AVALANCHE SIZE INCREASE RESULTING FROM FOREST REMOVAL AND WIND LOADING – A CASE STUDY FROM CENTRAL COLORADO USING AVAL-1D

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ABSTRACT: Forest removal for a proposed ski run within a ski-area expansion would increase the amount of wind-deposited snow in a downwind avalanche starting zone. In accordance with experience, the following effects are expected: 1) the size and runout distance of the design-magnitude, 300-year avalanche would be increased due to increased starting-zone volume; 2) an existing residence near the end of the runout zone may be reached by the 300-year avalanche, and 3) avalanche frequency would be increased. The local governmental jurisdiction (Gunnison County, Colorado) requires that avalanches with 300-year return periods be considered in land-planning and engineering near avalanche paths.

The avalanche path and private property are located 1km south of the Rocky Mountain Biological Laboratory (RMBL) in central Colorado, a field biological research and educational facility. Since 1974 the RMBL has collected detailed, high-quality, weather records. Data have documented the occurrence, frequency, size, destructive effects and runout distances of all avalanches, including those that have approached the residence located near the end of the runout zone. The RMBL data enables quantification of slab depth data with 30-year and longer return periods. Observations of major avalanches enable calibration of avalanche-dynamics models to real events.

The Swiss avalanche-dynamics program AVAL-1D v. 1.3.1 was used to compare the runout distances of the natural 300-year runout distance with the avalanche that would be made larger by wind transported snow transported from the proposed ski run. Parameters used in the program (ξ, μ, slab thickness d) were chosen to match field observations and RMBL data. The computed runout distance was found to increase by approximately 50m, reaching the residence which was previously beyond the runout limit of the 300-year avalanche.

KEYWORDS: avalanche, design-magnitude avalanche, runout distance, AVAL-1D, forest removal, wind-transported snow

1. INTRODUCTION

Experience has shown that increased avalanche starting zone volume can produce larger and more energetic avalanches with longer runout distances. Removal of trees above avalanche starting zones can increase avalanche volume because additional snow can be transported into starting zones. Proposed forest removal for a ski-area expansion will result in design-magnitude (300-year return period) avalanche size increase above private property in Gunnison County, Colorado. The affect of such forest removal has been quantified in this paper and represents a case-study in application of current technology.

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2. STUDY AREA

The study area is located in the south-central mountains of Colorado approximately 7km northwest of the existing Crested Butte Ski Area (200 km southwest of Denver, Colorado). Weather data have been collected within the study area for 31 years by the Rocky Mountain Biological Laboratory (RMBL) at 2,900m elevation, within the historic mining town of Gothic. The RMBL is located within the runout zones of some of the avalanche terrain studied. This area typically receives an annual average of 10m of snow (ranging from 6m to 14m) during the October through May snow season. Typically storms are of short duration and moderate intensity. They are usually followed by clear, dry weather of several days duration. Temperatures are well below freezing during most of the winter, and prevailing winds blow from the

southwest through northwest directions. Snow depth at the 3,000m elevation in mid winter ranges from 1.5m to 3.0m. The snow climate can be described as "continental" with extensive and sometimes well-developed weak layers between stronger wind slabs. Sustained, moderate-intensity storms are possible. These may last from 5 to 10 days with no significant break and have deposited 1.5 to 3.0m of new snow. Major storms at the 2,900m elevation have resulted in measured average new slab thicknesses of 1.0 to 1.5m with average densities of 150 to 200 kg/m^3.. These storms have return periods of 10 to 30 years. Slab fracture lengths of 1,500m-3,000m have been observed in the immediate area. Mixed-motion dry snow and powder avalanches constitute the design case and runout distances of 200m to 300m on slopes of 4° to 8° have been observed several times in the 31-year observation period on avalanches with total vertical displacements of only 300m to 450m. Some of these avalanches have entered private property and reached buildings.

