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PRELIMINARY INVENTORY OF DEBRIS-FLOW AND FLOODING EFFECTS OF THE JUNE 27, 1995, STORM IN MADISON COUNTY, VIRGINIA SHOWING TIME SEQUENCE OF POSITIONS OF STORM-CELL CENTER

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Preliminary inventory of debris-flow and flooding effects of the June 27, 1995, storm in Madison County, Virginia

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ABSTRACT

A severe storm on June 27, 1995, triggered hundreds of landslides from the steep hillsides of Madison County, Virginia. Most of these landslides transformed into debris flows that inundated the areas below causing damage to structures, roads, utilities, and crops. This report summarizes the meteorologic conditions of the storm, the methodology of preparing an inventory of debris flow and flooding effects, a generalized description of landslides, debris flows and flooding that occurred, the historical precedent for this type of event, and the potential hazards that remain as a consequence of the storm. Included is a map (scale 1:24,000) of the area showing debris flows and flood effects as well as the sequence of storm cell centers during the June 27 event.

INTRODUCTION

An intense storm on June 27, 1995, in a small area within Madison County in central Virginia triggered landslides, debris flows, and flooding. Because of the severity of these effects, many small rural communities were isolated by the failure of bridges, roads, telephones, and power lines. The full extent of the damage was not recognized until aerial reconnaissance was made several days later. The most severe effects were observed in the areas of heaviest rainfall in the Robinson, Rapidan, and Conway River drainages (Plate 1). Landslides on steep hillsides rapidly transformed into fast-moving debris flows[1] and many debris flows reached streams and rivers, contributing to flooding. Damage to houses, barns, roads, and power lines most commonly occurred where these debris flows emerged from steep ravines and spread widely over more gently sloping broad fan-shaped surfaces at intersection with valley bottoms. Houses and barns were crushed, inundated or moved by the bouldery debris and trees. Pastures and corn fields were covered by debris over broad areas; locally, livestock perished. Many uprooted trees were stripped of their bark, branches, and leaves and carried into streams and rivers. The tree trunks acted as battering rams against buildings and bridges greatly increasing the destructive effects of the flood waters. As each debris flow came to rest and discharged its pore water, finer sands, silts, and clays were washed from the bouldery debris-flow deposits and carried into streams and rivers contributing to the downstream sediment load of the floods.

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[1]Debris flow is a viscous, highly fluid form of rapid mass movement of granular solids, water, vegetation and air with flow properties that vary with water content, sediment size, and sorting of particles.

GEOLOGIC SETTING

The geology of Madison County was mapped and described by Allen (1963). More recent summaries of the geology of the underlying rocks have been published by Gathright (1976) and by Rader and Evans (1993). The area affected by the June 27 storm is underlain by quartzo-feldspathic rocks of mostly granitic composition. Allen has mapped these as part of the Pedlar Formation north and west of Graves Mill, and part of the Old Rag Granite to the south and east of Graves Mill. These rocks originated as igneous intrusions and were deformed and recrystallized during the Grenville orogeny, about 1 billion years ago. Recently determined ages of intrusion for these units are approximately 1075 Ma for the Pedlar Formation and 1115 Ma for Old Rag Granite. Both rock units were intruded by diabase dikes which presumably acted as conduits for the volcanic flows of the Catoctin Formation which formed about 570 million years ago and which outcrops to the west along the summit of the Blue Ridge. The majority of these dikes are nearly vertical sheet-like bodies that strike north to north-east and are less than 7 feet (2 m) thick. All of the rocks were altered more recently by metamorphism and deformation during the Paleozoic Era. The effects of this later deformation are mostly confined to a few well-defined faults and shear zones that cut through the bedrock of the region.

Prolonged exposure of the bedrock at the surface has resulted in deep weathering into loose friable soils with substantial quartz sand and clay. Weathered residual materials, or saprolite, as much as 30 feet (9 m) thick, mantles bedrock near the base of steep slopes. On steeper slopes (greater than 10 degrees), saprolite is thin or absent and rocks are overlain by colluvium formed by soil creep and slope wash and by diamict formed by accumulation from prehistoric debris flows. Relatively unweathered outcrops are prominent on the steepest slopes of 30 degrees or greater. Stream erosion has moved sand and clay materials downslope onto floodplains of the Robinson, Rapidan, and Conway Rivers. Much of the population of the area lives on or adjacent to these floodplains which provide a base for extensive farming of corn, hay, and livestock.

