation appear to vary from one site to another, depending on the other factors.

The path of the intense rainfall in the August and September 1969 storms outlined by the distribution of debris slides and precipitation amounts, runs approximately North 64 Degrees East across Greenbrier County, from somewhat east of Cold Knob (Plate II), at an elevation of 4,345 feet (1,324.4 m), to Hock Knob, elevation 3,950 feet (1,203 m). The path of the intense damage is approximately seven and one-half miles (12.1 km) long and slightly over three miles (4.8 km) wide at its maximum width. This major debris slide localizing influence appears to be an example of "triggering" by orographic lifting of

moisture laden air masses by the mountains as described by Horn and McGuire (1960).

Two intense local storms or cloudbursts caused debris slides in West Virginia in the past 24 years. The first occurred in the Petersburg area, 17-18 June 1949, the second in the Renick area, 5-6 September 1969. The storm in the Renick area on 19-20 August 1969 was due to locally intense thunderstorm cells, apparently "triggered" by orographic lifting of a large moist maritime tropical air mass, as the remainder of Camille's dying circulation moved into the area.

Records of storms known to have produced debris slides in the Appalachian Highlands south of the glacial border, assembled by Bogucki (1970) and Clark (1973) Table VII, illustrate some of the characteristics of rainfall intensity and duration associated with slide occurrences. Detailed precipitation data are very limited, however this information provides some range of the variability. The Renick area within this group, probably has the best information available as to when the debris slides occurred, within a specific period of precipitation. In this instance, sliding occurred near the end of the period of intense precipitation. This need not be true for all areas because of the many factors involved.

The example presented in Figure 10 gives some concept of the orographic effect on storms or hurricanes moving

TABLE VII

RAINFALL AMOUNT-DURATION VALUES FOR SELECTED APPALACHIAN
DEBRIS SLIDE PRODUCING STORMS SOUTH
OF THE GLACIAL BORDER

Slide Area	Date	Amount (Inches)	Amount (Centimeters)	Duration (Hours)
Webb Mountain Area, TN	4-5 August 1938	11-15	27.9-38.2	4
Watauga Area, TN	{ June 1924 August 1940	?	?	?
Radford Area, VA	August 1940	?	?	?
Grandfather Mountain Area, NC	August 1940	?	?	?
Little River Area, VA	17-18 June 1949	9	22.9	several
Petersburg Area, WV	17-18 June 1949	16	40.6	24
Mt. LeConte- Sugarland Mt. Area, TN/NC	1 September 1951	4-6	10.2-15.2	1

TABLE VII (Continued)

Slide Area	Date	Amount (Inches)	Amount (Centimeters)	Duration (Hours)
Cove Creek Area, NC	30 June 1956	12	30.5	1
Blue Ridge Area, GA	22-24 August 1967	?	?	?
Spring Creek Area, WV	19-20 August 1969	4-14	10.2-35.6	3
Lovington Area, VA	19-20 August 1969	?	?	?
Spring Creek Area, WV	5-6 September 1969	2.10-15?	5.3-38.2	10

Source: Compiled by D. J. Bogucki (1970) and G. M. Clark (1973) from U. S. Weather Bureau Reports, U. S. Geological Survey Water-Supply Papers, U. S. Weather Bureau Technical Papers, and Tennessee Valley Authority Data, and other sources. Selected localities have been identified from archival and file aerial photography and have been field checked.

See Plate 1 for locations of Appalachian Debris Slide Storms South of the Glacial Border.

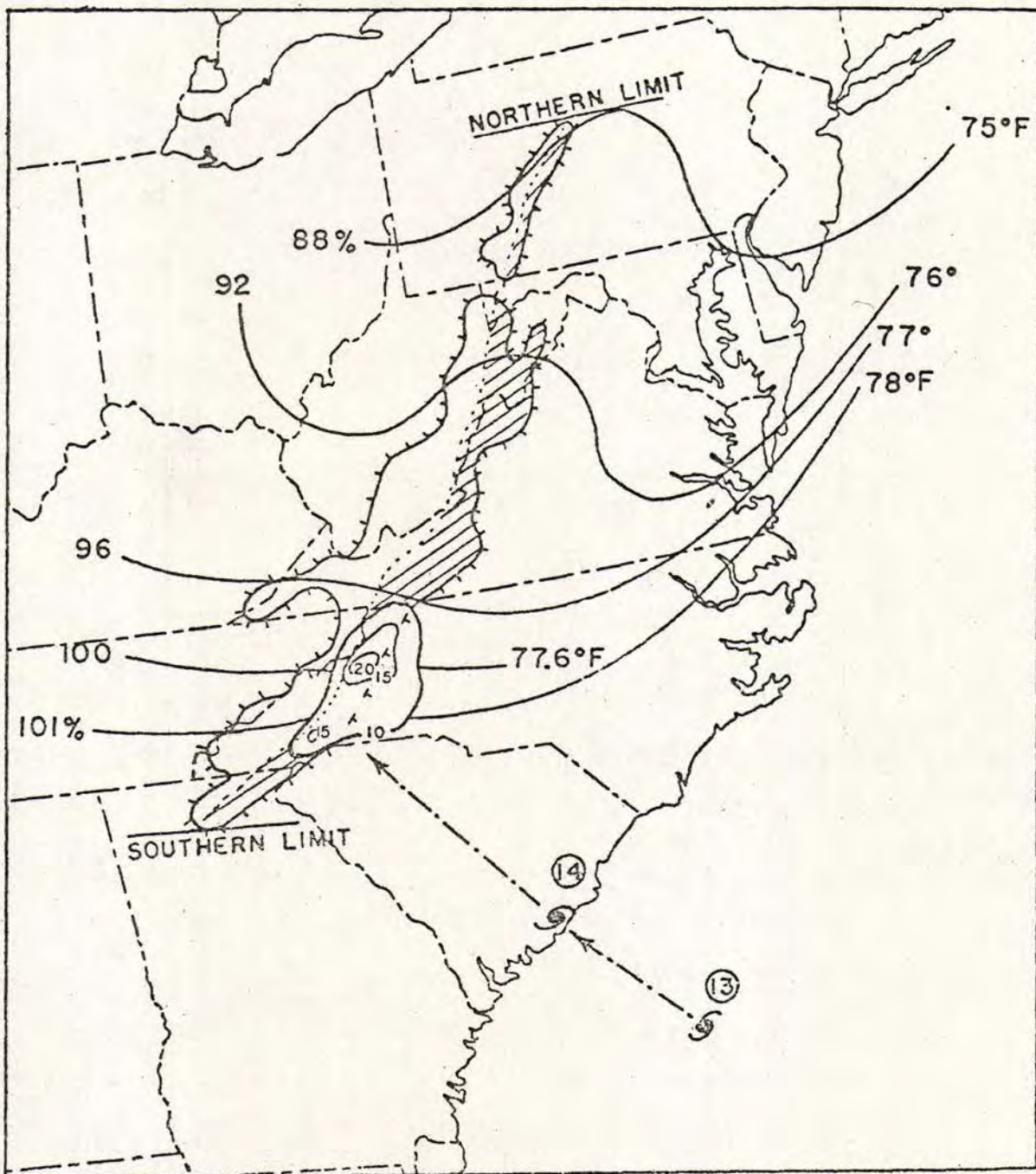


Figure 10. Transposition of July 13-17, 1916 hurricane rainfall. Transposable to shaded area. Line with spikes is 2000-ft. elevation contour. Light dashed line is ridge crest. Maximum dew point isopleths labeled as in figure 2.11.

