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DEBRIS FLOWS AND LANDSLIDES RESULTING FROM THE JUNE 27, 1995, STORM ON THE NORTH FORK OF THE MOORMONS RIVER, SHENANDOAH NATIONAL PARK, VIRGINIA

BY

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Debris flows and landslides resulting from the June 27, 1995 storm on the North Fork of the Moormans River, Shenandoah National Park, Virginia

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ABSTRACT

During the evening of June 27, 1995, an intense rainstorm triggered nearly 100 landslides in an area of about 5 square miles within the drainage basin of the North Fork of the Moormans River in Shenandoah National Park, Virginia. Most of these landslides began as soil slips or debris slides and then transformed down-slope into debris flows that destroyed forests, stream flora and fauna, roads and trails. Debris flows coalesced within the drainage basin of the Moormans River and proceeded downstream out of the park and into Sugar Hollow Reservoir, part of the water supply for Charlottesville, Virginia. The reservoir acted as a debris-flow containment basin for deposits ranging from silt to boulders and including organic debris such as tree trunks and limbs. Containment of the debris by the reservoir saved eight or more private, downstream residences from nearly certain destruction. This report provides an inventory map (scale 1:24,000) of landslides and debris flows within the affected area, a description of the debris flows, the historical precedent for this type of event and potential hazards

that remain as a consequence of the storm.

INTRODUCTION

An intense storm during the evening of June 27, 1995 triggered landslides, including soil slips, slumps, debris slides and debris flows, and associated flooding along the North Fork of the Moormans River, about 16 miles northwest of Charlottesville, Virginia. The entire area immediately affected by the storm is within the Shenandoah National Park. There were no eye witnesses to the landslide activities. However, downstream flooding into the Sugar Hollow Reservoir and below the reservoir was witnessed by the reservoir manager and a number of residents along the river. The full extent of damage within the Shenandoah National Park could not be assessed until helicopter flights were made by the National Park Service on July 19, 1995. Figures 1 and 2 are oblique photographs of the debris flows and slides taken on this day. Figure 3 shows the scour from a debris flow on the waterfalls at Big Run, a popular destination for hikers in the area. A reconnaissance inventory of damage was also carried out on foot by the National Park Service on August 2, 1995. Hillslopes in highly weathered rock or saprolite failed as thin soil slips or as debris slides. Within a few hundred feet downslope, these failures rapidly transformed into debris flows. These flows are viscous highly fluid forms of rapid mass movement of rocks, soils, water, vegetation and air. The flow properties vary with water content, sediment size and sorting of particles. Most failures moved directly into the North Fork of the Moormans River and continued downstream as debris flows. In places where the river channel was widened, park trails and an access road along the valley floor were undercut and destroyed. Stream banks were cut into bluffs 15 to 20 feet in height, as shown on the west bank of the river in figure 4. The Sugar Hollow Reservoir acted as an impoundment for the downstream movement of boulders, silt, and trees. Overflow through the flood gates and over the spillway of the reservoir dam contributed to downstream flooding for another four miles, as far as White Hall, Virginia.

GEOLOGIC SETTING

The geology of Albemarle County was described by Nelson (1962). More recent summaries of bedrock geology have been published by Gathright (1976) for the Shenandoah National Park and by Rader and Evans (1993) for a more regional perspective. The area affected by the June 27 storm consists of a gently, easterly dipping sequence of quartzites and metasiltstones of the lower Cambrian Chilhowee Group unconformably overlying the Late Proterozoic metavolcanic sequence of the Catoctin formation. The metavolcanic rocks overlie the Late Proterozoic Swift Run

Formation, a thin, discontinuous unit of metamorphosed siltstone, conglomerate and quartzite, which in turn, unconformably overlies Middle Proterozoic quartzofeldspathic rocks of mostly granitic composition. These granitic rocks were igneous intrusions that were deformed and metamorphosed during the Grenville orogeny, about 1 billion years ago.

