Loveland Basin Avalanche, February 1996

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ABSTRACT

On February 2, 1996, routine avalanche reduction work by ski area workers released an avalanche that ran significantly beyond the path's maximum known runout zone. The soft slab avalanche destroyed a thick stand of 200-year-old and older, conifers before crashing into the ski area parking lot where it damaged or destroyed a number of vehicles. The weather and snowcover conditions prior to the avalanche, the results of avalanche dynamic and runout formulas applied to the avalanche, and as the damage caused by the slide are illustrated and discussed on the poster. From this avalanche event several conclusions can be drawn regarding avalanche dynamics, land-use planning and forecasting.

INTRODUCTION

At about 0800 hours on February 2, 1996, at the Loveland Basin Ski Area a three-pound-explosive hand charge (1.4 kg) tossed into the starting zone of an unnamed avalanche path resulted in a larger-than-expected avalanche. The avalanche removed dense timber before stopping in the parking lot where it damaged several vehicles. Historically, avalanches from this starting zone were infrequent and had always stopped in dense timber, on a bench area about three-quarters of the way down-slope. On the morning of February 2, the release initially was unremarkable in size and depth; however, as the avalanche continued downslope it entrained additional snow and mass that resulted in a very remarkable, destructive and ironic avalanche—ironic in that it destroyed the car of the patroller who tossed the bomb.

The slab avalanche significantly extended the path through thick, mature conifers that had withstood the forces of avalanches for more than 200 years. Approximately 2.1 acres (0.85 hec) of mature Englemann spruce and Sub-Alpine fir trees were downed before the avalanche swept down the Rainbow ski trail and crashed into the parking lot where it destroyed a pickup truck, a car and a snowmobile. A shuttle bus, grader, and another car also sustained significant damage. The destruction could have been worse as the avalanche passed within 15 feet (4.6 m) of the ski area maintenance building. The building was not damaged nor were any people caught or injured by the avalanche. Fortunately, the parking lot had only been open for several minutes and people and cars were congregating on the far side of the lot, well away from the avalanche. The new avalanche path is now called "Over the Rainbow."

The debris traveled more than 100 feet into the ski area parking lot and stopped under a chairlift (Lift 5). The powder cloud continued across the parking lot and upslope to just beyond I-70, more than 500 feet away. The powder cloud scattered small tree branches north of the parking lot and dusted some people in the parking lot.

OBSERVATIONS

Weather Conditions

The Loveland Ski Patrol takes daily weather observations each morning at about 0730 hours. Maximum, minimum and current temperatures, and snowfall totals are recorded from a long-term site located at about 3,475 m (11,400 feet). At this same site the National Resources Conservation Service (formerly the U.S. Soil Conservation Service) maintains a Snotel pressure snow pillow that records daily snow water equivalents. Less than one-half mile east of the ski area weather site, and located directly above the Over the Rainbow starting zone, the Colorado Department of Transportation (CDOT) and the Colorado Avalanche Information Center (CAIC) maintain an automated weather tower at 3,633 m (11,920 feet). Temperatures, relative humidity and wind speed and direction are recorded hourly and are stored in a computerized data logger.(Figure 1)

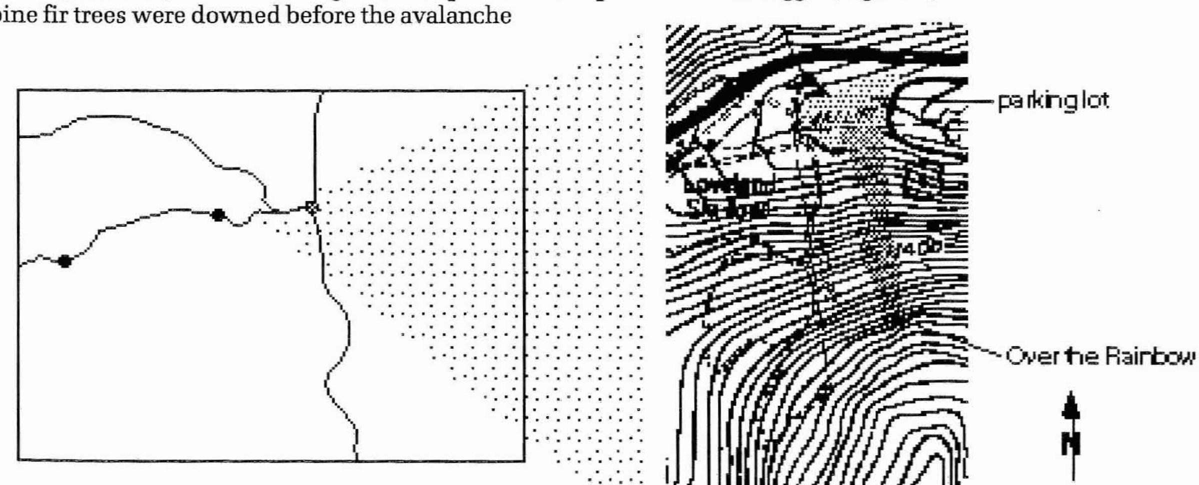

Figure 1. Loveland Basin Ski Area and the "new" Over the Rainbow avalanche path.