Source: World Meteorological Organization, Technical Note No. 98, 1969.

over the Appalachian region. Hurricane Camille was moving eastward through West Virginia in August 1969 and crossed the zone within the spiked line which outlines elevations above 2,000 feet (609.6 m). The Spring Creek drainage basin is largely above this critical elevation, which may explain why it received such intense precipitation. The example shown in figure 10 is one of the most severe rainstorms of record for the Appalachian Mountains. The degree of orographic control is demonstrated by the coincidence of outline of the isohyet lines and topographic contour lines. Figure 11 illustrates the probably maximum precipitation for 24 hours in a 200 square mile (516 sq. km) area. The Spring Creek drainage basin lies within the 25.5 inch (64.7 cm) zone on this map. When the area of the Spring Creek drainage basin (36.4 square miles, 94.0 km) is considered, figure 12 would provide a better estimate of the rainfall to be expected in a 24 hour period.

The recurrence interval of a storm of sufficient intensity to produce slides is probably somewhat longer than 100 years. This corresponds to the experience reported by residents of the area, and that reported by Hack and Goodlett (1960), in another Appalachian study of the Little River area of Virginia.

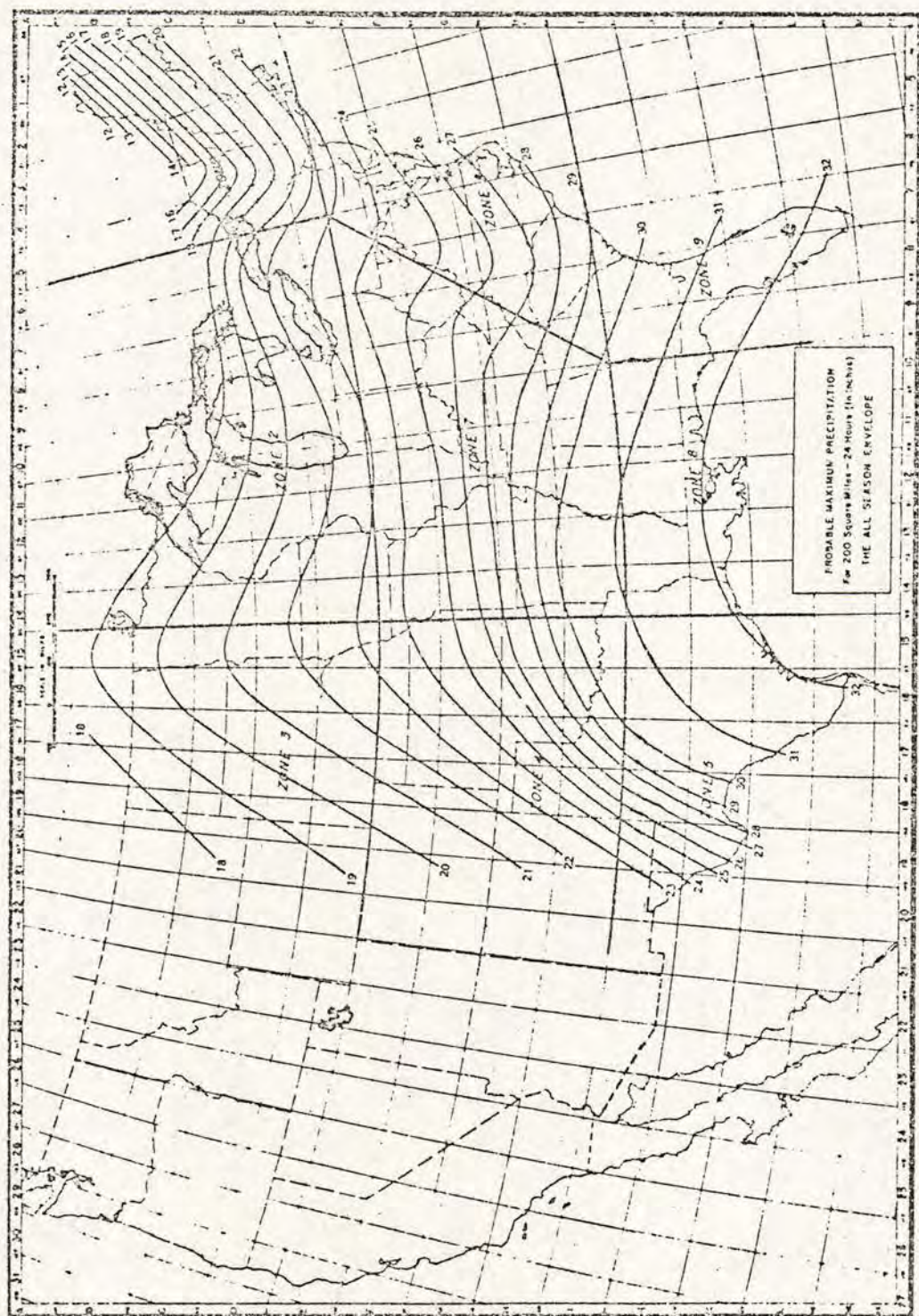
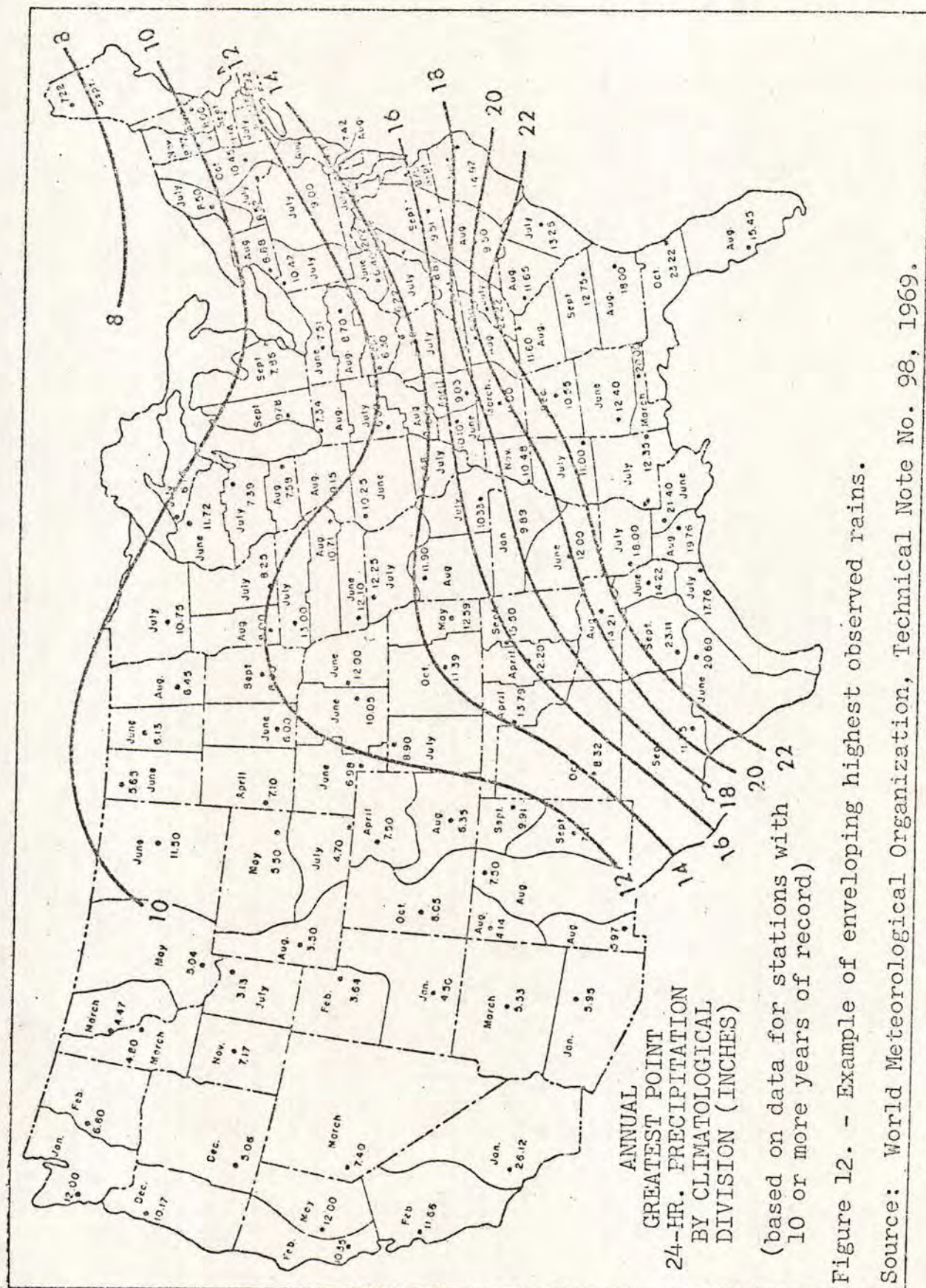


