4. SNOW AVALANCHE HAZARD: CHARACTERISTICS AND CONSEQUENCES FOR THE JUNEAU STUDY AREA

The interrelationship of three factors -- terrain, weather/climate, and snowpack determine the ability of a slope to produce snow avalanches and the character of the avalanches produced.[2] Snow avalanches vary considerably in their size, frequency, and dynamic energy because of these variables. Specifically:

- Topographic features such as slope shape, steepness, roughness, vertical drop, and aspect in relation to wind and sun influence not only velocity and avalanche motion but also the aerial extent of exposure;

- Snowpack features such as snow depth and distribution, layering and bonding, and moisture content largely determine the manner of failure and magnitude of the event as well as the flow dynamics.

- Weather and climate factors such as air temperature ranges, precipitation amounts and intensities, and wind speed and direction are significant because they influence the size and frequency of avalanches and act as triggering mechanisms.

Section 4.1 discusses the terminology and processes associated with avalanche release, motion, and impact while Section 4.2 addresses the character and diversity of avalanches found in the Behrends Avenue and White Subdivision avalanche paths.

4.1 Avalanche Release, Motion, and Impact Effects

In the Juneau area, two predominant types of snow avalanches occur: loose snow avalanches and slab avalanches.[3] By definition, *loose snow avalanches* or *point releases* initiate from a point in loose, cohesionless snow and widen in their descent as they entrain additional unconsolidated snow along their course. Most commonly observed on steep slopes in new snow which has not yet settled or in recently warmed surface layers that have lost their cohesiveness, loose snow avalanches generally pose the least risk to residential development (but a much higher risk to skiers and climbers).

Slab avalanches, on the other hand, occur when a cohesive layer or layers of snow fail as a unit (i.e., *a slab*) and release simultaneously across a broad plane, becoming detached at all of the slab boundaries. Slab avalanches generally pose the greatest potential risk to residential development (and backcountry recreationists alike) because they generally fail simultaneously across an extensive area, encompass a greater mass of material, and attain

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[2] In the sections of this report which deal with snow avalanches, the terms *snow avalanche, avalanche, snowslide*, and *slide* are all used interchangeably to describe a mass of snow moving down an inclined slope. Technically, such events may contain soil, trees, rocks, or ice as well as snow, but the principal mass involved is snow.

[3] Although *cornice breaks* (i.e., blocks of wind drifted deposits which have broken and fallen onto the slopes below) are technically a form of avalanche, they are not considered a "predominant" form in the paths under consideration in the Juneau area. They can be important, however, as a type of triggering mechanism for the release of larger slab avalanches under the right conditions.

greater velocities and dynamic energy in their descent. Thus, most of the discussion in this section relates to the failure of slab avalanches.

In order for *slab failure* to occur, the following requirements must be met. There must be:

a) an unstable snowpack which exists in a state of near equilibrium balance between strength and stress (i.e., a slab with stored elastic energy overlaying a weaker, poorly bonded layer resting on a bed surface);

b) a sufficiently smooth and steep slope (35° to 45° is typical for large avalanches in the study area) to create additional stress along the boundary regions of the slab; and

c) a trigger of sufficient force to tip the balance (i.e., new snow load, rain, cornice breaks, wind loading, explosives, earthquakes, etc.).

When an avalanche initially breaks away from the release zone[4] and slides downslope, the slab, if composed of dry snow, desegregates into smaller blocks and clods of snow, which tumble and bound into the air as they gain velocity. As the avalanche descends and grows in size, often entraining unstable snow in the track, it develops two distinct flow characteristics: a) a slower moving *core* of denser, semi-pulverized debris (50-200 kg/m^3 for dry snow and 350-500 kg/m^3 for wet snow) flowing within 2-5 meters of the surface and b) a less dense, faster moving turbulent suspension of fine-grained desegregated snow particles and small snow clods known as the *powdercloud or powderblast* (usually less than 10 kg/m^3 or approximately 8-10 times denser than air).[5]

Once initial velocity is attained (usually in the upper third to fifth of the path), evidence suggests that velocity is not likely to significantly increase lower in the track, even on very steep slopes, presumably because the driving force of gravity is unable to overcome the frictional resistance along the boundaries of the flowing mass. Maximum velocities for large dry snow avalanches (i.e., for paths ranging from 500-1,000 m (roughly 1,500-3,000 ft) vertical drop) are estimated to reach 70 m/s (approximately 150 mph) but even small avalanches (i.e., in paths ranging from 100-150 m (300-450 ft) in vertical drop) are capable of attaining velocities of up to 35 m/s (80 mph) under the right conditions. For wet snow avalanches, the velocities are likely to be considerably less due to the greater frictional resistance of the material. With large wet slab avalanches (i.e., falling within the range of 500-1,000 m (1500-3000 ft) vertical drop), the maximum velocities attained are likely to fall within the range of 20-35 m/s (45-80 mph), versus 10-20 m/s (20-45 mph) for smaller slides within the range of 100-200 m (300-600 ft) vertical drop (Mears, 1991, unpublished). Note that all conversions from metric to english units are approximations only.