METEOROLOGY OF THE STORM

The intensity and distribution of rainfall during a series of storms, which struck central Virginia during late June of 1995, directly influenced the areal extent and magnitude of the landslide, debris flow and flooding effects in Madison County. Rain during the week preceding the June 27 storm had already increased moisture in thin surface soils and shallow weathered rock less than several feet thick. A cold front stalled immediately east 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 morning and early afternoon of June 27, thunderstorms developed over Madison County. Apparently, the high topography of the Blue Ridge Mountains enhanced updrafts and turbulence and the storm cells intensified and stalled, producing exceptionally intense rainfall. The heaviest amount of rainfall was observed in the hilly and mountainous areas west of U.S. Highway 29 and east of the crest of the Blue Ridge. The meteorologic conditions leading to this storm have been compared to those of other stationary thunderstorms that caused rapid onset flooding, i.e. along the Big Thompson River in Colorado in 1976 (McCain and others, 1979) and at Rapid City, South Dakota in 1972 (Schwarz and others, 1975).

Rainfall measurements were gathered from unofficial observers because no weather stations existed in the area most severely affected by the June 27 storm. A partial reconstruction of the timing of the storm, as well as landslide, debris-flow, and flood events can be reconstructed from these observations. The beginning of the rainfall was not noted precisely, but several residents reported being awakened by heavy rainfall about 2 am on June 27. From about 6 to 9 am there was a lull in the storm with little or no rainfall. Then between 10 am and 3 pm heavy rainfall was accompanied by abundant thunder and lightning with sparse hail. After about 3 pm, the rainfall tapered off and the storm had generally ceased by about 6 pm. Thus, rainfall in the June 27 storm occurred over a period of about 16 hours, the heaviest within about a 5-hour period. The maximum measured rainfall of 21.0 inches (533 mm) occurred near Aylor, approximately 1 mile (2 km) east of Sag Top. Using the unofficial measurements to calibrate the National Weather Service (NWS) radar observations of reflectivity during the storm, led to rainfall maximum estimates of about 23.75 inches (603 mm) over small areas (0.386 mi^2; 1 km^2).

High-intensity rainfall during the storm was documented at irregular time intervals. Near Syria, heavy rainfall at a rate of about 4 in/h (102 mm/h) occurred around noon. Near Aylor, an observer measured 6.2 in (157 mm) of rain between 11 am and 12:30 pm (equivalent to a rate of 4.1 in/ h; 104 mm/h). An observer near Fletcher measured in excess of 10 in between 12:30 pm and 3 pm (4.0 in/h; 102 mm/h). These measurements indicate that maximum intensity rates equal to or slightly exceeding 4 in/h (102 mm/h) occurred at several scattered locations and lasted for longer than an hour. The timing and location of intense rainfall was generally confirmed by radar imagery of the center of the storm track at 6-minute intervals that progressed from the northeast to southwest during late morning and early afternoon (Plate 1).

Eyewitness accounts confirmed that landslides and debris flows occurred during heavy rainfall between about 10 am and 1pm on June 27. About 10:30 am, a rapidly moving debris flow from below Sag Top, west of Criglersville, struck, crushed, and carried away a house, killing the occupant (Madison County Eagle, 7/6/95). Near Graves Mill at about 11:30 am, a family sought refuge in the second story of their house, which a debris flow displaced approximately 35-40 feet (11-12 m) from its foundations (Mr. Randall Lillard, oral commun., 8/28/95). Between 11:30 am and 12 pm, a debris flow sheared off a portion of a house along Garth Run below Kirtley Mountain while the occupants scrambled to safety (Mr. James Crossgrove, oral commun., 9/8/95). A debris flow destroyed one house and filled a pond within a residential development near Kinderhook about 1 pm.

INVENTORY OF STORM EFFECTS

Color infrared stereo aerial photographs at approximately 1:18,000-scale taken during

August 1995 were used to prepare an inventory of storm effects. Taken more than a month after the storm, the photographs still displayed fine details of landslides, debris-flow channels and deposits on the fans, and the evidence of flooding erosion and deposition. However, high water lines associated both with debris flows and stream flooding could not be discerned. Landslide and flood features were mapped onto U.S. Geological Survey 1:24,000-scale 7.5-minute quadrangle base maps (Big Meadows, Old Rag Mountain, Madison, Fletcher, Rochelle, and Stanardsville). Mylar overlays of the mapped features were scanned, an ARC-INFO file was created using digital line graph data, and a computer-generated map was created (Plate 1). The preliminary inventory map shows that the most severe effects were concentrated within an area of about 30 mi^2 (78 km^2 centered around Graves Mill, Virginia (Plate 1).