Figure 11. - Example of generalized PMP where orographic effects are minimum.
From (34).

Source: World Meteorological Organization, Technical Note No. 98, 1969.



III. SLOPE AND GEOLOGICAL FACTORS

Slope angle influences the location of debris slides because for a specific type of regolith there is an angle at which slope failure due to gravity will occur. During intense rainstorms various slope segments react differently in response to soil saturation and the velocity and depth of water on them. The geologic formations in this area tend to produce slopes with relatively long segments of uniform angle. There are resistant units with outcrops within several formations but they tend to be widely spaced on the slopes. Slides are concentrated both above and below these resistant units. The velocity of the surface water would increase while passing over the resistant unit and would have additional impact as it plunged over to the surface below. These resistant ledges range in height from one to 25 feet (.3 to 7.6 m).

The slopes on which debris slides have occurred include a range of values. Sharpe (1938) reported 20 to 40 degrees for the scar head where the initial movement occurs, to 15 degrees near the terminus. Flaccus (1958) reported slides in the White Mountains started on slopes which range from 25 to 35 degrees, with an average of about 32 degrees. Bogucki (1970) found the slope of the slide scar head area of Mt. LeConte slides averaged 40 degrees, with a range of 35 to 44 degrees.

Bedrock orientation does not appear to be a significant factor with respect to causes of localizing debris slides in this area. The general trend is a strike with a northeast orientation and a low angle of dip to the northwest. The majority of the values of measured dip angles range from one degree, to one and one-half degrees. A very small number of localized dip values range from 14 to 15 degrees; the direction however remains northwest. Joints are spaced 6 to 10 feet (1.8 to 3.1 m) apart where present, however much of the rock has poorly developed to indefinite fracture. The nature of the bedrock lithologies does not vary a great deal, nor does the soil produced from them exhibit striking differences. The percentage distribution of slides on the various lithologies appears to be controlled primarily by slope and area of surface exposure. Flaccus (1958) found no correlation between lithologies and slide occurrence. Bogucki (1970) found geologic control by high angles of dip but no evidence of bedrock type influencing slide locations.

IV. PEDOLOGICAL AND VEGETATIONAL FACTORS

A number of interrelated factors appear to have some impact on localization of debris slides when soil and vegetation are considered. Table V (p. 52) illustrates the relationship of slope to thickness of soil removed, preslide soil thickness, and frequency of slide occurrence.

In timber, the maximum soil thickness removed corresponds to locations where soil thickness was greatest. The maximum frequency of slides occurs where slopes are steeper and soil thickness is slightly less. Available information would indicate precipitation was of sufficient quantity and duration to saturate all soil thicknesses common to these slopes, therefore the steepness of slope appears to be more important than soil thickness.

The relationship of slides to pedological factors is somewhat different in clear land Table V (p. 52). The greatest soil thickness occurs at a more gradual slope than the slope at which the maximum thickness of soil removal has occurred, however the most frequent occurrence of slides follows the behavior of timberland and is found on steeper slopes where soil cover is thinner. Steepness of slope dominates soil thickness factors in clear land as in timber.

Two soil types comprise the major area of debris slides. The Dekalb Series (Gorman, and others, 1972) of Greenbrier County is formed from gray acid sandstone and some interbedded shale. It occupies elevations above 3,000 feet (914.4 m) where much of the land consists of steep slopes. The permeability is somewhat greater than the Teas Series which occupies most of the land below 3,000 feet (914.4 m) elevation. The Teas Series originates on the Bluefield and associated rock units of the Mauch

Chunk Group. There is no indication that either of these soil types contributes to localization of debris slides.