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[4] *Avalanche paths* consist of three parts: the *release zone* or *starting zone* which is generally at the top of the path where failure initiates; the *track* down which the moving snow descends; and the *runout zone* or *deposition zone*, where the debris slows down and comes to rest. In large avalanche paths, the runout zone also usually includes the *powderblast zone* which extends far beyond the area of snow deposition.

[5] By comparison, 1000 kg/m^3 is the density of water (@ 62.4 $lbs/ft.^3$). 1000 kg/m^3 equals 100% water equivalency or 1.0 specific gravity.

The duration of time required for a large avalanche as described to flow past a given point is estimated to be within the range of 10-20 seconds depending upon topography and snow conditions. As the avalanche descends in a bounding, wave-like manner, the initial dynamic impact pressures typically reach a level two to five times as high as the norm, with subsequent peaks somewhat less. Each peak may last only .10 of a second, while the *powderblast* itself (i.e., the leading edge of the avalanche) may precede the core by only a fraction of a second or by many seconds depending upon the topography, the consistency of the snowpack, and the character of the climate. Generally however, the elapsed time from initial impact until maximum impact is less than a second. Such large, dry snow avalanches typically tend to descend in a straight line, regardless of small terrain barriers, and are capable of exerting tremendous thrust pressures, horizontally, vertically, and laterally.

Even moderate sized avalanches are capable of producing impact loads 10 to 20 times greater than the typical lateral loading capacity of wood frame structures. For example, an avalanche traveling at a speed of approximately 65 mph (30 m/s) with a flow density of approximately 100 kg/m^3 could exert a lateral pressure of 940 lbs/ft^2. By comparison a force of 40-80 lbs/ft^2 is sufficient to break windows in houses while forces ranging from 400-600 lbs/ft^2 are capable of breaking mature trees and destroying wood frame structures. [6] The problem of avalanche impact is exacerbated when structures are built broadside to the direction of flow as is the case in both the Behrends Avenue and White Subdivision paths.

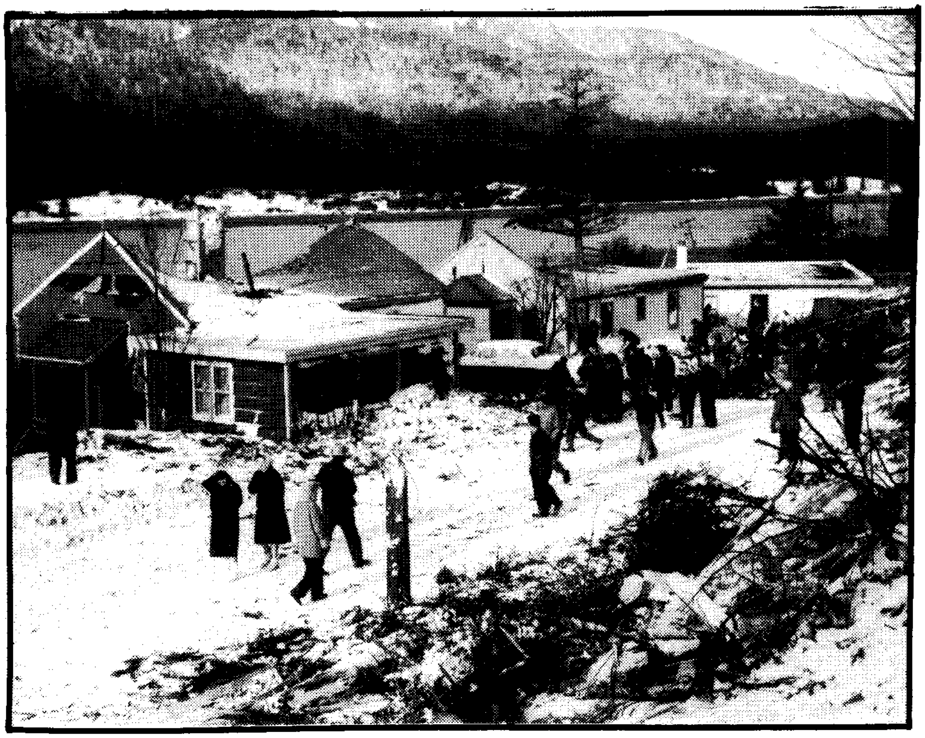

Figure 5: Taken shortly after the March 22, 1962 Behrends Ave. avalanche, this photograph illustrates some of the damage resulting from the powderblast of this fast moving low density avalanche. Thirty five houses were damaged: some were pushed off of foundations, roofs were blown off, walls pushed in, chimneys snapped off, trees broken and hurled through walls and roofs, and windows were blown in or sucked out. Photo source: Alaska Mountain Safety Center, Inc., Hart Collection.