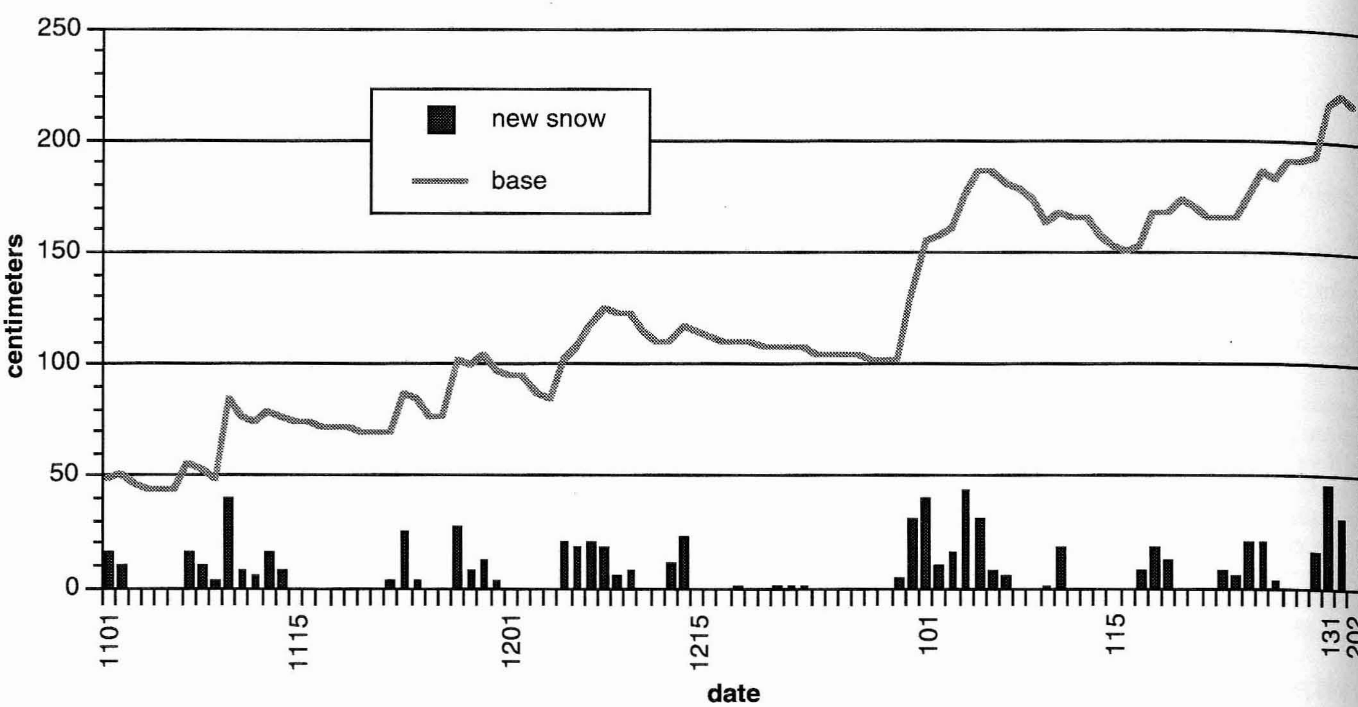

Figure 2. Snowfall and base depth at Loveland Basin historical site, November 1, 1995 to February 2, 1996.

The season's first permanent snows fell in late September and early October. November's snowfall total was 211 cm, followed by 162 cm in December and 399 cm in January. About one-third 147 cm of the January snow fell from January 23 to February 1; from January 30 to February 1, 91 cm fell (Figure 2). Snow water equivalents recorded by the NRCS Snotel site were for October, 74 mm; November, 160 mm; December, 61 mm and January, 218 mm. In the week prior to the avalanche 99 mm of water was recorded (Figure 3). This included 46 mm recorded on January 30 to February 1.

Figure 4 shows the wind record at the CDOT/CAIC weather tower from 0800 hours on January 27 to 0900 on February 2. During the 145-hour period winds averaged 10.3 m/s from 262 degrees; the hourly peak gusts averaged 20.1 m/s. The fastest one-hour average during this period occurred on the 28th between 1100 and 1200 hours. For one hour winds averaged 18.8 m/s from 267 degrees