Within the area affected by the storm, the North Fork of the Moormans River runs from north to south (Plate I) and flows entirely within the Catoctin Formation. The more resistant silica-rich rocks of the Chilhowee Group form the crest of ridges on the west side of the drainage basin at elevations of approximately 2400 feet. The floor of the valley and the ridges on the east side of the basin are underlain by Catoctin Formation. The Swift Run Formation and the granitic rocks outcrop at elevations lower than 1200 feet in Sugar Hollow and underlie only the area of the Sugar Hollow Reservoir. (Gathright, 1976, Plate 3).

Within the Moormans valley, the Catoctin Formation is approximately 1000 feet thick, dips gently to the east at about 10 degrees and has a pronounced foliation striking north-south and dipping 30 to 35 degrees to the east. The predominant lithology is a fine-grained chlorite actinolite schist. Subsidiary lithologies include breccias rich in epidote and quartz, massive flows containing vesicles filled with quartz, albite, and/or epidote, and phyllites rich in muscovite and chlorite. The protoliths for these rocks were basalt, basalt breccia, and volcanic ash (Reed, 1955).

Prolonged exposure of these rocks has resulted in deep weathering into dense clayey, reddish yellow to brown soils. Deep saprolite as much as 50 feet thick mantles bedrock on both noses and hollows of mountain slopes. Thick saprolite is deepest in the quartz poor, chlorite actinolite schists. Relatively unweathered bedrock, also present on steep slopes, forms the knickpoints for most of the waterfalls in Shenandoah National Park including the falls on Big Run (Figure 3). Stream erosion and mass wasting have moved clay, sand and gravel downstream into Sugar Hollow. Since the construction of the Sugar Hollow dam 50 years ago, some of these materials have been deposited in the reservoir. A bathymetric survey of the reservoir following the June 27 storm was conducted by the Rivanna Water and Sewer Authority (RWSA). The survey reveals that about one third of the floor of the reservoir is now covered by a delta reducing by 15 percent the volume capacity of the reservoir. Most of that volume was deposited during the June 27 storm (Eugene Potter, RWSA, oral communication, 1996).

METEOROLOGY OF THE STORM

A series of storms struck central Virginia during the week preceding the June 27 storm increasing moisture in soils and weathered rock. A cold front stalled immediately west of the Blue Ridge Mountains as a moist southerly tropical air mass met a northerly polar air mass (Goldsmith and others, 1995). In the late afternoon and evening of June 27, a small intense storm developed over the North Fork of the Moormans River. The high topography of the Blue Ridge enhanced updrafts and turbulence and the storm cell intensified and stalled, producing exceptionally intense rainfall. The storm cell was similar, but smaller, than the cell that developed the same day, a few hours earlier, 30 miles northeast in Madison County (Smith and others, in press; Wieczorek and others, 1996).

National Weather Service Radar imagery did not detect the storm cell on the evening of June 27 that severely impacted the North Fork of the Moormans River. According to Carlton Frazier, manager of the Sugar Hollow Reservoir Dam, intermittent rain fell throughout the day. Beginning about 8:30 pm, continuous rain began to fall in the area of the dam and continued for 9 hours. However, the most intense rain was between about 9 pm and 11 pm. Mr. Frazier emptied his 5 inch rain gage twice and states that a total of a least 11.5 inches of water fell during this approximately two hour period. At the outset of the storm, one of the dam's eight crest gates was open and there was a 5-foot buffer between the water level in the reservoir and the crest of the dam. Between 9 and 11 pm the water rose rapidly and Mr. Frazier successively opened the remaining crest gates. By 11 pm all gates were open and the water stood only 18 inches below the crest of the dam. Figure 5 is a photograph taken July 16, 1995 of the Sugar Hollow Reservoir showing the dam, the tree debris floating in the water and the delta of sediment and debris at the far end of the reservoir.

The downstream effects of the released water were dramatic. At 7 PM, Virginia Power had received reports of power failure in Sugar Hollow from residents below the dam. At 9-9:30 pm, a lineman rearming a safety device on a pole near White Hall, Virginia, found that water had suddenly risen up to his knees within a few minutes. Rapidly rising water to chest level flooded his truck before he could drive to higher ground.

