COLORADO GEOLOGICAL SURVEY

Open-file Report OF-18-11

Debris Flow Susceptibility Map of El Paso County, Colorado

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ABOUT THIS MAP

This map is intended for use by planners and regulators to support review of site-specific geologic hazard reports submitted for development purposes as required by law, and by professional geologists planning detailed site-specific geologic hazard studies. The red polygons represent areas that may be susceptible to debris flows, especially during extreme precipitation events. New and existing structures, roadways, bridges, utilities, and other infrastructure located within these mapped debris-flow susceptible areas may be at risk of structural damage and/or sediment inundation. For new/proposed development within these areas, site-specific geologic hazard reports should be required prior to approval of land subdivision or the issuance of building permits. These reports should discuss the degree, limits, and potential impacts of the hazard to the proposed development or land use changes; proper debris-flow mitigation techniques; and feasibility of any recommended mitigation techniques.

DESCRIPTION OF THE HAZARD

For this map and report, the term "debris flow" comprises a range of related natural phenomena variously described in Colorado State statutes (Rogers et al., 1974) and scientific and engineering literature (e.g., Costa, 1988; Pierson, 2005; Moase et al., 2017) as mudflows, debris flows, and/or sediment-laden floods (hyperconcentrated flows). Distinguishing between these phenomena can be important for site-specific hazard analysis and mitigation design, but is beyond the scope of this project.

Debris flows are common hazards in mountain and piedmont valleys and along the steep flanks of buttes, mesas, and hogbacks in Colorado (e.g., Mears, 1977; Costa and Jarrett, 1981; Coe and Godt, 2003; Coe et al., 2003; Godt and Savage, 2003; Morgan et al., 2004; Godt and Coe, 2007; Coe et al., 2014). They typically form when heavy rainfall or rapid snowmelt events trigger landslides on steep slopes and/or flash floods in steep drainages. Intense wildfires can increase the likelihood of debris flow initiation by removing soil-stabilizing vegetation and reducing the soil's ability to absorb rainfall and rapid snowmelt; as a result, relatively common (e.g. 2-year recurrence) rain storms can trigger debris flows in burned areas where debris-flow initiation would typically require a relatively rare extreme rainfall or rapid snowmelt event. In general, the risk of debris-flow initiation from relatively common rain storms tends to be greatest in the first few years after a major fire; however, elevated debris flow hazard in burned basins can persist for a period of time ranging from a few years to several decades or more, until the vegetation recovers and soil infiltration returns to pre-fire conditions or sufficient erodible material is removed from the basin.

Once initiated, debris flows can grow rapidly, transforming into muddy, sediment-charged slurries that can become as dense as wet concrete as they erode hillslope soils and channel sediment and entrain loose debris. Fully formed debris flows can transport rocks, trees, and other debris for long distances until the channel eventually widens and/or the channel slope flattens and the entrained material begins to deposit, usually on an alluvial and/or debris fan. Alluvial/debris fan flooding can be much more spatially random than typical floodplain flooding along streams; it is typically characterized by lateral movement of flow over a wide area from the mouth of a drainage basin onto a lower lying area. Established channels can suddenly fill with sediment and debris, be abandoned, and new channels formed during a single event. For that reason, structures and infrastructure developed on alluvial or debris fans may be susceptible to debris-flow impacts, even if they are located relatively far from the established stream channel.

Historically, human development along mountain fronts and within mountain and piedmont valleys commonly occurred on alluvial fans. Roads and other linear infrastructure in these areas may cross alluvial fans or debris-flow generating drainages. Debris flows that reach and inundate structures or other manmade features in these areas may cause serious issues including: injury or death, potentially costly outlay of funds for repairs and (or) sediment removal, temporary road closures, and temporary or permanent loss of access to buildings, roads, and other infrastructure. Debris flows can block improperly designed culverts where roads cross debris fans or steep drainages, leading to unanticipated flooding, deposition of debris on roadways, damage to the road surfaces, or washout of the road. Where debris-flow generating tributaries meet larger streams, deposition of entrained material can lead to upstream flooding due in part to temporary damming and downstream aggradation. The latter commonly results in degraded water quality owing to increased sediment loading.