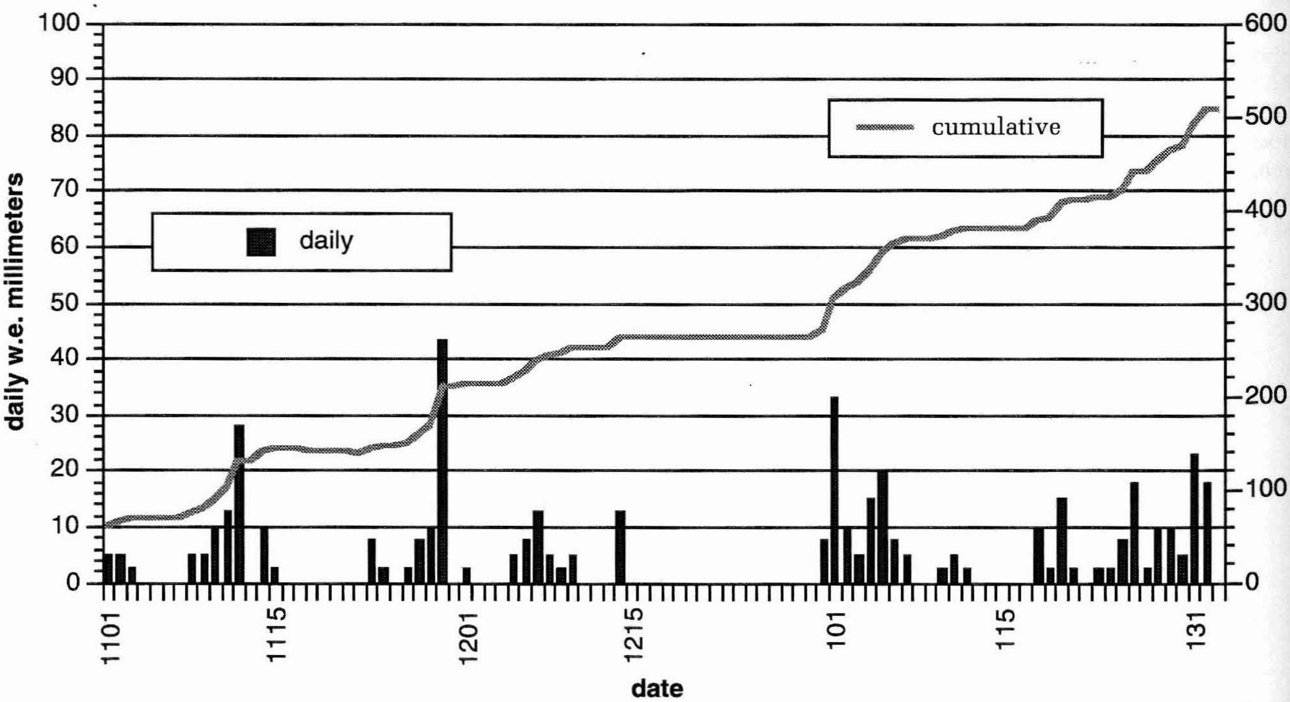

Figure 3. NRCS Snotel snowfall water equivalent at Loveland Basin historical site, November 1, 1995 to February 2, 1996.