3. METHODS

Tree removal for a ski run is proposed as part of the expansion of the Crested Butte Ski Area which could take place on the terrain of adjacent Snodgrass Mountain, approximately 5km northwest of the existing ski area. According to plans, an area 50m to 150m in width would be removed for a ski run directly above avalanche paths that exist above private property. This proposed ski run would be exposed to southwest winds which are most common in major storms. Additional snow, therefore, would be transported into starting zones, increasing the size of the design-magnitude, 300-year avalanche.

The Swiss avalanche-dynamics simulation program *AVAL-1D v 1.3.1* was used to quantify the increase in avalanche runout distance resulting from tree removal. This output of this program is dependent on the following parameters: (a) released slab area and thickness, d, (b) avalanche path steepness and width, and (c) an inertial flow coefficient, ξ, and a dynamic friction coefficient, μ. Avalanche terrain was accurately quantified by a detailed topographic map with 10-foot (3m) contour intervals and a scale of 1:4800 (1" = 400'; 1cm = 48m).

Starting-zone area assumed in analysis is based on personal observations of avalanches in the path during the past 30 years. The released slab thickness, d, was determined from detailed storm data that enabled snowpack depth increase during major storms to be quantified. Data were obtained near the runout zone of the avalanche path by the RMBL over a 31-year period.

The inertial and dynamic friction coefficients ξ and μ were chosen to simulate the observed runout distance of the largest avalanche to have been documented in the past 31 winters. This avalanche stopped approximately 100-120m directly west of an existing house. In this way the 30-year return period avalanche (the observed event) was simulated using the avalanche-dynamics model AVAL-1D. In other words, the model was used to simulate the observed runout distance, the slab thickness, d was obtained from snow data obtained locally, and the coefficients ξ and μ where chosen to fit observation of avalanche runout.

The AVAL-1D model also enables calculation of the runout distance, flow thickness, velocity and impact pressure of the 300 year avalanche. This 300-year period is also the design period to be considered in land-use planning and engineering in Gunnison County, Colorado. To simulate the 300-year event, the 300-year slab depth was determined by a Gumble (Gumble, 1954) extreme-value extrapolation (R^2=0.93) of the existing RMBL snowpack data. The inertial flow coefficient ξ was increased in accordance with standard Swiss recommendations and μ was decreased according to these same recommendations. With the new input parameters d, ξ, and μ thus established, AVAL-1D was used to simulate the 300-year avalanche. The simulated 300-year avalanche was found to stop 20m short of the house mentioned in the preceding paragraph.

As a final step, the effect of increased wind-transported snow resulting from the proposed tree removal was quantified. This was done by applying the methods of Tabler (1975, 1991, 1994) and Tabler and Schmidt (1972).

The 300-year return period slab depth which was increased by wind transported snow increased the avalanche runout distance by approximately 50m. This increased runout distance would cause the avalanche to impact the residence that was previously beyond the limit of the 300-year avalanche and travel approximately 30m beyond it.

4. RESULTS AND CONCLUSIONS

The quantitative analysis of design-magnitude avalanche dynamics illustrated here utilized existing snowpack and storm data, a highly detailed topographic map and observed avalanche runout data obtained over 3 decades of observations. A current avalanche-dynamics model (AVAL-1D v 1.3.1) was applied to simulate observations; and recent research on snow-transport technology was applied.

The methods applied indicate that the 300-year avalanche will impact an existing residence as a result of increase snow transport into a starting zone. This increased snow transport results from forest removal for a proposed ski run. This would be an adverse affect of the proposed ski-area expension.

5. ACKOWLEDGEMENTS

I wish to thank RMBL director Dr. Ian Billick for his cooperation, support and encouragement. Mr. billy barr collected all the snow and avalanche data during the 31-year observation period and provided an invaluable resource. Mr. Hal Hartman was my partner during several phases of the consulting work for RMBL and provided wind-transport analysis, calculations, and other technical support.

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