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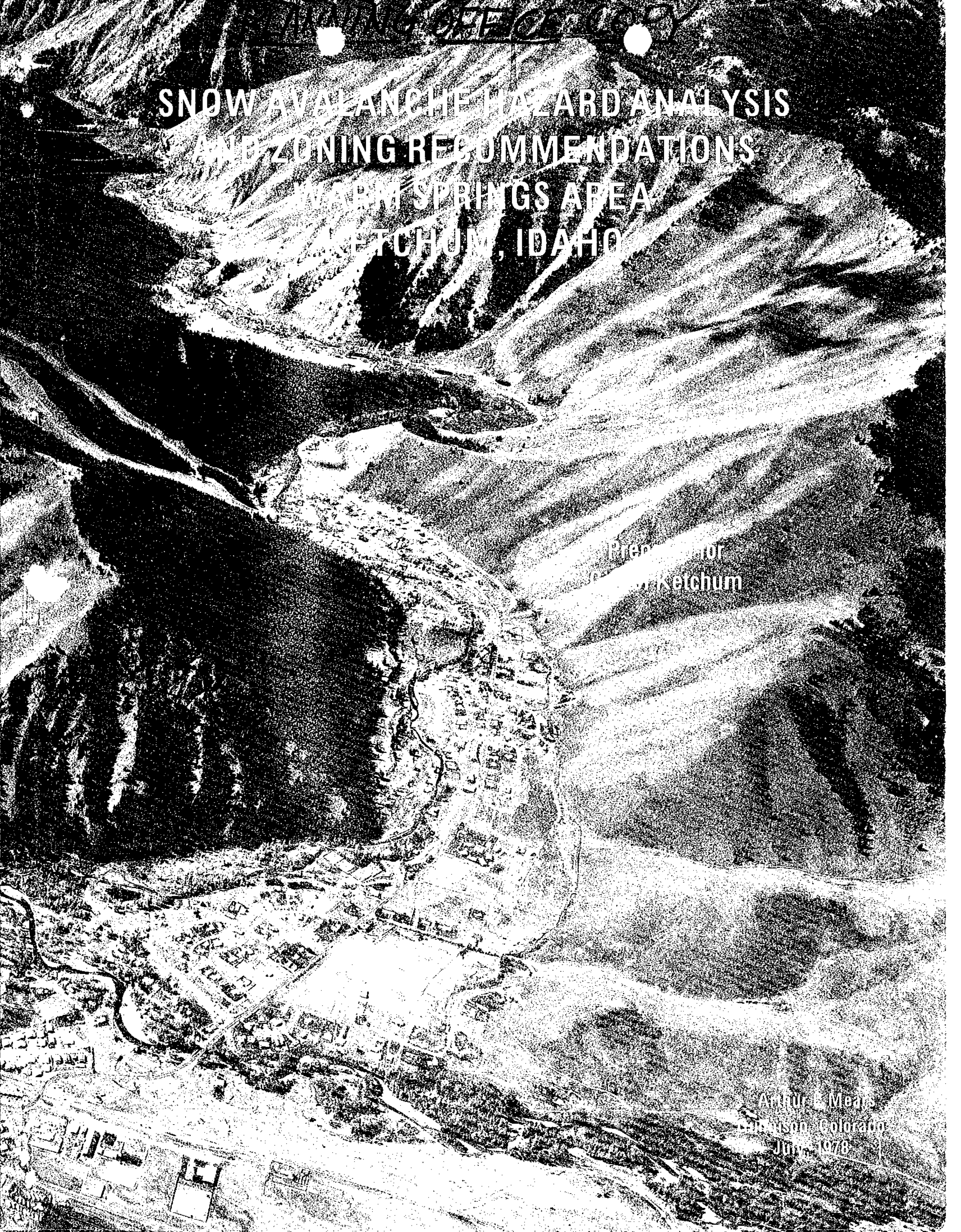

SNOW AVALANCHE HAZARD ANALYSIS AND ZONING RECOMMENDATIONS WARM SPRINGS AREA KETCHUM, IDAHO

Prepared for
City of Ketchum

Arthur I. Mears
Gunnison, Colorado

July, 1978

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July 3, 1978

Mr. Russ Pinto
City of Ketchum
Ketchum, Idaho 83340

Dear Mr. Pinto:

Enclosed is my report on the snow avalanche hazard and related land-use recommendations in the Warm Springs area of Ketchum. This study has been completed in accordance with my proposal letter to you dated May 25, 1978.