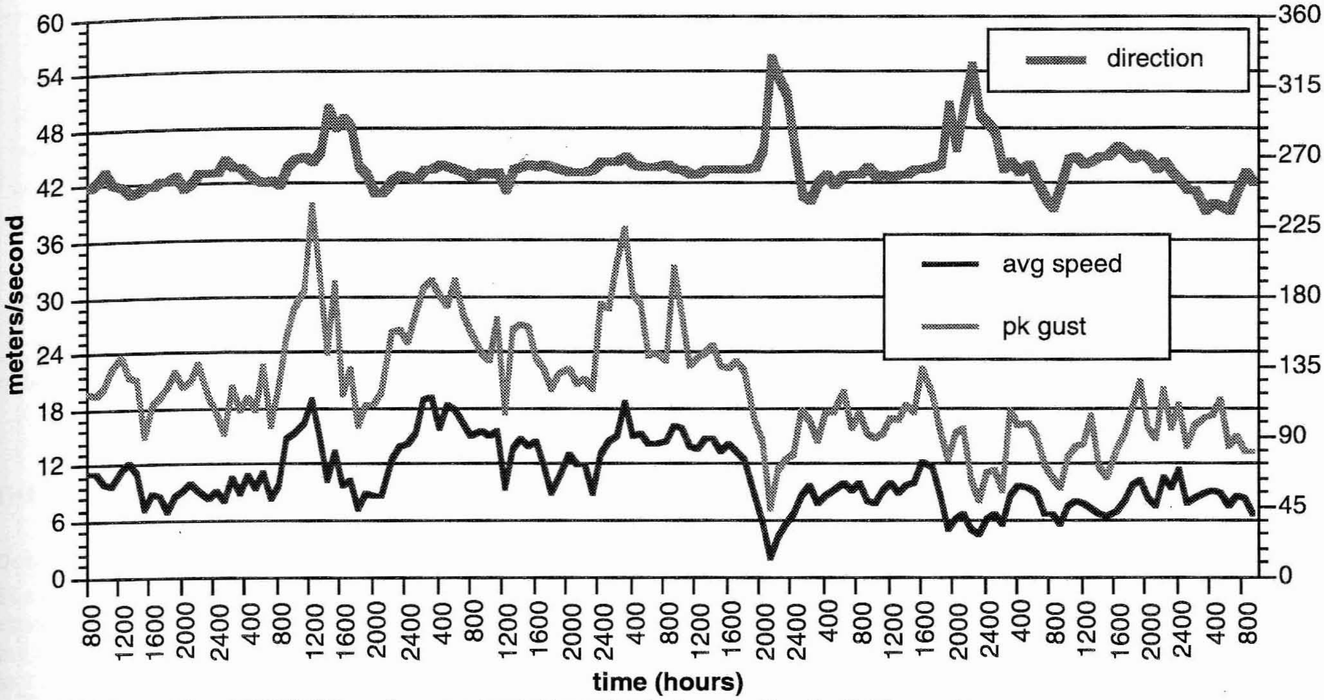

Figure 4. Wind record from CDOT/CAIC weather tower located immediately above the Over the Rainbow path.

and the peak gust was 39.8 m/s. The strongest sustained winds occurred during one 19-hour period on January 30: winds averaged 14.3 m/s from 262 degrees. Peak gusts during this period averaged 26.4 m/s.

Heavy blowing snow was observed in the days before the avalanche. Due to a small ridge along the west flank of the avalanche path the westerly winds cross-load the starting zone with snow. These winds created hard slab conditions but added little additional snow in the upper starting zone. However, lower in the starting zone and track where a narrow but relatively thick stand of conifers borders the path, the strong winds likely added significant snow to the pack.

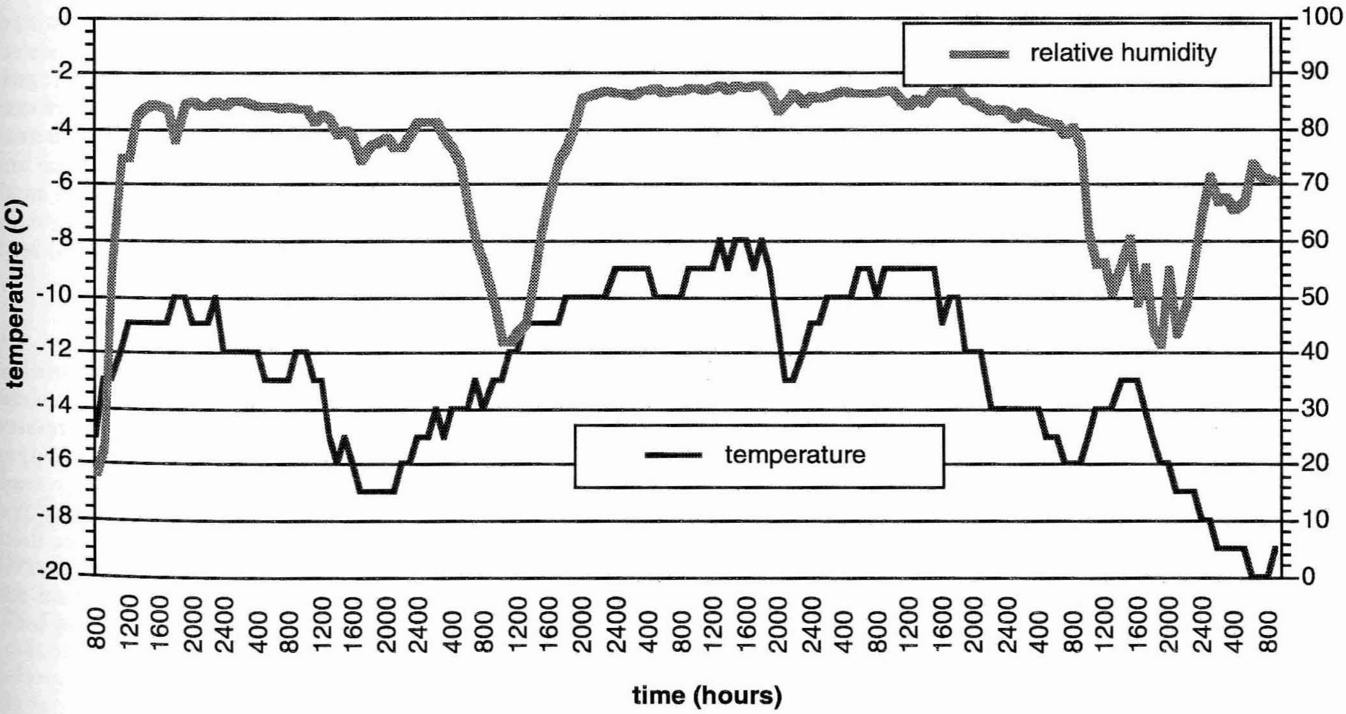

Figure 5. Hourly maximum and minimum temperatures and relative humidity from the CDOT/CAIC weather tower.