INVENTORY OF STORM EFFECTS

An inventory of storm effects was prepared using color infrared stereo aerial photographs at approximately 1:18,000 scale taken on August 22, 1995. The photographs display fine details of landslides, including soil slips, debris slides, debris-flow channels and fan deposits, and the evidence of flooding, erosion and deposition. Debris-flow and flood features were mapped onto U. S. Geological Survey 1:24,000 scale 7.5-

minute quadrangle base maps (Browns Cove and Crimora, Virginia, see Plate I). The map was field checked and parameters of the debris flows were measured during March-May, 1996.

The sites where landslides initiated on mountain slopes were easily detected on the color infrared aerial photographs because of the sharp tonal contrast between the exposed soil/bedrock in the soil-slip scars (white) and the adjacent mostly deciduous forest (deep red tone). The visibility of the soil-slip scars and the debris-flow channels depends largely on their width and surrounding forest canopy. Features narrower than about 30 feet wide were difficult to detect because tree canopy obscured these features, particularly near the edge of each frame where radial distortion is greatest. From the aerial photographs, nearly 100 individual slope failures were mapped. Inspection of these features in the field indicated that perhaps an additional 25 to 50 per cent were undetected in the photographs. These failures, noted during field mapping, are small and concealed beneath the tree cover.

DESCRIPTION OF LANDSLIDES AND DEBRIS FLOWS

Landslides associated with the June 27 storm in the Moormans River drainage basin took place in second growth or multigrowth forested areas. No correlation was observed between the age of the forest or health of the forest (for example, infestation of gypsy moth) with landslide occurrence.

The principal slope failures shown on Plate I are of two types: (1) shallow soil slips on slopes of approximately 30 degrees or greater which evolve within several hundred feet of travel into debris flows with well defined channels; these may extend for a thousand feet to the valley floor; and (2) massive debris slides within saprolite with deep scarps at the head of the failures, and broad poorly defined channels, usually less than 1000 feet in length. For this second type, failure is on slopes between 19 and 26 degrees; several large failures are on the noses of hills rather than within hollows.

Debris flows developed from individual large or coalescing soil slips on steep slopes of about 30 degrees, similar to debris flows in 1969 in Virginia (Gryta and Bartholomew, 1989), in California (Campbell, 1975), in 1985 in Virginia and West Virginia (Jacobson and others, 1989) and on the same day in Madison County, Virginia (Wieczorek and others, 1996). Most of the flows began as slope failures within the Catoctin Formation. Only two slides developed in areas underlain by quartzite from the lowest unit in the Chilhowee Group. It was noted however that blocks of quartzite litter the west slope of the Moormans River valley and are now incorporated in debris-flow fans at the Moormans River. Soil slips and slope failure were facilitated by the prominent easterly dip of foliation within the greenstones. Therefore, the majority of debris flows began on the west side of the valley and moved down the dip slope controlled by the foliation towards the Moormans River.

A number of smaller failures were investigated in the area of Big Run which are beneath tree cover and are too small to be shown on Plate I. These failures are typically slumps and soil slips on slopes ranging from 19 to 30 degrees. Many of these failures have not moved more than a few feet down slope.

Weathering of the metavolcanic rocks is intense and the debris-flow channels are choked with transported saprolite and shattered saprolite fragments. The flow channels are only moderately scoured by later runoff and gullies rarely incise deeper than the transported debris material to expose older colluvium or bedrock.

The great majority of debris flows reached the Moormans River without depositing debris. A few debris flows produced fans that rest on 10 degree slopes or less. Boulders in these fans rarely exceed six feet in diameter. Logs are a major part of the deposit, and several of the fans formed behind log jams. There were no observed log jams within the Moormans River. Surges within the river channel moved logs and other organic debris downstream into the Sugar Hollow Reservoir.

