DEBRIS FLOW SUSCEPTIBILITY MAP OF LARIMER COUNTY, COLORADO

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INTRODUCTION

The large-scale precipitation events of September 11 to 14, 2013 resulted in catastrophic flooding on the floors of existing stream and gulch valleys in Larimer County. In addition to the flooding within the 100-to 500-year floodplains, there were also many upland flows that occurred well above and outside mapped floodplains. These types of flows are classified as earth flows and debris/mud flows, which are considered geologic hazards. This report and the accompanying map coverage address only these types of hazards. Hydrologic flooding within main stream channels and their floodplains, rockfall, landslides, and other geologic hazards were not included in this study.

EARTH AND DEBRIS/MUD FLOWS

Earth and debris/mud flows are generally rapid-moving, turbulent, hyperconcentrated flows that are bulked with entrained sediment that has been eroded from a slope. Conditions for these types of flows are: steeper channelized slopes, loose soils or disaggregated rock, and sufficient water from either rapid precipitation runoff and/or saturated ground conditions. The density of mud matrix of these hyperconcentrated flows gives them the hydraulic “lifting” capacity to mobilize and “float” very large boulders, trees, and any other large debris in its pathway. Other characteristics of debris/mud flow are lateral levees that form along the sides where flow rates slow and frictional shear forces of the entrained aggregate re-engage. Where slope grades decrease, debris flows can plug channels and form alluvial fans by channel migration and lateral spreading of successive flows. Initiations of these types of flows are usually a combination of high precipitation events, rapid erosive overland flows, and soil-slip type landslides. Triggering thresholds are lower, and risk higher, in locations where forest fires have occurred. Land-use impacts can vary widely depending on the site-specific velocity of the flow, depth or thickness, and bulking factor and debris entrained within it; from nuisance flooding of a thin low-viscosity mud to catastrophic bouldery debris with the consistency of wet concrete that can collapse walls, knock homes off foundations or completely destroy a structure.

MAP GENERATION PROCESSES

This dataset was generated by a multi-step process that included mathematical modeling, verification of outlined areas by professional geologists, and geoprocessing functions using GIS. Initial source areas and run-out zones were calculated using Flow-R (Flow path assessment of gravitational hazards at a Regional scale) (Horton and others, 2013; http://www.flow-r.org/), a MATLAB-based flow-path modeling program. Flow-R was developed at the University of Lausanne for empirical modeling of regional susceptibility assessments of debris flows. It has been used successfully in many projects around the globe and for a variety of different gravitational hazards, including rockfall and avalanche.

Flow-R requires a digital elevation model (DEM) as the base dataset; in this case a mosaiced 10meter U.S. Geological Survey National Elevation Dataset (NED) of Larimer County. From the 10m DEM, Flow-R generated a stream network that was used to calculate the debris flow pathways. Land-use and geology were not considered in the model, mainly due to time limitations and ubiquity of geologic rock types over much of the area. To further constrain the model, a stream curvature and slope map created from the 10-m DEM were added to the list of inputs. On the basis of the studies by Horton and others (2011) of similar mountainous terrains, this model used a stream curvature of <-2 and slope values ≥15° and ≤40°. Flow-R has several built-in spreading algorithms and friction models. In this case, an exponent value of 6 (the greater the exponent the more convergent the flow) was used in conjunction with the slope-related spreading algorithm of Holmgren (1994). The friction model of Perla and others (1980) was utilized with $\mu = 0.09$ and M/D = 30 where μ is coefficient of friction, and M/D the mass-to-drag ratio. Mapped debris flows from the September 11-14, 2013 flooding events by Morgan and others (2013) and the U.S. Geological Survey for Larimer County were used to calibrate the model where feasible.

The resulting raster dataset from Flow-R was converted into polygons using ArcGIS. The polygons were overlain on stereo National Agriculture Imagery Program (NAIP) using the StereoAnalyst extension in ArcGIS and in Google Earth to compare source areas and run-out zones with post-flooding satellite imagery and topography. Polygons were modified using the post-flooding imagery, topography, and geology, as well as field observations. Flow-R effectively modeled most source areas and run out zones in steeper terrain. In areas of more subdued topography, Flow-R underestimated the source areas and run out zones. Thus, the resulting polygons required modification by a geologist. Due to limitations imposed by the 10-m DEM, stream channel bottoms and fans were manually digitized in some areas where the model segmented the channel polygons. In addition, holes in large run out zones, another issue imposed by the DEM and artifacts derived from the modeling process were manually smoothed or deleted. The verified polygons were imported into ArcGIS and were cleaned using the “merge” and “eliminate” geoprocessing functions.

HOW TO USE THIS DATASET

The polygons on this map coverage outline those mountainous and foothill areas of Larimer County that may be susceptible to debris/mud flow hazards during extreme precipitation events. Debris flow behavior and occurrence is very difficult to predict. For new development within the mapped zones, site-specific geotechnical or engineering geology reports should investigate and address the potential risk of debris/mud flow hazards prior to the issuance of building permits or land subdivision. The data were generated at a scale of approximately 1:24,000; limitations of this coverage relate to the scale of the 10-m DEM that it was created from. The data accuracy is not verified beyond a scale of 1:24,000. This map is not meant to assign risk or take the place of a site specific investigation and should not be used in that manner.

Small, isolated areas that may not be included in the polygon coverage could potentially run following heavy precipitation. Factors such as land modification from development or wildfire can also impact drainage and debris flow patterns beyond the areas shown in this map.

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