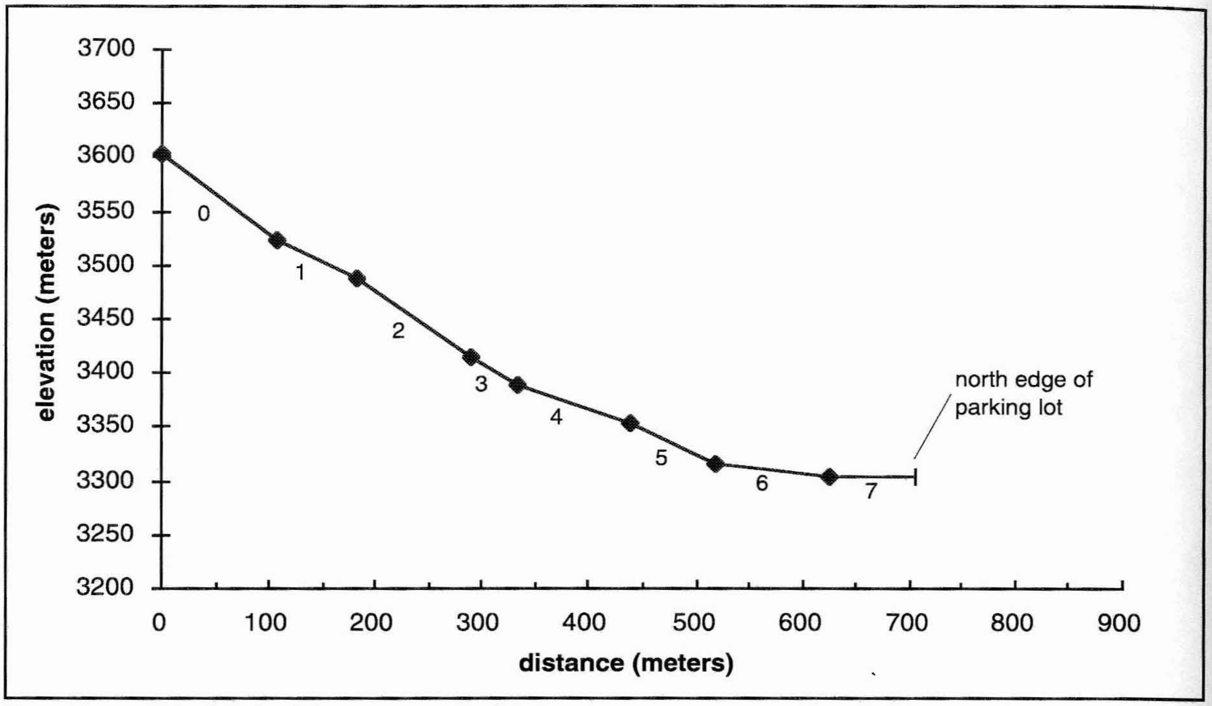

Figure 6. Profile of the Over the Rainbow avalanche path.

Temperatures were rather unremarkable prior to the avalanche: they stayed between about -18°C and -4°C. Cold air moved into the area on February 1 and the temperature cooled to -20°C by the morning of February 2. Figure 5 shows the temperature and relative humidity trends for the 145-hour period from January 1 to February 2.

Certainly the strong winds and heavy January snows played a significant factor in the magnitude of the Over the Rainbow avalanche, but other weather factors earlier in the season might also have made a significant contribution.

From December 15–30, high pressure dominated the Southern Rockies. At Loveland Basin the average temperature during this period was -14°C, and for those 15 days winds averaged only 3.9 m/s (s = ±2.3). Only 3.5 cm of snow fell during the period. Cold temperatures, light winds and generally clear skies fueled surface hoar and kinetic-snow metamorphism in the upper portion of the snowcover. Avalanche workers throughout Colorado reported extensive surface hoar development on all aspects. The largest crystals formed on north-facing slopes.

SNOWPACK CONDITIONS

Snowpits dug in early November near the starting zone showed a shallow and strong snowpack. Snow depths ranged from 0.40 to 0.80 m. Most of the snowpack consisted of small, rounded grains perched on a 3.5-cm-thick rain crust that had formed in late October. The only weakness in the pack was in the 10 cm between the rain crust and the ground where cohesionless kinetic grains (2-5 mm) were forming. The average temperature gradient of the snowpack was 16°C/m.

Hasty snowpits in the same areas in November and December showed the snowpack to be losing strength. Air temperatures continued their seasonal cooling, but the snow depth rarely rose above 1 m as winds scoured the area. The clear, calm and cold conditions in late December caused the entire snowcover (about 1 m) to change to faceted crystals. The weakest snow was at and just below the surface where surface hoar crystals and large faceted crystals formed.

When 71 cm of new snow fell over 2 days at the start of January widespread natural and triggered avalanches occurred. Small avalanches ran on top of the old snow, while large and long-running avalanches, stepped down and released near the ground. On January 1, low in the track of the Over the Rainbow path, snow fell from a tree and released a small soft slab in thick conifers. Though small it ran a surprising distance with debris spilling onto the Rainbow ski run. The snow slid on a thick (1.5 cm) layer of surface hoar crystals.