The area of Pocahontas County involved in this study consists primarily of Upshur stony silt loam (Williams and Fridley, 1938), with lesser amounts of Upshur silt loam, and a very small area of Leetonia stony loam. Again there is no indication that a specific soil type contributes to slope failure by sliding. The Upshur stony silt loam which has the greatest frequency of slides occupies the largest area of slope angles favorable to sliding, and therefore it is not possible to determine the role of a specific soil as opposed to slope angle.

Based on the observations in many slide scars the soils do not have pronounced horizons. They are classed as Inceptisols because they lack eluvial and illuvial horizons (Soil Survey Staff, Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys). This is an indication of a "young" land surface, in the sense that soil is constantly being formed and removed by slope processes, even though the topography is not entirely of recent origin. In addition, general slope instability is indicated by the lack of well-developed soil horizons.

Samples for X-ray analysis were collected from several elevations on the slopes ranging from the Hinton-Bluefield contact, near the slope crest, to lower elevations within 100 feet (30.5 m) of the base of the Bluefield. All

samples were taken from undisturbed soil profiles adjacent to the slide scar heads. Profile one was collected on a 42 degree slope, on a well drained site, in Taylor Place Valley (Plate III A). The site lies on the concave portion of the slope. Profile two was collected in Beard Place Valley (Plate III B), on a 35 degree slope at a well drained site, 200 feet (61 m) from the ridge crest, on the convex portion of the slope. Profile three was collected near the contact of the Bluefield-Hinton Formations at the uppermost slide in Beard Place Valley at a somewhat poorly drained site, on a 33 degree slope. Profile four was collected in Taylor Place Valley, on a concave portion of the slope near the ridge crest. The slope angle was 33 degrees. Profile five was collected from Taylor Place Valley on a 33 degree slope, from a well drained site, in a northwest tributary chute to the main valley. The slope is concave at the point of collection.

X-ray diffraction of soil samples (Table VIII) done at the laboratories of the West Virginia Geological and Economic Survey indicate the presence of Kaolinite comprising 40 to 50 percent, Illite 30 to 45 percent, Vermiculite 0.3 to 25 percent and Chlorite 0 to 1.7 percent. Montmorillonite was not detected. When Illite to Vermiculite ratios are compared within the profiles there is only a very slight rise in the amount of Vermiculite below the surface horizon, however the increase does not

TABLE VIII

CLAY MINERALOGY, X-RAY DETERMINATION, SPRING CREEK DRAINAGE BASIN

Depth Centimeters	Semi-quantitative Clay Mineralogy Results			
	Kaolinite	Illite	Vermiculite	Chlorite Mixed Layered Response
Profile 1				
0-4 cm	4	3	2	1 X
5-9 cm	4	3	2	1 X
10-20 cm	4	3	2.5	0.5 X
Profile 2				
0-1- cm	5	4	1	0 X
11-21 cm	5	3	0.5	1.5 X
22-32 cm	4.5	4	1.3	0.2 X
33-43 cm	5	3	0.3	1.7 X
44-54 cm	4.5	4.5	0.6	0.4 X
Profile 3				
0-5 cm	5	3	2	0 X
6-11 cm	4	3	2.5	0.5 X
12-50 cm	5	4	1	0 X

TABLE VIII (Continued)

Depth Centimeters	Semi-quantitative Clay Mineralogy Results			
	Kaolinite	Illite	Vermiculite	Chlorite Mixed Layered Response
Profile 4 0-105 cm	6	2	2	0 X
Profile 5 0-120 cm	4	2	1	3 X

Source: West Virginia Geological and Economic Survey, Laboratory Analysis.

continue throughout the remainder of the profile. There is no corresponding decrease in the proportion of Illite at these levels in the horizon. The results reflect the instability of soils on the slopes, which generally permit only limited soil horizon development. The variation in the proportion of Kaolinite, which is the dominant clay mineral, is only 10 percent throughout the sampled area and therefore apparently is not a factor in the localization of slides, nor is hydration of swelling clay minerals.

Vegetation in the research area consists of the mixed hardwood forest on approximately 78 percent of the area and clear land comprising the remainder. The clear land is primarily unimproved pasture with less than ten percent under cultivation or in hay crops. Despite the fact that the area of timber is a large percentage of the total, only 47 percent of the slides occur there. It appears that forest cover is a localizing factor in that it reduces the frequency of slides. Temple and Rapp (1972) find an even greater impact in Tanzania where forest reduces the number of slides to one percent of the total number. In a study of debris slide locations in the Appalachian Mountains, Scott (1972), concludes that healthy forest cover does reduce the incidence of debris slides. The results may have been different if high winds had accompanied the storms. In other areas such as Alaska, Bishop and Stevens (1964) and Swanston (1967) noted an increase

in slope failure by sliding after clear-cut logging operations. The Taranaki-Wanganui (Cumberland, 1944) region of North Island, New Zealand was forested until the late 1800's and early 1900's when the forests were burned and grass was planted. The area was then grazed by cattle and sheep. Thousands of debris avalanches have occurred on these slopes in recent decades. The clear land of the Spring Creek drainage basin comprises approximately 22 percent of the total area, however it has 53 percent of the slides. The clear land with unimproved pasture which is grazed by sheep and cattle appears to slide more readily than timberland, however the total thickness of soil removed tends to be less in pasture.

V. CULTURAL FACTORS

The major cultural factor that has localized debris slides in Greenbrier County is the clearing of forested land and subsequent grazing of this land. The process of land clearing extends over a period of time with some of the older pastures having been cleared approximately 100 years ago. In forested land, timber cutting was intense from the late 1920's through the mid-1930's. Railroads were built into the larger valleys to remove the logs, while horses were used to move the logs to the railroad. There are no reports of major fires associated with the logging in this area as there were in many other areas.

Logging with horses did not produce major slope damage in the way that today's mechanized equipment does. Selective cutting of timber continues in the area to this day.

Logging roads used by mechanized equipment produce slides both up slope from the trail and on the slopes immediately below. An area of timber cut 10 to 15 years ago, (Plate II, directly south of Kennison Mtn.), demonstrates this very well. The road cut and berm tend to slide easily in the more recently used roads, primarily because of the response of the oversteepened surfaces to sheet flow and undercutting. There is little evidence of impact in areas where logging was accomplished 35 to 40 years ago. The mechanized logging trails appear to interfere with the subsurface soil water movement in such a way that the water will burst through up slope from the highly compacted trail in the form of a water blowout because of the increased pore pressure. As an example of extreme pore pressure, Rapp (1963) reports an eye-witness account by a Norwegian of water spraying out in small cascades from the moving earth. Where this concentrated flow strikes the land surface below the trail, a second slide is initiated. In some cases whole segments of the trail are removed as one unit by the activity described above, rather than as two separate slides.

