

By TC Wait and Karen Berry  
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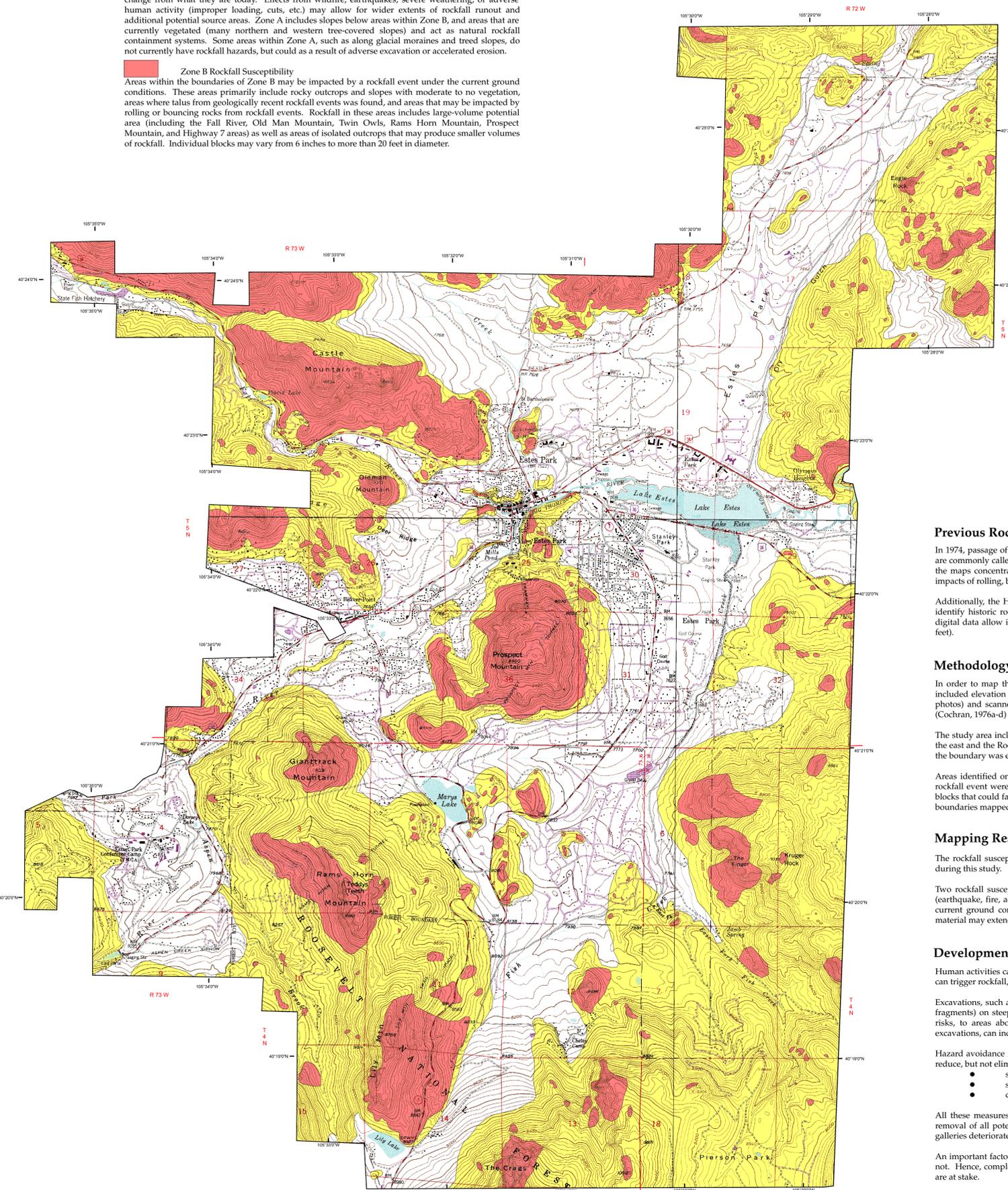
## EXPLANATION

### Zone A Rockfall Susceptibility

Zone A defines the extent of areas where a rockfall event may occur should ground conditions adversely change from what they are today. Effects from wildfire, earthquakes, severe weathering, or adverse human activity (improper loading, cuts, etc.) may allow for wider extents of rockfall runoff and additional potential source areas. Zone A includes slopes below areas within Zone B, and areas that are currently vegetated (many northern and western tree-covered slopes) and act as natural rockfall containment systems. Some areas within Zone A, such as along glacial moraines and freed slopes, do not currently have rockfall hazards, but could as a result of adverse excavation or accelerated erosion.

