

FOOTHILL AND MOUNTAINOUS REGIONS IN BOULDER COUNTY, COLORADO THAT MAY BE SUSCEPTIBLE TO EARTH AND DEBRIS/MUD FLOWS DURING EXTREME PRECIPITATION EVENTS

by

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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 Boulder 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 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 10-meter U.S. Geological Survey National Elevation Dataset (NED) of Boulder County. From the 10-m 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 $\geq 15^\circ$ and $\leq 40^\circ$. 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) for Boulder 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. Flow-R effectively modeled 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 professional geologist. Due to limitations imposed by the 10-m DEM, stream channel bottoms 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, were manually 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 Boulder County that may be susceptible to debris/mud flow hazards during extreme precipitation events. For new development within these 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 was 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. Use of the data beyond a scale of 1:24,000 is not recommended. This map is suitable for informational and planning purposes only and is not meant to assign risk or take the place of a site-specific investigation.

The degree of susceptibility to a particular geologic hazard, in any given area, is related to ever-changing natural and human-induced conditions. Any alteration in the natural landscape may increase or decrease susceptibility to a particular hazard. This dataset is based upon our understanding of existing conditions. Because of limitations associated with the map scale, the polygons on this map do not cover all areas that may be subject to shallow landslides or soil slips which could mobilize into debris flows and impact structures.

REFERENCES

Holmgren, P., 1994, Multiple flow direction algorithms for runoff modeling in grid based elevation models — An empirical evaluation: *Hydrological Processes*, vol. 8, no. 4, p. 327-334.

Horton, P., Jaboyedoff, M., Zimmermann, M., Mazotti, B., and Longchamp, C., 2011, Flow-R, a model for debris flow susceptibility mapping at a regional scale — some case studies: *Proceedings of the 5th International Conference on Debris-Flow Hazards Mitigation: Mechanics, Prediction and Assessment*, University of Padova, Italy, June 14-17, 2011, *Italian Journal of Engineering Geology and Environment*, p. 875-884, on-line at:
http://www.ijege.uniroma1.it/rivista/5th-international-conference-on-debris-flow-hazards-mitigation-mechanics-prediction-and-assessment/topic-8-prediction-and-assessment-of-debris-flow-hazards/flow-r-a-model-for-debris-flow-susceptibility-mapping-at-a-regional-scale-2013-some-case-studies/ijege-11_bs-horton-et-alii.pdf

Morgan, M.L., Fitzgerald, F.S., and Morgan, K.S., 2013, Preliminary Survey of Debris Flow, Landslide, and Rockfall Deposits as a result of the September 11-14, 2013 Flooding Events, Boulder County, Colorado: on-line at:
<http://www.arcgis.com/home/item.html?id=39e6c721635f40c8add90112c9d1a646>

Perla, R., 1980, A two-parameter model of snow-avalanche motion: *Journal of Glaciology*, vol. 26, no. 94, p. 197-207.

Horton, P., Jaboyedoff, M., Rudaz, B., and Zimmermann, M., 2013, Flow-R, a model for susceptibility mapping of debris flows and other gravitational hazards at a regional scale: *Natural Hazards Earth Systems Sciences* 13, p. 869-885.