TERRAIN

The Over the Rainbow avalanche path is situated at treeline at an elevation of 3603 m, immediately east of the Loveland Basin Ski Area. The starting zone is a shallow depression covered by bare ground and talus. The path is stair-stepped in the starting zone and track, creating several very small potential starting zones within the path. Historically avalanches had always stopped before, or just into, the thick conifers on the bench at about 3,414 m feet. At about 3,353 m the slope steepens and becomes the Rainbow ski run that ends at the south edge of the ski area's parking lot.

top elevation	3603 m
width, top	70 m
crown face	1.4 m
bottom elevation	3304 m
width, bottom	101 m
vertical	299 m
length	693 m
aspect	north-northwest
α angle	25.5°

Table 1. Avalanche dimensions, Over the Rainbow.

segment	length meters	elev. meters	segment length m	slope angle θ	Vtop m/s	Vbottom m/s
	0.0	3602.7				
0	106.7	3523.5	132.9	36.6	0	29.08
1	182.9	3486.9	84.5	25.6	28.55	29.68
2	289.6	3413.8	129.4	34.4	29.68	34.98
3	332.2	3389.4	49.1	29.7	34.86	35.08
4	438.9	3352.8	112.8	18.9	34.24	27.13
5	518.2	3316.2	87.3	24.7	27.13	24.84
6	624.8	3304.0	107.4	6.5	23.89	0
7	662.9	3304.0	38.1	0	–	–

Table 2. Segment descriptions and calculated avalanche velocities at the top and bottom of each segment, for the Over the Rainbow avalanche path.

THE AVALANCHE

Description

The avalanche was classified as a HS-SS-AE-5-O. A small explosive initiated a hard-slab release in the upper starting zone and a soft slab in the lower portion. As the avalanche swept down the mountain it entrained softer snow and stripped the entire snowcover to the ground. The crown face and flanks averaged 1.4 m deep. Table 1 shows the dimensions of the avalanche.

The PCM model (Perla et. al. 1980) was used to compute velocity and acceleration along the Over the Rainbow avalanche path. Terrain measurements were made from the USGS 7.5-minute topographic map (1:24,000) and were field checked for general accuracy. The PCM model is an extension of the original Voellmy model (Voellmy 1955).

The PCM model consists of three equations that depend upon slope angle, θ; length, *L*; dynamic friction, μ; and a mass-to-drag ratio, *M/D*. Figure 6 shows a centerline profile of the Over the Rainbow avalanche path extending from starting zone to the runout. The avalanche path has been subdivided into seven segments where θ can be considered consistant within each segment of length *L*.

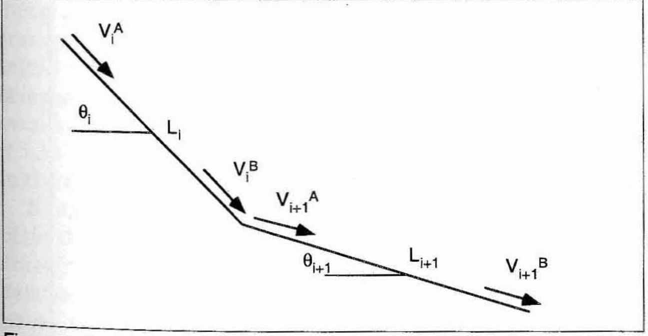

Figure 7. Consecutive segments used in the PCM avalanche dynamics model.

The PCM model determines the velocity of the avalanche at the begining (V_i^A) and end of each segment V_i^B (Figure 7). The avalanche velocity at the bottom of V_i^B is used to calculate V_{i+1}^A, at the top of the next segment. V_i^B cannot always be subsituted directly for V_{i+1}^A because sometimes it is necessary to include a correction for momentum change at the slope transition.

The computed velocities at the top and bottom of each segment of Over the Rainbow are given in Table 2.

The value assumed for m depends upon factors such as snow type, path roughness and trees or rock outcrops in the avalanche path. In the upper portion of the avalanche path a value of m=0.2 was assumed in segments 0-3. Lower internal friction of the avalanche increased when the moving snow impacted and removed the thick, heavy timber; in segments 4–5, m=0.30 was used; and m=0.35 was used in segment 6. (The avalanche did not reach into the 7th segment.)

The *M/D* value was chosen from successive iterations forcing the model to match the actual runout distance. In practice, typical values for M/D range from 100m to 10,000m. The PCM model performed well as the computed stopping position was within 3 m of the actual position.

VEGETATION

Vegetation can provide clues to past avalanche occurrences, and prior to February 2, a thick stand of mature conifers stood above the Rainbow ski run. Englemann spruce and Sub-Alpine firs from 15 to 61 cm in diameter and 12 to 24+ m had withstood previous avalanches. Sawed sections from trees broken by the avalanche showed ages of almost 200 years and older (189 years, 15-cm diameter; 239 years, 24-cm diameter). A section taken from a large Englemann spruce that was uprooted in the lower track revealed it was over 500 years (61-cm diameter).