### Zone B Rockfall Susceptibility

Areas within the boundaries of Zone B may be impacted by a rockfall event under the current ground conditions. These areas primarily include rocky outcrops and slopes with moderate to no vegetation, areas where talus from geologically recent rockfall events was found, and areas that may be impacted by rolling or bouncing rocks from rockfall events. Rockfall in these areas includes large-volume potential area (including the Fall River, Old Man Mountain, Twin Owls, Rams Horn Mountain, Prospect Mountain, and Highway 7 areas) as well as areas of isolated outcrops that may produce smaller volumes of rockfall. Individual blocks may vary from 6 inches to more than 20 feet in diameter.



The Colorado Geological Survey (CGS) worked with the Town of Estes Park planners to develop a GIS coverage for potential rockfall hazard areas in 2003. The scope of the project was to map potentially hazardous rockfall areas within the Estes Valley Development Area in Larimer County and provide these mapped zones in digital GIS format to the Town of Estes Park. This publication includes a map of the GIS data and a description explaining the hazard, mapping methodology, and implications to development in the area. The project was funded by the Colorado Department of Local Affairs, Division of Emergency Management, the Town of Estes Park, and CGS.

## Overview

Poorly planned growth in Colorado's natural hazard areas can impact some communities with declining property values, public safety concerns, and high reconstruction costs. Communities, such as the Estes Park Valley, face the need to accommodate growth in difficult terrain while trying to protect community character and foster a wise use of limited natural and financial resources.

Rockfall is considered a geologic hazard in the Colorado Revised Statutes (C.R.S. § 24-65.104), and local communities are encouraged to identify rockfall hazards and adopt land-use policies to regulate development in rockfall prone areas. This publication identifies these areas and describes the methods used to determine rockfall susceptibility within the Estes Valley Development Code Boundary.

## Background

Rockfall is the falling of a detached mass of rock from a cliff or down a steep slope. Rocks in a rockfall, vary greatly in size (from baseballs to houses), and roll, bounce, or slide rapidly down a slope under the force of gravity. Rockfall can be a continuous process over a considerable period of time, a single event, or series of single intermittent events. A rockfall event can involve a single rock or large volumes of broken material.

Rockfall, a type of landslide, is common near cliffs of massive broken, faulted, or jointed bedrock, or where steep bedrock ledges are undercut by natural processes or development. A major natural cause of rockfall is repeated freeze-thaw of water; freezing water expands, weakening and wedging apart blocks of rock.

Rockfall occurrences are difficult to predict, and can range from a single rock falling or rolling to large-scale catastrophic events. The size of the falling rock depends on the source area geology (bedding thickness, bedding dip and dip direction, hardness, jointing/fracturing orientation), weathering, and position. Rolling or sliding rocks occur on steep slopes where loose rocks may mobilize from gravity (slope creep) or hillside development activity. This may occur in areas where loose rocks are located on steep slopes, regardless of the presence of an outcrop.

Water erosion from rain or melting snow or chemical weathering (decomposition of rock due to molecular changes) can remove the underlying support for blocks of rock and trigger down-slope movement. Root growth, water pressure, and ground shaking can also cause rockfall.

Rockfall events can quickly demolish structures and injure or kill people in the rockfall path. Rocks falling on highways may strike vehicles, block traffic, or cause accidents and road damage. However, most areas susceptible to rockfall can be identified and steps can be taken to avoid, reduce, or mitigate rockfall risk.

## Previous Rockfall Hazard Mapping

In 1974, passage of House Bill 1041 (C.R.S. § 24-65.1-101 through 204) provided funding to map geologic hazards; the resulting maps are commonly called "HB 1041" maps (Cochran, 1976a-d). Rockfall hazards near and surrounding Estes Park were mapped; however, the maps concentrated on identification of rockfall source areas and did not fully identify runoff areas that may be subject to the impacts of rolling, bouncing or sliding rock fragments.

Additionally, the HB 1041 maps were mapped at a scale of 1:24,000 or 1 inch = 2,000 feet. The mapping scale made it difficult to identify historic rockfall events, and fully evaluate potential hazards. Current high-resolution aerial photography, GIS, and other digital data allow improved susceptibility mapping at a scale more appropriate for community planning (i.e., 1:6,000 or 1 inch = 500 feet).