MAPPING METHODOLOGY

This map was prepared by combining GIS-based debris-flow source and runout models with visual interpretation of high-resolution lidar-based digital terrain data, digital geologic maps, and digital USDA soil survey data. The lidar data used has covers the entire county with a nominal horizontal accuracy of 2-m; it is not publicly available. Burned area outlines for fires that have occurred since the year 2000 were delineated using the US Historic Fire Perimeters dataset downloaded from the Geospatial Multi-Agency Coordination (GEOMAC) website (https://www.geomac.gov/). Figures 1 and 2 show the coverage and scale of digital geologic maps and digital soil survey maps available for the study area, respectively.

Debris-flow source areas, typically defined by steep gullies and colluvial hollows where potentially debris-flow generating landslides, erosion, and transport may occur, were identified in ArcGIS by overlaying slope, plan curvature, and flow accumulation rasters derived from a lidar-based digital elevation model (DEM). The computer-generated source areas were evaluated and the extents were manually revised by the analyst to exclude source areas considered to be erroneously generated and to include potential source areas missed by the automated model. Debris-flow runout zones were modeled using the MATLAB-based runout modeling program Flow-R (http://www.flow-r.org/). The resulting polygons were evaluated and the extents were manually revised by the analyst to produce the final susceptibility polygons shown on the map.