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[6] Mears, A., In Press, *Avalanche Analysis for Land-Use Planning and Engineering*, Colorado Geological Survey Bulletin 38.

4.2 The Behrends Avenue and White Subdivision Avalanche Paths

Within any given path, an enormous diversity exists in the type of avalanche activity, the depth and distribution of coverage, and the frequency of large events. For example, avalanches may typically descend along the east side of a given path, while at other times, they may impact the west side. Sometimes the path will produce an immense volume of snow but the slide will exhibit little or no powderblast while at other times, there may be a tremendous powderblast but little or no debris at the same location. Likewise, the path may normally fail under certain predictable weather conditions and then unexpectedly, it may release under a completely different set of circumstances.

Most avalanches in a given path are relatively small and frequent and affect only a small portion of the potential path area. Occasionally, much larger avalanches release which extend nearly to the observed limits of the path. These larger events are usually referred to as "10 year" events but in reality, reflect an order of magnitude return period of > 3 years but < 30 years.[7] On rare occasions, exceptionally large avalanches occur which extend well beyond the "normal" limits of observed activity. These design magnitude avalanches[8], often referred to as "100 year" avalanches, are likely to affect all or most of the potential path area.

For the purposes of this report, the *design avalanche* is defined as an avalanche occurring within an order of magnitude range of > 30 years but < 300 years. Such an avalanche by nature is an unusual event, precipitated by exceptional meteorological and snow conditions. In most cases, design magnitude avalanches involve the release and entrainment of weak, poorly bonded, cold dry snow layers. These avalanches usually break big, run fast, hit hard, and have a significant powderblast component. In a lesser number of cases, design magnitude avalanches may involve the release of very wet, poorly bonded, water-saturated snow with a significant volume of debris, but little or no powderblast. Statistically, design avalanches have a 1% probability of occurring during any given year, but could occur on consecutive years or many years apart. In the final analysis, most avalanches occurring in a particular path will stop far short of reaching the 100-year boundary limits, but exceptional events may, on very rare occasions, even extend beyond these limits.

Several factors contribute to the development of potential avalanche hazard in the Behrends Avenue and White Subdivision avalanche paths:

1) The terrain above the subdivisions is suitably steep, smooth, and leeward. The starting zones are extensive in all but the three Bartlett paths and the tracks are

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[7] The *return interval* or *return period* for a given path is an estimate of the average time interval between avalanche events and does not necessarily refer to the actual time interval between events. A "10 year" avalanche, for example, may occur on consecutive years or many years apart. As a planning tool, the concept of a return interval is useful not only for site selection and design, but also as an estimate of replacement or repair costs for structures located at exposed sites where protection may not be possible.

[8] *Design magnitude avalanches* or *design avalanches* are by definition, infrequent major events of sufficient magnitude to overrun or extend beyond the "normal" limits of observed avalanche activity and are of sufficient destructive force that they must be carefully considered in the design and planning of residential structures or facilities.

relatively steep and unobstructed, thus allowing avalanches to maintain maximum velocities to the base.

2) The Juneau area receives significant quantities of precipitation with greater amounts of snow at higher elevations and rain at lower elevations. Snow has been recorded in excess of 100" (2.5 m) at sea level (with up to 65" recorded in a single month) and perhaps twice that amount falls at starting zone elevations. If wind loading is factored in, the accumulation levels at starting zone elevations could be four to five times greater than those at sea level.

3) The area is subject to extreme temperature fluctuations which contribute to a diversity of metamorphic processes affecting the snowpack. These play a significant role in the development of structurally weak snow layers which can then act as potential shear or failure planes once buried under the weight of subsequent layers.

4) The upper slopes of both Behrends Avenue path and White path are subject to intense periods of snow loading caused by predominantly strong N-NE winds. Most of the unconsolidated snow available for transport will likely be deposited in the starting zones during a short period of time. These winds tend to not only build cornices and deep slabs below but also, due to the added load, act as triggering mechanisms for slab failure.

5) Given the topography, elevation range, and snow climate of the paths, avalanches starting at higher elevations can entrain significant quantities of new snow during descent. Entrainment may significantly increase the volume of snow transported to the runout zone where private property is located.