The small diameters and old trees are consistent for the spruce-fir forest where the frost-free growing season is only about 2 months (Mutel and Emerick, 1984). The thickness of the timber stand and the age of the conifers suggest that there have been no avalanches of similar magnitude—to remove timber—for more than 200 years.

Investigation along the eastern perimeter of the avalanche path revealed past avalanches had also stopped in the conifers. Trees higher on the slope showed scars and broken branches, but lower on the slope evidence of past avalanches ended as branches on the uphill sides remained intact.

The calculated maximum impact pressures (Table 3) are consistent with values required to destroy mature forests (Mears, 1992). Looking at the carnage of downed timber it appeared that the avalanche broke trees up to 30 cm. The larger diameter trees were mostly uprooted when the root/soil system failed.

volume (moving snow)	52,109 m^3
$\Delta\rho$ pre to post avalanche	–
(250 kg/m^3 to 450 kg/m^3)	1.8x
maximum velocity	35 m/s
maximum impact pressure	137 kPa
average impact pressure	68 kPa
volume (stopped)	28,900 m^3
debris in runout zone	60%
volume (runout zone)	17,400 m^3
mass (debris in runout zone)	7,800 tons (m)

Table 3. Summary statistics for Over the Rainbow avalanche, February 1996.

AVALANCHE RUNOUT DISTANCE POTENTIAL

The runout distance potential was computed using Mear's adaptation of the Norwegian Geotechnical Institute (NGI) method (Lied and Bakkehoi, 1980; Bakkehoi et. al., 1983; Lied and Toppe, 1989). Mears performed the same multiple regression analysis on 112 extreme avalanche paths in Colorado (Mears, 1992) and found that the parameter X_β (horizontal distance from starting point to 10° point, or β, in the runout zone) in addition to β (10° point in the runout zone) produced the best regression equation. For Over the Rainbow, β was measured and calculated at 27.9°. Mears' Colorado equation is:

$$\alpha = -3.0° + 0.79\beta + 0.0036X_\beta$$
$(r^2 = 0.75;\ s = 1.4°)$.

When applied to the Over the Rainbow avalanche path, the predicted a = 21.0° (Figure 8). Statistically 21° is a reasonable a angle for Colorado avalanche paths (McClung et al., 1989). McClung's study found the mean value of b = 27.4° and the mean value of a = 22.6° for 98 Colorado paths.

In the case of Over the Rainbow the predicted a = 21.0° means future avalanches could cross the parking lot. However, extreme avalanches would not be expected to travel beyond the parking lot, nor the distance necessary to achieve a 21° α angle (assuming a flat runout). At the north edge of the parking lot the slope climbs steeply for 24 vertical meters, effectively creating a barrier that would stop avalanches. It is the opinion of this author that it would be unlikely for avalanches to over run this slope. The α angle at the north edge of the parking lot is 23° (Fig. 8).

CONCLUSION

The newly-created Over the Rainbow avalanche path poses a real, and at certain times a serious, threat to the Loveland Basin Ski Area parking lot. From the February 2 avalanche event several conclusions can be drawn either from deduction or inference.

STATISTICAL AND DYNAMICAL ANALYSIS

Statistical and dynamical analysis shows that future avalanches in the Over the Rainbow path can be expected to travel further than the February 2 avalanche event. Large avalanches can be expected to travel into and even across the ski area parking lot. This analysis is also important as it provides numerical insight to the dynamic forces involved in the avalanche. In terms of avalanche size the February 2 event was not a large avalanche (299 m), but it clearly demonstrated how powerful and destructive a relatively small avalanche can be.