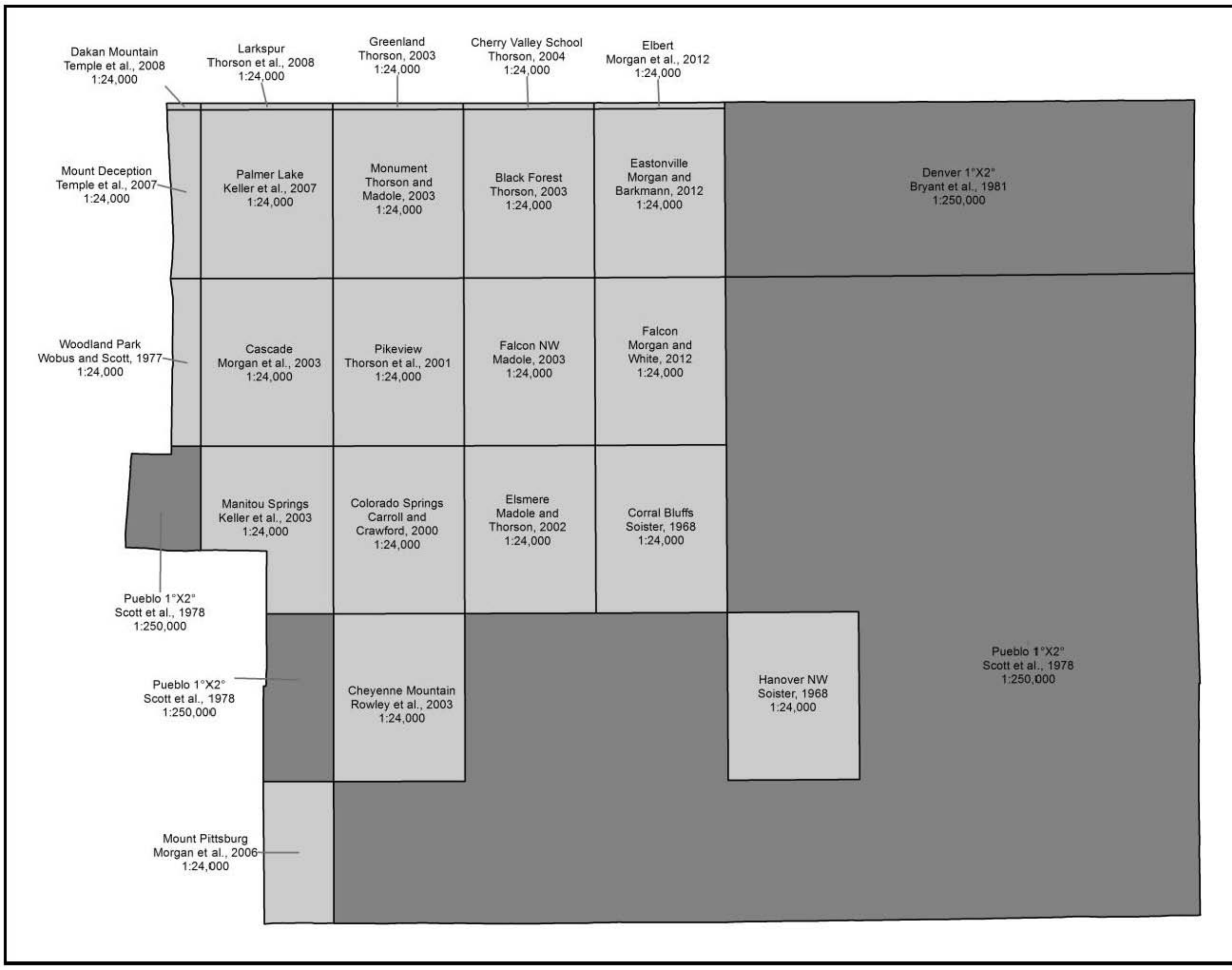

Figure 1. *Index of geologic map data sources available for the study area.*

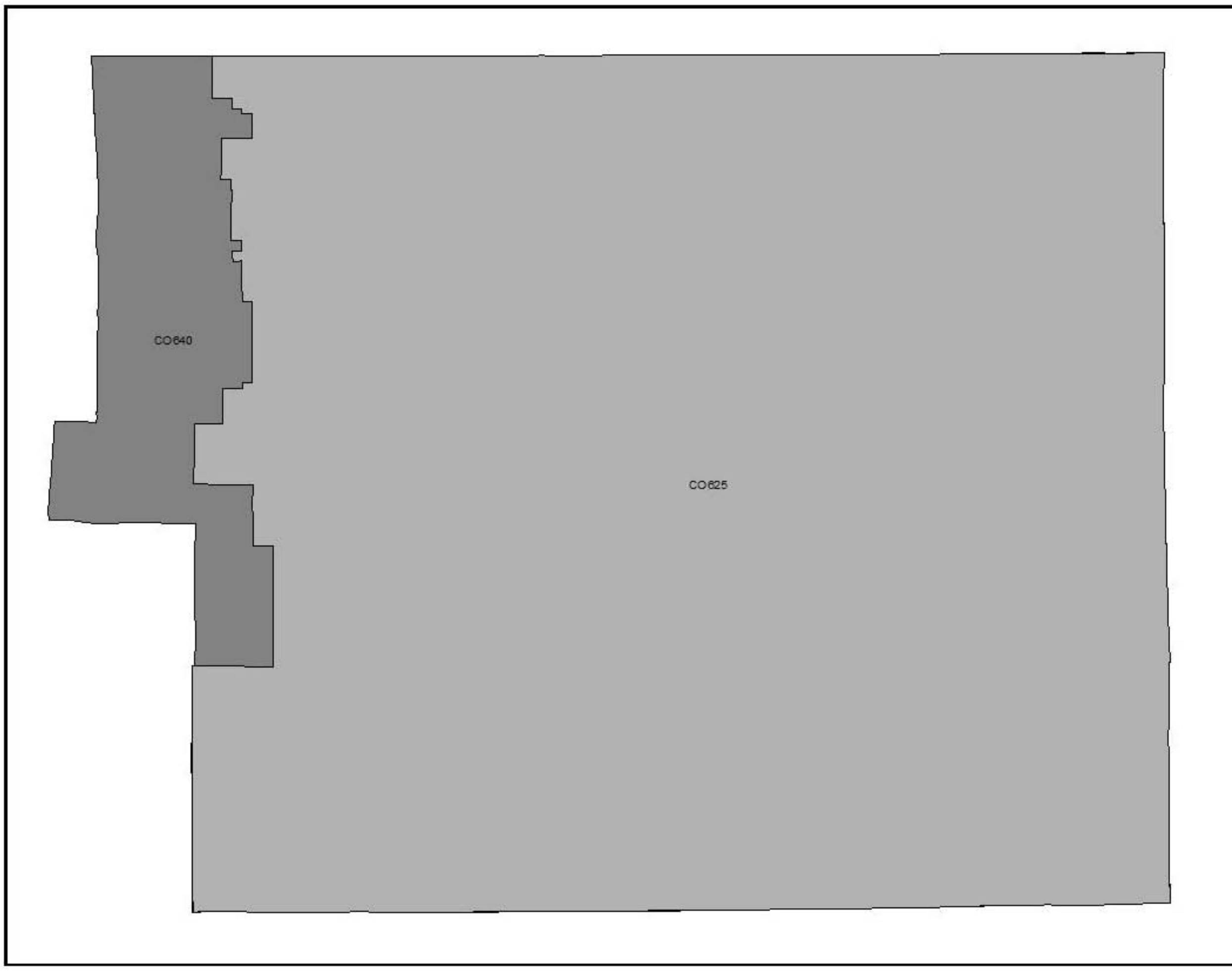

Figure 2. *Index of digital soil survey reports available for the study area.*

HISTORICAL DEBRIS FLOW EVENTS IN THE COUNTY

Significant debris flow events have impacted developed portions of El Paso County in recent history. Debris flows associated with intense rainfall in steep unburned drainages damaged portions of the Cheyenne Mountain Zoo in 1965 and the Cheyenne Mountain Air Force Station in 1965 and 2013 (Lovekin, 2014). Aerial imagery from the late 1960's shows that the 1965 storm, which generated significant flooding and debris flow activity in Douglas County (Douglas County Library; Colorado Legislative Council, 1965; Matthai, 1969; Morgan et al., 2004), triggered debris flows in several drainages along the south side of Austin Bluffs before the area experienced significant urban development. Debris flow and sediment-laden flooding may occur in these areas during future extreme rainfall events.

Damaging debris flows, mudflows, and hyperconcentrated flows (i.e. sediment-laden flooding) originating in burned drainages have occurred multiple times following the 2012 Waldo Canyon fire. A particularly intense rainstorm on August 9, 2013 generated debris flows and hyperconcentrated flows (i.e. sediment-laden flooding) that killed one person, stranded many motorists in muddy flood water, and caused extensive damage to residential and commercial structures in Manitou Springs (Draper, 2016; Handy, 2015; Huffington Post, 2013; Keaton et al., 2013). Information about potential debris flow hazards in the Waldo Canyon burn area was provided by Morgan, (2013), RMFI, (2016), Staley et al., (2015), and Verdin et al., (2012).