VI. OTHER FACTORS

Terzaghi (1950) mentions a number of factors which have been noted as being responsible for landslides such as construction operations, tectonic movements, earthquakes or blasting, melting snow, frost, lightning and seepage from artificial sources. Two of the factors listed, lightning and poor natural drainage, did exist in this area. Lightning may have been a factor by way of the vibrations created by the thunder, but was not associated with the time of slide occurrence in conversations with residents in the area. Lightning struck trees have also been noted as possible ways to create slides, however this is not the case to any degree in the area under investigation, because only one such tree was found near a slide scar head in a total of 1,534 sites visited. Natural seepage did not play a role in localizing a specific slide as illustrated by the tabulated data (Table VI, p. 58). A total of 77 debris slide sites were observed to have some degree of impaired drainage, or actually contained a seep or spring. The above number constitutes only 0.5 percent of the total number of slide sites, certainly not a possible cause of localizing slides. It is impossible to establish whether these specific slides would have occurred had the added moisture not been there.

Soils with greater stone content (Table VI, p. 58) resist sliding better than soils with a lower stone content illustrated by the 527 slides in timberland, which occurred on soils with the least stone and constitute 74 percent of the total slides in that land use category. When a comparison is made with stone content of soils in clear land and its affect on slide localization, 610 slides or 74 percent occurred in soils with the least stone content. The type of vegetation has no apparent impact on soils with a very low stone content. Based on field observations, the author interprets this to mean that the stone content reflects bedrock characteristics which have an impact on slide localization, rather than stone content within the soil affecting its potential to slide. The soils with higher stone content generally are derived from rocks with higher quartz sandstone content, especially in the higher elevations of forested land. Terzaghi (1950) explains that for quartz, water acts as an anti-lubricant. Therefore increased content of quartz-bearing stone in the soil would reduce its tendency to slide. The low stone content soils occur on shale and calcareous shale, especially the Blue-field Formation, which is extremely slick when wet.

One additional factor which appears to have prevented slides was noted on a small portion of the area located in the narrow strip of timber just west of Jacox Knob. An area consisting of approximately 30 acres (12.4 hectares),

most of it timber which was open and park-like in character, with very limited litter on the forest floor had no slides. Investigation revealed that the area had been grazed extensively by goats for a period of time. It would appear that the reduced infiltration on this type of land may have prevented slides. Slides were found surrounding this area, and evidence of heavy sheet flow is present on the land immediately down-slope. The storm does not appear to have missed this small area.

CHAPTER VI

SUMMARY AND CONCLUSIONS

A large number of debris slides, extensive channelway, and flood plain damage resulted from the two intense rainstorms of 19-20 August and 5-6 September 1969. The damage to buildings, roads and bridges was extensive. The loss of two lives and hardships imposed on the survivors add to the tragedy of these events.

The two storms followed much the same path through the area suggesting the importance of the topographic setting of the Spring Creek drainage basin. It is unusual for these two events to follow each other so closely, when the best available projections indicate an expected recurrence interval greater than 100 years. A total of 1,534 individual slide scar heads were found and a record was made of their physical characteristics. The majority of the slides were concentrated in an area of approximately 22.5 square miles (58.1 sq. km), in an elongate pattern directly under the area of most intense rainfall, in a total area of approximately 36.5 square miles (94.2 sq. km).

Movement is thought to be initiated by failure of a segment of slope regolith at the scar head with the mass of moving rock, soil, forest debris and water developing into a debris flow as it continued down slope. The path over which it flows is eroded to a depth ranging from a

few inches to several feet, forming a chute, which may be a new headward extension of an existing ephemeral channel or a deepening and widening of a channel that was present before the slide occurred. If the slide enters a large existing channel the material is usually carried entirely out of the area. Slides that occurred where no channel existed, spread their materials over the area down slope, with sheet wash removing material up to cobble size, and only lodged timber and boulder size material remains on the slope.

Slide dimensions mean values are 30.15 feet (9.2 m) for the length of the scar head, and 36.35 feet (11.1 m) for the scar head width. The range of slide scar head length is less than a foot (.3 m) for some slump blocks to 150 feet (45.7 m) for the large debris slides. The range in maximum slide scar head width is from less than ten feet to 590 feet (3.1 m to 159.8 m). The area of land disturbed at an individual site and the volume of regolith removed range from 20 square feet (1.9 sq. m), disturbed and 6.6 cubic feet (1.9 cu. m) removed to 64,900 square feet (6,029.2 sq. m) and 860,500 cubic feet (24,369.4 cu. m) removed. No attempt was made to establish the volume of material removed from the slide tracks and chutes or the total land surface area that was disturbed (as by sheetwash, erosion and by gullying) because of the large area involved and the lack of pre-storm channel size and form data.

Slide scar heads were found at elevations ranging from 2,150 feet to 3,960 feet (655.3 m to 1,207 m). Mean slope angles for individual slide scars on natural slopes range from 18.89 degrees in clear land to 16.67 degrees in timberland with a mean value for all slides of 34.97 degrees.

As a geomorphic process the debris slide is an agent in valley formation and modification. Sliding may initiate first-order valley development and increase headward length of existing valleys. Higher-order valleys and slopes may be modified. The relative importance of debris slides in valley and topography modification depends on the recurrence interval and severity of slide producing storms. The recurrence intervals are based on present climatic data. Climatic changes and revisions of climatic data through time may alter these results.

The Southeastern United States is most likely to receive severe rainstorms with debris slide producing capability according to available precipitation data. This hazard exists throughout the entire length of the Appalachian Highlands, but appears to be slightly less in the New York-New England area (Worth Meteorological Organization, Technical Note No. 98, 1969). Critical precipitation amounts will vary somewhat throughout this area because of other local factors that may be of more importance. Continued accumulation of data and additional studies will refine the relative importance of the factors involved.

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abstract

Slide location and distribution are controlled by the complex interaction of several natural physical factors and the influence of man's activity. The impact of man's activity is changing with time. At present some of the cleared land is being reforested or no longer grazed and cultivated so it can reforest naturally. An opposing influence is presented by greater use of the land for recreation, which involves construction of roads and recreational facilities and buildings. All known debris slides in the unglaciated Appalachian Highlands have been associated with heavy or prolonged rainfall on steep slopes. The added impact of man's activity involving these steep slopes must be considered when evaluating the probability of slope failure.

Precipitation is the critical localizing agent, especially when high infiltration rates cause sudden rise in pore water pressure, reducing soil and regolith shearing strength (Temple and Rapp, 1972).

How much rain and how fast it must fall to produce slides are not accurately known. Calculation of an accurate recurrence interval is practically impossible because of limitations of available data and is of little help to the people directly involved when two severe storms occur within an unexpectedly short time interval. The best available recurrence interval of somewhat greater than 100 years for the Spring Creek drainage basin has its

greatest value for assessing the relative importance of debris slides in drainage system and slope modification.