The sites where shallow landslides mainly within soil (soil slips) 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 debris-flow channels depended largely on their width and surrounding forest canopy. Features narrower than about 30 feet (9m) 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 photography more than 550 individual soil slips from this storm were mapped. Preliminary inspection of these features in the field indicated that perhaps an additional 25% were undetected in the photography. Many undetected flows are small and were concealed beneath the tree cover (these additional features were not added to Plate 1). Field mapping was conducted to distinguish between channels affected by debris flows or flooding.

DESCRIPTION OF LANDSLIDES, DEBRIS FLOWS, AND FLOODS

Debris flows had their inception during the June 27 storm as shallow landslides or soil slips on steep slopes of about 30 degrees, similar to debris flows in 1965 and 1969 in California (Campbell, 1975), in 1985 in Virginia and West Virginia (Jacobson and others, 1989) and in 1985 in Puerto Rico (Jibson, 1989). All of the landslides examined occurred in second growth or multi-growth forested areas. No correlation was observed between age of the forest or health of the forest (for example, infestation of gypsy moth) with landslide occurrence. The scarps of the landslides (not shown on Plate 1) are often only 3 to 6 feet (1-2 m) high. In the peripheral areas of the storm such as north of Graves Mill or west of the Conway River, debris-flow channels formed from single landslides. Near the areas of greatest storm intensity, such as Kinsey Run, Graves Mill, and Kirtley Mountain, multiple or clusters of landslides produced debris flows that converged and moved down a single channel. An observer just east of Graves Mill observed five surges of debris flows moving down the same channel with an estimated velocity of 20 miles per hour (9 m/s) about fifteen minutes apart (Mr. Leighton Brown, oral commun., 10/10/95). Kirtley Mountain was severely affected by multiple events. Plate 1 shows more than 50 landslide sites (uppermost end of mapped debris flows) that produced debris flows that moved down 6 separate channels. Most of the scarps that were examined are clear of partially moved material. No areas of extensive cracks and potential failure were observed above the scarps. Likewise, most channels were cleared of major accumulations of debris. Following the landslides and debris flows, continued rainfall on June 27 cut steep-walled gullies as much as 30 feet (9 m) deep into the channels exposing old colluvium and bedrock. The debris flows and subsequent fluvial erosion have made major modifications in stream channels resulting in new steep gullies, waterfalls, and plunge pools as deep as 15 feet (5 m). Trees adjacent to the channels commonly were stripped of bark on the up slope side to about 6 feet (2 m) above their base. Fallen trees and log jams choke the channels in many areas trapping sediment and boulders behind them. No impoundment of water was observed in any channel, behind the log and debris dams.

Debris was deposited either directly into second- or third-order stream channels (for example, the Staunton and Rapidan Rivers in Shenandoah National Park), or it emerged from ravines along the mountain slopes onto fans and the flood plains of the Robinson, Rapidan, and Conway Rivers (for example, along the Rapidan flood plain at Graves Mill). Typically, the debris flows lost momentum and deposited material in channels and on fans of gradients between 4 and 10 degrees. Most debris-flow deposits are between 3 and 6 feet (1-2 m) thick and consist of cobbles and boulders averaging about 2 feet (0.6 m) in diameter supported by a sandy matrix with minor clay in combination with edge to edge contact. A few of the fan deposits contain large boulders as much as 20 feet (6 m) in diameter some of which were exhumed and possibly rolled into their present position. Other boulders with lichens or weathering indicated previously exposed surfaces. Drainage after debris flows stopped and the continued rains and floods on June 27 winnowed out some of the fine-grained matrix material from flows. Aerial photographs show substantial outwash areas of sand downstream from the toes of the debris-flow deposits. The total distance from the main scarp of a landslide to the toe of any individual debris-flow deposit rarely exceeds one mile (1.6 km); hence debris material containing fallen trees within channels and fans are all of local origin.

The sudden onset of flooding of the Robinson, Rapidan, and Conway Rivers washed away many roads and bridges. More than 25 people in Madison County had to be rescued by helicopter during the flooding. Half of the farms in the county sustained damage. Most of the hay crop was lost and half the corn crop. Hundreds of livestock were killed, and 500 to 1000 miles (800-1600 km) of fencing was damaged or washed away. In Madison County, total damages were estimated at $64 million with an additional $29 million in agricultural losses (Goldsmith and others, 1995). The recurrence frequency of the flood peak on the Rapidan River near Ruckersville was in excess of 500 years. The flood peaks on the Rapidan River attenuated as the flood crest moved downstream. Near Culpeper, the flood peak had a recurrence frequency of slightly more than 100 years (Byron Prugh, written commun., 8/29/95).