Debris flows moved down the Moormans River widening the channel, destroying portions of the road alongside the stream as well as bridges and trails. The steepened stream banks reveal older, pre-historic debris-flow deposits along the valley floor, which predate the establishment of the Shenandoah National Park in the early 1930's. Several bluffs reveal a sequence of two older debris flow deposits that are 15 feet thick each with an intervening fossil soil horizon (figure 4).

Surges of muddy debris moved downstream into the Sugar Hollow Reservoir and deposited a substantial delta of boulders and cobbles over an older delta of mud and gravel that has been built up over the 50-year life of the reservoir. Figure 6 is a photograph of the delta taken on July 19, 1995. The delta now extends underwater covering about one third of the floor of the reservoir. The new delta is a composite of discrete lobes about 30 feet in width with crude size sorting of larger fragments within each lobe and with a fine matrix supporting the fragments. The lobes apparently were built by successive surges of the debris-laden fluid. Evidence for deposition from a viscous slurry includes lack of imbrication of larger cobbles, matrix support of rock clasts, and the transport of boulders up to three feet in diameter onto the nearly flat surface (less than 2 degrees) of the delta.

HISTORICAL PERSPECTIVE

The Moormans River has been subjected to repeated flooding, in 1895, in 1924 and in 1942; the most recent major flood occurred in 1985 (Dr. A.R. Maslow, written communication, 1995). None of these floods were associated with landslides and debris-flows similar to those of the June 27, 1995 storm. Inspection of aerial photographs did not reveal old scars either exposing bedrock or in vegetation changes that would have resulted from debris flows, suggesting that there has not been major landslide - debris flow activity on the North Fork of the Moormans River for at least a half century. Scars from landslides at least 50 years old can be recognized in nearby central Virginia. For example, the scars from soil slips and debris flows from a 1949 storm on the Little River, Augusta County, Virginia and Wills Mountain, West Virginia can still be recognized. Nevertheless, field investigations in the Moormans River valley revealed abundant evidence for the presence of prehistoric debris flows in small depressions in the topography and in older deposits exposed by widening of the Moormans River channel during the June, 1995 event. No other historical event of debris flow activity has been recorded. An examination of tree rings on several "recent looking" debris fans on the east bank of the Moormans River about one mile north of the Reservoir showed that the forest both on and off the fans is about 70 years old (Tom Yanosky, 1996, USGS, unpub. data). This age coincides roughly with the cessation of logging in the area and the establishment of Shenandoah National Park. Thus, there has been no obvious debris flow since at least that time.

Clark (1987) documented 51 historical events with associated debris flows in the central and southern Appalachians during a 140-year period which suggests that conditions promoting debris flows occur somewhere in the region approximately every 2 to 3 years. However the areas severely affected are usually small: about 97 square miles from Hurricane Camille in Nelson County in 1969 (Kochel, 1987), about 30 square miles in Madison County on the same day on June 27, 1995, and about 5 square miles on the Moormans River. Because the total Appalachian area is large on the order of thousands of square miles, the probability of recurrence within a given region during the historical period of several hundred years is quite small. Average recurrence intervals of about 3000 to 4000 years were determined from Carbon 14 dates for debris flows in Nelson County, Virginia (Kochel, 1987). Preliminary information from Carbon 14 dates in Madison County also supports that recurrence intervals are on the order of thousands of years.