MAP LIMITATIONS

This map depicts generalized areas that may be susceptible to debris flows based on available GIS data, including lidar data, and limited field observations in easily accessible areas. The map was generated at a scale of approximately 1:24,000 (1 inch = approx. 0.4 mi.) and is not valid if enlarged to scales greater than 1:24,000.

The degree of susceptibility to a particular geologic hazard, in any given area, is related to ever-changing natural and human-induced conditions, and any alteration in the natural landscape may increase or decrease susceptibility to a particular hazard. The polygons shown on this map are not intended to assign risk, or indicate the degree, severity, recurrence interval, or exact boundary of individual debris flows or debris-flow susceptible areas. Because of limitations associated with the map scale and the scope of this project, some areas that may be susceptible to potentially damaging but localized debris flows near the mouths of small gullies or at the base of steep slopes may not be included on the map. Additionally, some higher-order (larger) streams in larger mountain valleys that have been mapped as debris flow susceptibility areas may be more likely to produce water floods and/or sediment-laden floods than debris flows depending on local rainfall-runoff conditions and the amount of erodible sediment and debris in the basin. Inclusion of existing structures and infrastructure within a mapped susceptibility area does not necessarily indicate that debris-flow impacts will occur, it only indicates that these features may be more exposed to debris-flow events than similar features located in other areas. This map should not be used in place of a detailed site-specific geologic hazard study.

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