Water covered the majority of the flood plains of streams and rivers within the area shown on Plate 1. The effects of the flooding varied locally; in some sections, flooding cut into stream banks and bottoms removing sand and gravel and exposing bedrock in places. Elsewhere, deposition occurred, resulting in sand and gravel bars or sheets of fine-grained sediment. Tree trunks lodged behind bridges deflected streams out of their banks around bridges. While these diversions protected some bridges, displaced streams imperiled other structures outside of the channels. Similarly, hedges or rows of trees protected some structures on the flood plain by catching debris and deflecting the flood waters around the structures. Deposition of sediment and evidence of stream erosion was the basis for establishing the approximate flood boundary shown on Plate 1; the maximum height of water during the flood was probably slightly higher.

HISTORICAL PERSPECTIVE

Madison County and adjacent Orange County have experienced previous catastrophic floods in April 1937, October 1942, and June 1972; but none of these were associated with the abundant landslide and debris-flow effects observed in the June 27, 1995 storm. No older scars from soil slips and debris flows were revealed by inspection of aerial photographs or team field reconnaissance. This suggests that there has not been a similar landslide and debris-flow triggering storm in the upper watersheds of the Robinson, Rapidan, and Conway Rivers of Madison County for at least the last century. The scars remaining from soil slips and debris flows from a 1949 storm on the Little River, Augusta County, Virginia (approximately 80 miles (130 km) to the west) can still be recognized. Clark (1987) documented 51 historical events with associated debris flows south of the glacial border in the Appalachian Highlands during the last 150 years. Whereas these catastrophic storm events occur somewhere in the Appalachians on the average of about once per 3 years (150 yr/ 51), they generally affect relatively small areas. Landslide and debris-flow effects in the Madison County storm were limited to an area of only about 30 mi^2 (78 km^2). Although frequent somewhere within the entire region, such events are not likely to be historically repeated in any single area for the limited period of record; average recurrence intervals of about 3000 to 4000 years were determined for debris flows in Nelson County, Virginia (Kochel, 1987). Although historical data suggest that recurrence rates for such extreme events are low, the presence of gently-sloping depositional fans along the flanks of the mountainous region indicates that debris-flow events were common in the Pleistocene and Holocene geologic record, about last two million years.

Rainfall duration and intensity during a storm event, as well as other geologic, topographic, and hydrologic factors within a region effect the triggering of debris flows (Wieczorek, 1987). The conditions of 1969 Hurricane Camille in Nelson County provide a comparison for the Madison County event because both events occurred in similar lithology and topographic setting in the Blue Ridge Mountains of central Virginia. The severe landslide/debris-flow effects in Nelson County from Camille were concentrated within an area of about 97 mi^2 (250 km^2) (Kochel, 1987). Reliable reports of 28 inches (711 mm) of maximum rainfall were reported over the central part of Nelson County during the storm that lasted about 7 or 8 hours (Williams and Guy, 1973). Maximum rainfall during the 1969 Nelson County storm was higher and the debris-flow effects occurred over a wider area than in the 1995 Madison County event.

HAZARDS DURING FUTURE STORMS

Unless there is a storm of similar magnitude to the June 1995 event, extensive landslides and debris flows are unlikely in Madison County. Rainfall data from this event and from

Hurricane Camille in Nelson County suggests that at least 20 inches (508 mm) of rain within less than 24-hour period are necessary to cause abundant landslides and debris flows within this part of the Blue Ridge Mountains. In Madison County, the mountain slopes and channels that experienced landslides and debris flows in this event are probably less likely to experience additional debris-flow problems because the majority of unconsolidated material has already been removed from the channels. Because of modification to the drainage channels, the potential for flooding has been slightly increased in drainages affected by the June 27 storm. These areas can probably expect erosion and/ or sedimentation of cobbles, gravel, sand and silt in excess of that normally experienced during large annual storms. This 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 major 100-yr type storm, potential for debris flows has been reduced in drainages where unconsolidated material has been removed; flooding hazards would remain high throughout the area.

Although the frequency of storms capable of triggering abundant landslides and debris flows is rare at any specific location in the Appalachians, it is possible to plan for avoiding the most hazardous areas. Debris flows caused the most damage in Madison County just beyond the mouths of channels where flows deposited their voluminous bouldery debris on the fans. Locating structures away from the channel mouths and ephemeral channels on these fans will significantly reduce the risk of debris flows.

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