One of the unique features of the Behrends Ave. path (which lies in a northeast/southwest alignment) is the presence of a large transverse gully which diagonally intersects the main path in a north/south alignment midway in the track. This natural diversion berm provides limited "structural protection" for the subdivision by catching some of the debris from small to moderate sized avalanches and diverting most of the remainder to the southeast side of the path. This increases both the distance debris must travel to reach the subdivision and the frictional resistance to which it is subjected while moving. The net result is that most of the avalanche debris generated by small to moderate sized avalanches stops short of reaching the subdivision. However, once the gully starts filling with snow, its effectiveness as a diversion berm diminishes. Nor is the transverse gully likely to have much effect in retarding large avalanches, even when it is empty. Although it may dissipate some of the energy from large slides, particularly early in the season when the gully is nearly empty, it will have little effect in reducing the powderblast component from major avalanches. These larger events will easily override the berm and continue in a southwesterly direction through the subdivision into Gastineau Channel.

Another factor which tends to inhibit avalanches from reaching the subdivision is the maritime snow climate. Maritime snowpacks (generally heavier and denser) are renowned for their ability to hold in place on steep slopes, and at lower elevations, to retard the flow of moving debris. This is due, in part, to a certain amount of strengthening that takes place through the processes of settlement and melt-freeze metamorphism, and to the development over time of a lattice of drainage channels that allow free water to percolate easily through the snowpack rather than be retained as weight. This retarding effect tends to hold the snowpack to the mountainside and to "dampen" the flow of debris once failure has occurred. This also applies to small or moderate sized avalanches which may start in cold dry snow at higher elevations but encounter warmer, wetter snow at the mid and lower elevations. It is not likely, however, that large avalanches releasing under similar conditions will be significantly deterred from reaching the subdivision area. These larger avalanches are of sufficient magnitude and energy to easily overcome any retarding effect caused by warmer and wetter snow at lower elevations and, in fact, may actually produce higher dynamic pressures due to their greater densities.

There is also the potential problem of debris deflection where stationary debris deposits from previous avalanches inadvertently act as "deflecting walls", causing the moving debris from subsequent avalanches to be deflected in a slope perpendicular direction toward the lateral boundaries of the path. Under most conditions, this would not present a problem but with the recent development of residential structures in the forest along the periphery of the paths, some recent structures are now at risk.

Historically, only a few major avalanche events are known or alleged to have occurred in Behrends Avenue path. Because these events are infrequent, they are often easily forgotten or conveniently dismissed as "freak" events. Based upon the information compiled in Appendix A of this report the return interval for large avalanches occurring in the Behrends Ave. path is estimated to be approximately 14.4 years, based upon 7 major events in 101 years (1890, 1917, 1926, 1935, 1946, 1962, and 1985: see Appendix A-2). Of these large events, the 1962 and 1985 avalanches are the best documented and provide the most useful information. The March 22, 1962 avalanche, for example, resulted in the greatest amount of property damage caused by a single avalanche in this path (see Figure 5). This avalanche also produced the largest powderblast yet recorded in the path. By comparison the Feb. 26, 1985 avalanche was smaller but represented the largest event recorded since 1962. This event, however, is considered small when compared with the potential of the path and snow climate.[9] There undoubtedly have been additional large avalanches but these were either unobserved or unrecorded.

White Subdivision is affected by four avalanche paths; three of these are narrow chutes with relatively small starting zones (Bartlett No. 1, Bartlett No. 2, and Bartlett No. 3) while the fourth, referred to as the White path , is considerably larger and more formidable. Although the number of years of historical record for avalanches affecting the White Subdivision is even shorter than the Behrends Avenue path, a number of impressive avalanches have occurred in the White path and buildings have been hit on four occasions in the past ten years (see Figure 6). Based upon data from the last 29 years (the period of record), the return period for large avalanches affecting private property in the White

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[9] Although the 1985 avalanche was considered "large" in reference to recent memory, it is not considered "large" in relation to the path's potential. By analyzing the depth and distribution of slab failure after the event and comparing this with the path's potential for release under "extreme" conditions, it was determined that the Behrends Ave. avalanche path is capable of producing avalanches approximately <u>four times larger</u> in volume than the Feb 26, 1985 event (Fesler, 1985, Personal investigation).

path is 3.6 years. Thus, although the scope of exposure may be less in terms of the number of structures exposed, the frequency is four times greater than the Behrends Avenue path. Of equal importance is the fact that none of the recorded events to date have even come close to approaching the potential size of a design magnitude event, given the capability of the terrain and the snow climate.[11]

Figure 6: The avalanche which hit and damaged this occupied residence in White Subdivision was the 4th slide of the season in this path and the second one in a month to hit the house. Only the second story is visible above the debris and the garage (immediately to the right of the house) is still buried along with the owner's vehicle which was parked in the driveway. Damage from wet snow avalanches such as this usually results from crushing and dislocation. Photo by Doug Fesler, Feb. 20, 1985.

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[11] Comparisons of fracture depth and distribution data from some of the most recent "large" avalanches which have occurred in this path support this conclusion (Fesler, 1985,1989, and 1990, Personal investigation).