## Methodology

In order to map the rockfall susceptibility boundaries, existing digital data was compiled using ArcMap GIS version 8. The data included elevation data from the Estes Park Planning Department (including 10-foot topographic contour data and orthorectified air photos) and scanned geologic data from USGS mapping in the area (Braddock and Cole, 1990). Additionally, the HB 1041 maps (Cochran, 1976a-d) were digitized and areas identified as rockfall, talus, or unstable slopes were evaluated for their rockfall potential.

The study area included the Estes Valley District, roughly defined as the area bounded by the Roosevelt National Forest boundary to the east and the Rocky Mountain Park boundary to the west. No precise boundary was available through the planning department, so the boundary was estimated using small-scale maps.

Areas identified on HB 1041 maps and air photos as potentially having geologic and topographic conditions that might produce a rockfall event were field checked. Observations regarding the extent of the historic runoff area, volume of material and size of the blocks that could fall, and topographic features that could affect rockfall were defined by GPS points and used to refine the preliminary boundaries mapped on air photos. This digital data was then placed on a topographic base map for easier referencing.

## Mapping Results

The rockfall susceptibility data was developed at a mapping scale of 1 inch = 500 feet (1:6,000) to discern rockfall areas identified during this study.

Two rockfall susceptibility categories were mapped: Zone A includes areas where rockfall may occur under changed conditions (earthquake, fire, adverse grading, catastrophic event, etc.), and Zone B depicts areas where rockfall may be present or occur under current ground conditions. The mapped boundaries include potential source areas and runoff areas where bouncing or rolling material may extend. Relative rockfall risk may vary within each category; detailed risk distinction was not within the project scope.

## Development Considerations and Mitigation

Human activities can create rockfall hazards or cause rocks to fall sooner than they would naturally. Vibration from trains or blasting can trigger rockfall, as can development related changes in surface and ground water conditions.

Excavations, such as road cuts, often remove support for overlying or overhanging rock and create rockfall risks. Talus (loose rock fragments) on steep slopes is often the result of numerous small rockfall events. Construction on talus slopes can increase rockfall risks, to areas above and below construction, by increasing or renewing movement of talus. Over-steepened cuts, and other excavations, can increase the danger and frequency of rockfall events.

Hazard avoidance is by far the simplest, most effective, and least costly mitigation strategy. However, other forms of mitigation can reduce, but not eliminate, rockfall risk. Some typical types of mitigation include

- stabilization of rocks by removal of unstable rocks (scaling), rock bolting, or installation of retaining walls;
- slowing or diverting moving rocks with rock fences, screens, berms or ditches;
- concrete barriers or covered galleries placed around vulnerable structures and facilities.

All these measures are expensive, require regular maintenance, and do not eliminate the risk of rockfall. For example, complete removal of all potentially unstable rocks is often not possible; berms, ditches, and fences fill with fallen rock; concrete barriers and galleries deteriorate, due to weather and rock damage, and require replacement.

An important factor to keep in mind is that although the place of potential rockfall is to some degree predictable, the time of failure is not. Hence, complete avoidance of areas of potential rockfall is the most sensible mitigation measure where lives or property values are at stake.

## Map Usage and Limitations

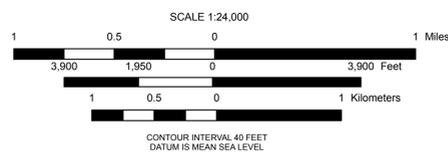
The rockfall hazard map of the Estes Valley District was mapped on a 1 inch = 500 feet (1:6,000) scale. Inclusion of properties within a rockfall susceptibility zone does not imply that rockfall events will impact a property at any given time; it means that the property has a higher risk compared to areas not within a mapped area, based on geologic and topographic conditions. Conversely, areas not identified as being susceptible to rockfall could become susceptible due to blasting, grading, excavation, or a change in natural conditions.

Potential rockfall susceptibility areas, shown on the map, were constructed qualitatively using available geologic, topographic, and field evidence. No levels of risk assessment (high vs. low risk) were made within each zone. The mapped boundaries are intended for general purposes and do not replace the need for detailed site-specific studies.

Prior to any development, a qualified geotechnical engineer or engineering geologist should further evaluate potential hazard areas. These investigations should include consideration of current and future geologic conditions, and how the proposed development might impact adjacent properties. Mitigation measures may be required to reduce potential rockfall risks.

## References

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Bill Owens, Governor,  
State of Colorado



Russell George, Executive Director,  
Department of Natural Resources



Vincent Matthews,  
State Geologist and Division Director,  
Colorado Geological Survey