Slope form and inclination rank second in importance as slide localizing factors. Slide scars in forested land are most common in low order valleys and incipient water collection areas, especially if these correspond to areas of young regrowth timber or bear some impact of logging with mechanized equipment within the past 10 to 15 years. Slides in clear land are not associated with the drainage network to any great degree but respond directly to precipitation and slope inclination. Higher rates of water infiltration appear to increase the incidence of sliding. Minimum slope angle in forest land is 16.67 degrees while in clear land it is 18.89 degrees.

The most important geologic factor is lithology. Rock units that weather into uniformly fine textured soils with relatively low quartz content in both rock units and soil are much more prone to sliding in both timber and clear land (Terzaghi, 1950, Yatsu, 1967). Resistant units within the above lithology increase the incidence of sliding both above and below where they crop out. Inclination of bedding was too small to be of any significance and the vertically oriented joints appear to be too widely spaced to have an effect. Lithologies with relatively high quartz sand content and a characteristic of weathering in such a manner as to produce boulder size blocks and boulders

are located on steep forested slopes but are not prone to sliding.

Observations of exposed soil profiles and X-ray analysis of soil samples show the soils to be Inceptisols. No relationship between soil mineralogy alone and slope failure could be identified. Mass movement initiated by hydration of swelling clays is not proposed because these were not detected in the samples.

The influence of vegetation is primarily confined to its role in controlling the thickness of soil removed by the slides. In forested areas the entire thickness of soil and regolith was removed in 75 percent of the slides, while in clear land the entire thickness of soil and regolith was removed in 60 percent of the slides, indicating the tendency for soils vegetated by grass to fail above the "C" horizon boundaries. Tree types are too mixed for specific associations to be identified with slide localization, with the exception that no slides were found in laurel thickets. All other types of vegetation were found at slide sites.

Numerous possible causes of landslides have been proposed by various authors for occurrences in other areas. These were found to have no application or such limited application to the research area of this study as to be insignificant.

Detailed field investigation of a large area with an extremely large number of debris slides in the Spring Creek drainage basin provided the data for the analysis of factors causing debris slides in this physical setting and for locating the storm path with respect to the topography. The evaluation of imagery indicated the value of several types and conditions under which they were used. The ASCS photography was the most useful, though its usefulness was reduced by leaf canopy and shadows on steep slopes to the extent that it was necessary to visit each site to obtain the accuracy desired for this study. Twenty-eight percent of the slides would have been missed and a small fraction of a percent of the scars visible on the photographs would have been impossible to correctly identify. The four-emulsion film and thermal scanner mission was flown 18 months after the storms occurred, in March before leafing had occurred. The time element considerably reduced its possible effectiveness, despite the fact that the absence of leaves was a great help over the October 1969 ASCS photography. The slide chutes and splays which had made possible the location of many slides in the dense tall timber, on the October 1969 photography were now invisible. The importance of prompt aerial missions cannot be over emphasized. The Ektachrome Infrared Aero imagery was the most useful material acquired on the 1971 mission. The relatively small target provided by the slide scar heads

was inadequate for the thermal scanner to record with sufficient clarity to be useful, despite attempts to photographically enlarge the negatives and to enhance the results using a microdensitometer. Improper tape speed at the time of the flight and navigational problems which produced extensive holidays in the coverage compounded the problem.

The need for improving the timing and accuracy of the flight path is obvious and will provide data which will greatly reduce the field time required for this type of study. Accumulation of more meteorological data through time will improve the recurrence interval projections. It is doubtful whether great improvement can be achieved at the site of the individual slide until continuous monitoring of possible debris slide sites and model study is established. Further study will be useful in identifying more of the factors and their relative importance.

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APPENDIXES

APPENDIX A

DISTRIBUTION OF SLIDES WITH RESPECT TO LAND USE

LOCATION	T-RATIO	T-SLIDES	C-RATIO	C-SLIDES
1:	0.94	0	0.06	0
2:	1.00	0	0.0	0
3:	0.65	0	0.35	2
4:	0.75	0	0.25	0
5:	1.00	0	0.0	0
6:	0.90	0	0.10	0
7:	0.52	0	0.48	1
8:	0.70	0	0.30	5
9:	0.88	0	0.12	0
10:	1.00	0	0.0	0
11:	1.00	0	0.0	0
12:	1.00	0	0.0	0
13:	1.00	0	0.0	0
14:	0.55	0	0.45	0
15:	0.52	0	0.48	0
16:	0.38	0	0.62	4
17:	0.75	0	0.25	0
18:	0.85	0	0.15	0
19:	1.00	0	0.0	0
20:	0.73	0	0.27	0
21:	0.91	0	0.09	1
22:	0.25	0	0.75	6
23:	0.13	0	0.87	0
24:	0.85	0	0.15	0
25:	1.00	0	0.0	0
26:	1.00	0	0.0	0
27:	1.00	0	0.0	0
28:	1.00	0	0.0	0
29:	0.79	0	0.21	1
30:	0.70	0	0.30	0
31:	0.25	0	0.75	7
32:	0.39	1	0.61	0
33:	0.25	1	0.75	9
34:	0.77	0	0.23	3
35:	1.00	0	0.0	0
36:	1.00	0	0.0	0
37:	0.85	0	0.15	0
38:	1.00	0	0.0	0
39:	0.94	0	0.06	0
40:	0.75	0	0.25	0

APPENDIX A (Continued)

DISTRIBUTION OF SLIDES WITH RESPECT TO LAND USE

LOCATION	T-RATIO	T-SLIDES	C-RATIO	C-SLIDES
41:	0.55	0	0.45	0
42:	0.64	4	0.36	0
43:	0.70	9	0.30	8
44:	0.38	10	0.62	2
45:	0.20	18	0.80	27
46:	0.88	0	0.12	0
47:	1.00	0	0.0	0
48:	1.00	0	0.0	0
49:	1.00	0	0.0	0
50:	1.00	0	0.0	0
51:	1.00	0	0.0	0
52:	1.00	0	0.0	0
53:	0.90	0	0.10	0
54:	0.50	0	0.50	34
55:	0.32	5	0.68	30
56:	0.44	1	0.56	0
57:	0.50	0	0.50	0
58:	0.75	0	0.25	0
59:	0.36	0	0.64	0
60:	0.55	0	0.45	0
61:	0.21	0	0.79	0
62:	1.00	0	0.0	0
63:	0.90	2	0.10	0
64:	0.45	0	0.55	0
65:	0.32	0	0.68	0
66:	0.20	0	0.80	1
67:	0.34	0	0.66	4
68:	0.48	1	0.52	3
69:	0.45	19	0.55	7
70:	0.0	0	0.0	0
71:	0.70	6	0.30	0
72:	0.55	18	0.45	26
73:	1.00	29	0.0	0
74:	1.00	3	0.0	0
75:	1.00	0	0.0	0
76:	0.75	2	0.25	3
77:	0.62	11	0.38	5
78:	0.50	25	0.50	19
79:	0.38	10	0.62	39
80:	0.30	4	0.70	12