HAZARDS DURING FUTURE STORMS

The area of the North Fork of the Moormans River is almost entirely within the Shenandoah National Park. Hazards associated with a storm cell of this size, magnitude and location are principally related to hikers and campers in the area, automobiles at the park boundary, and fishermen at the Sugar Hollow Reservoir. Recurrence of debris flows and landslides of the magnitude of the June 27, 1995 storm are unlikely without a storm cell of equal intensity lasting for at least two hours and occurring subsequent to precipitation which had already saturated the soil and saprolite on steep slopes. The mountain slopes and channels that experienced landslides and debris flows in this event are probably less likely to experience additional debris flows because the majority of unconsolidated material has already been removed from the channels. However, a major debris flow chute above the falls at Big Run is an exception. Substantial amounts of loosened material remains in the upper end of the chute. This material could become detached during a heavy rain and impact the area around the falls on Big Run. The potential for flooding of the Moormans River has been slightly increased. This area can expect erosion and/or deposition of cobbles, gravel, sand and silt in excess of that normally experienced during large annual storms. Turbidity of the water reaching the Sugar Hollow Reservoir will be increased. The slightly increased potential for flooding will gradually be reduced as mountain slopes and channels are revegetated. In the unlikely event of a repeat of a storm with an intensity equal to the June 1995 storm, potential for debris flows has been reduced in drainages where unconsolidated material has been removed; flooding hazards will remain high throughout the area.

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FIGURE CAPTIONS

Figure 1. Debris flow scars on west bank of the North Fork of the Moormans River. The two scars on the left (south) side of the photograph are at Big Run falls. Photograph taken by National Park Service, July 19, 1995.

Figure 2. Debris flows on west bank of the North Fork of the Moormans River looking south. The two debris flows in the far distance are at Big Run. Photograph taken by National Park Service, July 19, 1995.

Figure 3. Waterfalls at Big Run showing stripping of regolith and vegetation. Photograph taken August 2, 1995.

Figure 4. Bluffs on North Fork of Moormans River created by the June 27 storm revealing two large prehistoric debris-flow deposits separated by a fossil soil horizon. Photograph taken March 15, 1996.

Figure 5. Sugar Hollow Reservoir showing the dam and floating logs. Delta created by debris flows is in the distance. Photograph taken by National Park Service, July 19, 1995.

Figure 6. Delta produced by debris flows in the Sugar Hollow Reservoir. Photograph taken by National Park Service, July 19, 1995.