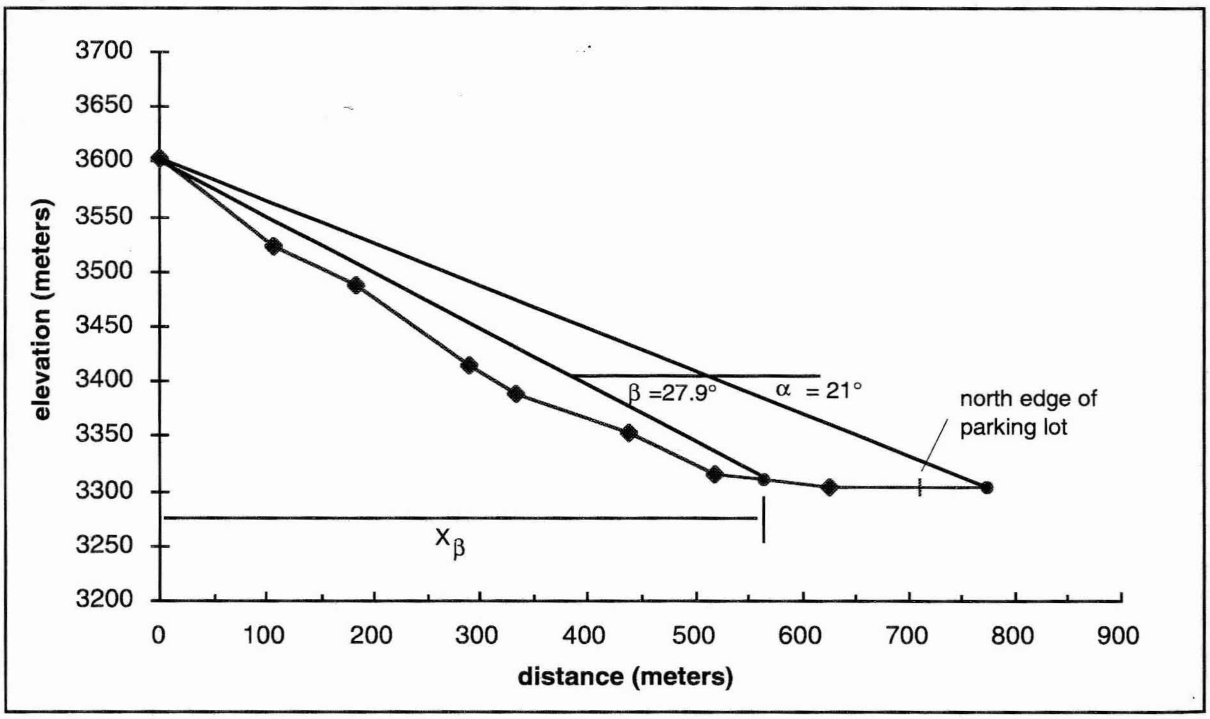

Figure 8. Statistical runout prediction model. Runout distance is predicted to extend beyond the parking lot.

Land–use Planning

In land–use planning, direct methods such as observational, historical, geomorphic and vegetative records typically provide the best indication of the area affected by an avalanche. Conventional wisdom holds that when these records are not available, the indirect methods of statistical and dynamical analysis should be used to determine runout distance. However, this incident demonstrates the importance of doing statistical and dynamical analysis to determine runout distance of avalanche paths that can potentially affect developments even when conventional wisdom suggests otherwise.

At Loveland Basin the observational record (50+ years) and the vegetative record (200-500 year-old conifers) indicated avalanches would not reach the parking lot. Nature does not abide by man's rules or follow his reasoning. Had statistical and dynamical analysis been done prior to the February 2 event, ski area personel would have known it to be possible for an avalanche to reach, and even travel across, the parking lot. Canadian avalanche consultant Chris Stethem (1992) said it well: "Our knowledge tells us that if we use explosive control for protection of valley developments, sooner or later we'll shoot down the big one...." Knowing the calculated runout distance for the rare event can aid the avalanche forecaster so that an extraordinary avalanche does not become an unprecedented event.

FORECASTING

The February 2, 1996, Over the Rainbow avalanche was an extraordinary event. However, it was caused by a combination of ordinary factors. The weather conditions in the months prior to the avalanche were typical for the Loveland Basin area and the rest of the Northern Mountains of Colorado: several storms separated by days or weeks of dry conditions. Snowfall during January was almost a record, and snowfall from January 23 to February 1 was impressive. But snowfall during the storms of February 1995 and 1986 (and other storms) were even greater, and no destructive avalanches occurred at Loveland Basin.

The weather had contributed to a weak snowpack; however, local knowledge suggested the strength of the snowpack was no worse than typical mid-winter conditions. If anything local experience suggested the lower portion of the snowpack may have been slightly stronger than usual. The initial release of the February 2, 1996, event did not seem unusual. (A year earlier during the February 1995 storm an even larger slab released on an even weaker snowpack, but it, like previous events, plowed into soft snow and stopped in the trees far above the parking lot.)

Since the snow conditions in the starting zone do not explain the avalanche's extreme runout, that leaves the conditions in the runout zone as the likely culprit. Unfortunately detailed snowpack observations in the runout zone were never taken, but the small avalanche (described in the **Snowpack conditions** section) on January 1 gives an important clue to conditions in the runout zone, which leads by inference to one further conclusion.

Previous avalanches had always stopped before, or just into, the thick conifers on a bench at about 3,414 m. Small avalanches would lose energy and momentum on the bench, and larger avalanches would meet resistance when the debris plowed into stable, fresh snow in the track. On February 2, 1996, it seems plausible the surface hoar and upper-level kinetic crystals may have reduced the frictional resistance of the moving avalanche and allowed its leading edge to move further and travel across the old runout zone. The avalanche, once across the bench spilled down onto the steeper slope (segment 5) where it released additional snow that crashed into the parking lot. (Though the average gradient of segment 5 is about 25°, it includes several very short but steeper pitches.)

For the avalanche forecaster the lessons learned from the February 2, 1996, avalanche include the obvious and hackneyed lessons of "expect the unexpected" and "expect avalanches to run further than expected," but there is another important lesson. When large avalanches are expected, snow conditions in the runout zone can be just as important, or perhaps more important, in determining runout distance than the volume of snow in the starting zone. Being aware of snow conditions in runout zones may reduce the surprise when ordinary conditions result in extraordinary avalanches.

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