APPENDIX A (Continued)

DISTRIBUTION OF SLIDES WITH RESPECT TO LAND USE

LOCATION	T-RATIO	T-SLIDES	C-RATIO	C-SLIDES
81:	0.44	12	0.56	6
82:	0.50	4	0.50	0
83:	0.31	0	0.69	4
84:	0.94	0	0.06	0
85:	0.75	0	0.25	0
86:	0.85	7	0.15	3
87:	1.00	10	0.0	0
88:	0.96	18	0.04	0
89:	0.57	0	0.43	3
90:	0.50	0	0.50	8
91:	0.75	0	0.25	2
92:	0.80	7	0.20	0
93:	0.33	0	0.67	13
94:	0.82	0	0.18	0
95:	0.90	0	0.10	0
96:	0.30	0	0.70	0
97:	0.91	0	0.09	0
98:	0.82	0	0.18	0
99:	0.43	0	0.57	4
100:	0.56	3	0.44	0
101:	0.48	1	0.52	2
102:	0.40	2	0.60	1
103:	0.88	5	0.12	0
104:	1.00	11	0.0	0
105:	1.00	0	0.0	0
106:	1.00	22	0.0	0
107:	1.00	2	0.0	0
108:	1.00	0	0.0	0
109:	1.00	0	0.0	0
110:	1.00	0	0.0	0
111:	0.98	0	0.02	0
112:	1.00	0	0.0	0
113:	1.00	0	0.0	0
114:	0.74	4	0.26	0
115:	0.32	1	0.68	0
116:	0.50	0	0.50	0
117:	0.60	1	0.40	0
118:	0.32	0	0.68	0
119:	0.52	0	0.48	0
120:	0.45	0	0.55	1

APPENDIX A (Continued)

DISTRIBUTION OF SLIDES WITH RESPECT TO LAND USE

LOCATION	T-RATIO	T-SLIDES	C-RATIO	C-SLIDES
121:	0.80	1	0.20	0
122:	0.12	0	0.88	11
123:	0.40	0	0.60	0
124:	0.82	0	0.18	0
125:	0.87	0	0.13	0
126:	0.64	0	0.36	0
127:	0.42	10	0.58	1
128:	0.76	4	0.24	0
129:	0.85	17	0.15	8
130:	0.75	22	0.25	14
131:	0.82	5	0.18	0
132:	1.00	0	0.0	0
133:	1.00	0	0.0	0
134:	1.00	0	0.0	0
135:	0.82	0	0.18	0
136:	0.82	8	0.18	0
137:	0.82	62	0.18	8
138:	0.79	0	0.21	0
139:	0.55	1	0.45	1
140:	0.91	17	0.09	0
141:	0.60	4	0.40	1
142:	0.44	3	0.56	2
143:	0.82	0	0.18	0
144:	0.85	0	0.15	0
145:	0.97	0	0.03	0
146:	0.94	2	0.06	0
147:	0.82	3	0.18	0
148:	0.75	2	0.25	0
149:	0.62	0	0.38	0
150:	0.82	0	0.18	0
151:	1.00	0	0.0	0
152:	1.00	0	0.0	0
153:	0.62	0	0.38	7
154:	0.48	0	0.52	13
155:	0.30	26	0.70	23
156:	0.66	15	0.34	0
157:	0.55	15	0.45	2
158:	0.68	23	0.32	3
159:	0.80	3	0.20	0
160:	0.94	9	0.06	0

APPENDIX A (Continued)

DISTRIBUTION OF SLIDES WITH RESPECT TO LAND USE

LOCATION	T-RATIO	T-SLIDES	C-RATIO	C-SLIDES
161:	1.00	0	0.0	0
162:	1.00	0	0.0	0
163:	1.00	1	0.0	0
164:	0.90	7	0.10	0
165:	0.82	4	0.18	0
166:	0.85	23	0.15	0
167:	0.82	7	0.18	8
168:	0.18	1	0.82	20
169:	0.60	7	0.40	3
170:	0.40	6	0.60	3
171:	0.43	2	0.57	20
172:	0.75	0	0.25	0
173:	0.97	1	0.03	0
174:	1.00	0	0.0	0
175:	1.00	0	0.0	0
176:	0.48	0	0.52	0
177:	0.50	2	0.50	0
178:	0.85	0	0.15	0
179:	0.77	0	0.23	0
180:	0.76	1	0.24	0
181:	0.43	1	0.57	1
182:	0.36	3	0.64	0
183:	0.24	2	0.76	4
184:	0.52	10	0.48	2
185:	0.21	4	0.79	25
186:	0.12	3	0.88	50
187:	0.38	14	0.62	9
188:	0.82	33	0.18	0
189:	0.45	27	0.55	4
190:	0.98	8	0.02	0
191:	1.00	0	0.0	0
192:	1.00	0	0.0	0
193:	1.00	0	0.0	0
194:	0.95	2	0.05	2
195:	0.24	2	0.76	22
196:	0.64	4	0.36	12
197:	0.68	9	0.32	6
198:	0.88	4	0.12	3
199:	0.50	4	0.50	2
200:	0.97	0	0.03	0

APPENDIX A (Continued)

DISTRIBUTION OF SLIDES WITH RESPECT TO LAND USE

LOCATION	T-RATIO	T-SLIDES	C-RATIO	C-SLIDES
201:	0.82	6	0.18	0
202:	0.98	5	0.02	0
203:	0.38	0	0.62	1
204:	0.90	2	0.10	0
205:	0.91	9	0.09	2
206:	0.82	0	0.18	0
207:	0.50	3	0.50	2
208:	0.24	2	0.76	5
209:	0.12	0	0.88	20
210:	0.88	2	0.12	4
211:	0.24	0	0.76	13
212:	0.15	0	0.85	5

APPENDIX B

SAMPLE T-STATISTIC CALCULATIONS

ENTER SAMPLE $\overline{TSTAT}$ SIZES N1 N2...
:

101 101

.....
STATISTICS FOR THIS SAMPLING...

XBAR = 5.810993859
YBAR = 8.334223562
SX2 = 171.6951285
SY2 = 223.8224137
N1 = 101
N2 = 101
DEGREES OF FREEDOM = 200

T = 1.275071681

ENTER SAMPLE SIZES N1 N2...
:

131 131

.....
STATISTICS FOR THIS SAMPLING...