FIG. 1

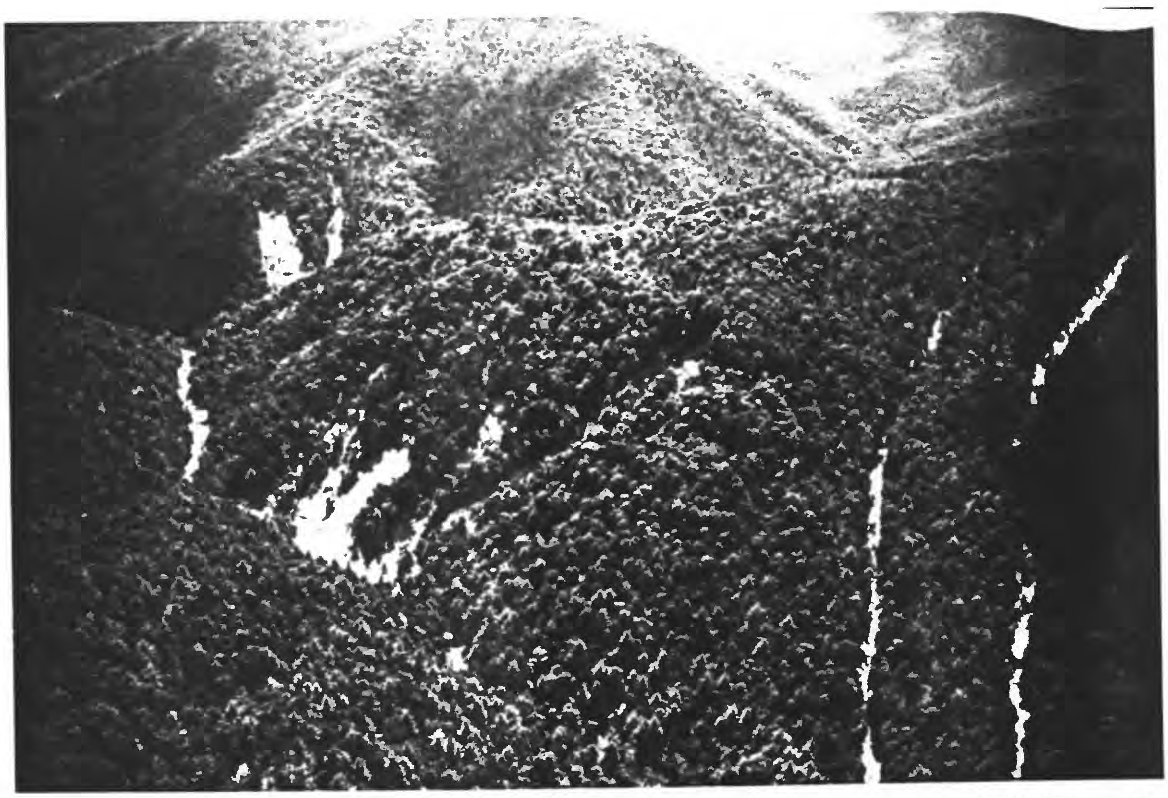

FIG. 2

FIG. 3

FIG. 4

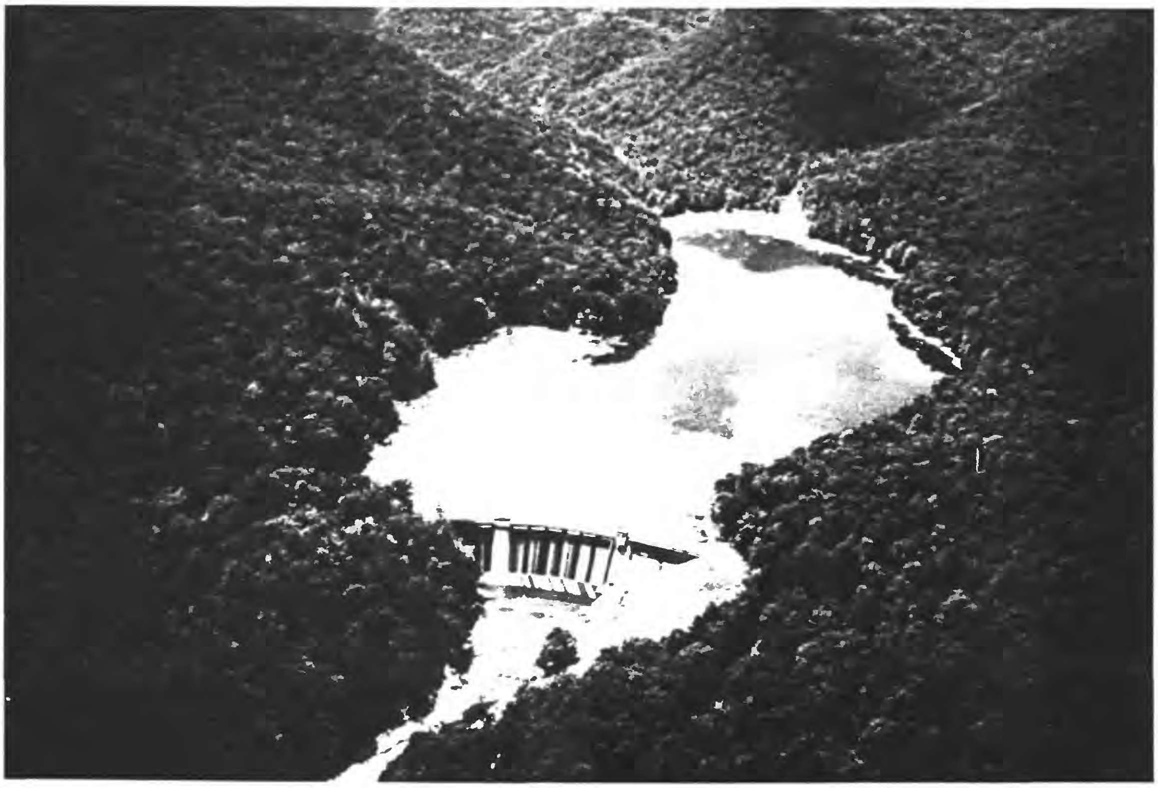

FIG. 5

FIG. 6