XBAR = 6.743681919
YBAR = 8.395471394
SX2 = 196.4498166
SY2 = 200.7863041
N1 = 131
N2 = 131
DEGREES OF FREEDOM = 260

T = 0.9485625548

APPENDIX B (Continued)

ENTER SAMPLE SIZES N1 N2...
:

80 80

.....

STATISTICS FOR THIS SAMPLING...

XBAR = 5.436391355
YBAR = 8.648197017
SX2 = 99.41106836
SY2 = 250.4867152
N1 = 80
N2 = 80
DEGREES OF FREEDOM = 158

T = 1.53576108

ENTER SAMPLE SIZES N1 N2...
:

80 80

.....

STATISTICS FOR THIS SAMPLING...

XBAR = 4.791785587
YBAR = 7.595089202
SX2 = 80.50659048
SY2 = 198.6778235
N1 = 80
N2 = 80
DEGREES OF FREEDOM = 158

T = 1.500615908

ENTER SAMPLE SIZES N1 N2...
:

80 80

ENTER SAMPLE SIZES N1 N2...
:

90 90

.....

STATISTICS FOR THIS SAMPLING...

XBAR = 6.907944824
YBAR = 8.153773461
SX2 = 177.2821419
SY2 = 226.7137884
N1 = 80
N2 = 80
DEGREES OF FREEDOM = 158

T = 0.5543892595

.....

STATISTICS FOR THIS SAMPLING...

XBAR = 7.824850696
YBAR = 7.820435489
SX2 = 252.1902395
SY2 = 225.0340525
N1 = 90
N2 = 90
DEGREES OF FREEDOM = 178

T = 0.001917392729

APPENDIX B (Continued)

ENTER SAMPLE SIZES N1 N2...

:

78 78

ENTER SAMPLE SIZES N1 N2...

:

120 120

.....

STATISTICS FOR THIS SAMPLING...

XBAR = 6.487239331

YBAR = 8.070527316

SX2 = 210.5643367

SY2 = 178.5891306

N1 = 78

N2 = 78

DEGREES OF FREEDOM = 154

T = 0.708837631

.....

STATISTICS FOR THIS SAMPLING...

XBAR = 5.547143496

YBAR = 8.348751034

SX2 = 140.7136853

SY2 = 213.561399

N1 = 120

N2 = 120

DEGREES OF FREEDOM = 238

T = 1.630525575

ENTER SAMPLE SIZES N1 N2...

:

80 80

ENTER SAMPLE SIZES N1 N2...

:

130 130

.....

STATISTICS FOR THIS SAMPLING...

XBAR = 7.956976463

YBAR = 7.629744125

SX2 = 292.547398

SY2 = 187.8376787

N1 = 80

N2 = 80

DEGREES OF FREEDOM = 158

T = 0.1335384882

.....

STATISTICS FOR THIS SAMPLING...

XBAR = 6.661224916

YBAR = 7.622449285

SX2 = 200.2849647

SY2 = 202.046692

N1 = 130

N2 = 130

DEGREES OF FREEDOM = 258

T = 0.5463920176

APPENDIX B (Continued)

ENTER SAMPLE SIZES N1 N2...

:

140 140

ENTER SAMPLE SIZES N1 N2...

:

48 48

.....
 STATISTICS FOR THIS SAMPLING... STATISTICS FOR THIS SAMPLING...

XBAR = 7.059026563

YBAR = 8.321931247

SX2 = 185.5485401

SY2 = 217.3240271

N1 = 140

N2 = 140

DEGREES OF FREEDOM = 278

T = 0.7444760725

XBAR = 5.559941963

YBAR = 10.86270344

SX2 = 86.73104592

SY2 = 312.6243872

N1 = 48

N2 = 48

DEGREES OF FREEDOM = 94

T = 1.83841228

ENTER SAMPLE SIZES N1 N2...

:

30 30

ENTER SAMPLE SIZES N1 N2...

:

50 50

.....
 STATISTICS FOR THIS SAMPLING... STATISTICS FOR THIS SAMPLING...

XBAR = 3.981127284

YBAR = 7.87060447

SX2 = 46.79365154

SY2 = 159.8376836

N1 = 30

N2 = 30

DEGREES OF FREEDOM = 58

T = 1.482018977

XBAR = 6.233506972

YBAR = 3.388577666

SX2 = 235.2462192

SY2 = 59.38983384

N1 = 50

N2 = 30

DEGREES OF FREEDOM = 98

T = 1.171962019

APPENDIX B (Continued)

ENTER SAMPLE SIZES N1 N2...

:

150 150

ENTER SAMPLE SIZES N1 N2...

:

25 25

.....

STATISTICS FOR THIS SAMPLING...

XBAR = 6.46052836

YBAR = 8.572679427

SX2 = 202.7763551

SY2 = 227.5280068

N1 = 150

N2 = 150

DEGREES OF FREEDOM = 298

T = 1.247046742

.....

STATISTICS FOR THIS SAMPLING

XBAR = 8.70530303

YBAR = 11.26201043

SX2 = 336.3747393

SY2 = 254.4305955

N1 = 25

N2 = 25

DEGREES OF FREEDOM = 48

T = 0.5259310699

ENTER SAMPLE SIZES N1 N2...

:

160 160

WS FULL

T_STAT 9 XX XXX V1;

ENTER SAMPLE SIZES N1 N2...

:

70 70

)COPY CONTINU

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STATISTICS FOR THIS SAMPLING...

XBAR = 6.885828543

YBAR = 5.288663945

SX2 = 246.4936024

SY2 = 88.48825771

N1 = 70

N2 = 70

DEGREES OF FREEDOM = 138

T = 0.7301095856

VITA

Raymond Henry Schneider was born in Bay, Missouri, on March 28, 1929. He was graduated from Owensville High School, Owensville, Missouri, in 1948, and was associated with his father in farming until he entered the United States Air Force in July 1951 where he served until his honorable discharge in July 1955. He received a Bachelor of Arts degree in geology from the University of Missouri in June 1959. He accepted a teaching assistantship at the University of Missouri in the summer of 1959 and began study for a Master of Arts degree in geology which he received in August 1961. Since September 1961, he has been employed as an Assistant Professor of Earth Sciences by the State University of New York, College of Arts and Sciences at Oswego, New York.

He began study for the Doctor of Philosophy degree at the University of Tennessee in September 1968 and was in residence there until June of 1970. He held a teaching assistantship in the Geology Department during the academic year 1968-1969. Mr. Schneider received the Doctor of Philosophy degree from the University of Tennessee in August 1973.

He is a member of the National Association of Geology Teachers, New York State Geologists, International Association for Great Lakes Research, The American Society of

Photogrammetry, American Association for Quaternary Environment, and Sigma Zeta.

Mr. Schneider is married to the former Marlene Wacker of Owensville, Missouri and they have five children.