The avalanche runout areas and hazard zones are delineated on the large-scale (1" = 100') maps which accompany this report.

Please contact me if you have any questions.

Sincerely,

Arthur I. Mears

Arthur I. Mears, PE

Encl.

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I. SUMMARY OF REPORT

Design magnitude avalanches in the Warm Springs area were used to define an avalanche zoning plan. These avalanches consist of dry-flowing avalanches which, in some cases, have powder avalanche components. The potential hazard to developable areas in Warm Springs has been subdivided and mapped into 3 levels of intensity (see Maps 1, 2, and 3). Red Zones are subject to high hazard, Blue Zones to moderate hazard, and Yellow Zones to very low hazard.

Specific land-use recommendations correspond to these hazard levels (see sections VIII and IX). Building should be excluded from the Red Zone. Building should be permitted in the Blue Zone if specially designed avalanche defenses are provided. Building can also be permitted in the Yellow Zone if defenses are provided.

Avalanche defense requirements, including design loads and dimensions, cannot be specified without knowledge of building location, size, shape, and orientation with respect to avalanche flow. Because of this, structural defenses must be designed individually.

II. INTRODUCTION AND OBJECTIVES

This study of the avalanche hazard to the Warm Springs area of Ketchum, Idaho has been requested by the City of Ketchum.

Specifically, the study calculates the sizes of "design" magnitude avalanches which affect Warm Springs, and recommends a zoning plan based on the avalanche hazard. The magnitudes of the design avalanches are determined through study of the terrain, historical record of avalanches, climate and weather of the area, and through application of the Swiss equations of avalanche dynamics. Modification and verification of these techniques are objectives of ongoing research conducted by the U. S. Forest Service, Forest and Range Experiment Station (Mears, unpublished data). This new research was applied to the present analysis.

Determination of the sizes and characteristics of the design avalanches enables the development of an avalanche zoning plan. This zoning plan is based on the natural characteristics of the avalanches, including avalanche

1. Types,
2. Velocities,
3. Discharges,
4. Flow depths,
5. Runout distances, and
6. Dynamic pressure potentials.

An estimate of avalanche frequency is also made.

The design avalanches are of a size which must be considered in planning, location, and construction of structures in and near avalanche paths. In this case they are defined as avalanches of magnitudes expected to recur less often than once in a century, on the average. Stated another way, the design avalanches have annual occurence probabilities of less than 1 percent. This statement of probability does not specify the distribution of design avalanches through time. Hence, they may occur in two or more successive years without changing the occurrence probability in succeeding years. Avalanches larger than the design avalanche can occur, but the probability is small enough so they can be disregarded in planning.

The findings and recommendations of this study are applicable to the study area only. They may not necessarily be applied to other areas.

III. CLIMATE AND WEATHER

The study area lies within a generally continental climate characterized by cold winter temperatures, a dry, cold, and relatively shallow snowpack, and moderately strong winds. This conclusion is based on study of 30 years of record from Ketchum and 7 additional years of record from the Sun Valley Ski Area. Structural weaknesses are commonly found within the snowpack and serve as locations for snowpack failure during avalanche conditions.

Occasionally, sustained and heavy snowfall occurs and produces large and destructive avalanche cycles. For example, in 1969, 104 inches (2.6 meters) of new snow fell at the 8900 foot (2700 meter) elevation at Sun Valley Ski Area in 18 days time. As a result, destructive avalanches fell in the Warm Springs area. Another example of intense snowfall in this area occurred in February, 1959 when 38 inches (1 meter) of snow fell in Ketchum during a single day. Similar or greater snowfall intensities are to be expected occasionally, and will often be associated with large avalanche cycles.

The weather and resulting snowpack conditions producing the very large design-sized avalanches which are the subject of this study occur infrequently. However, it should be remembered that they do have a finite probability and may occur during any winter.

IV. AVALANCHE TERRAIN

The avalanche paths affecting the Warm Springs area are located on the north side of the valley of Warm Springs Creek. The types of avalanche paths can be placed broadly within two categories: (1) confined or channelized, and (2) unconfined. The confined paths concentrate the flowing snow in gullies and channels. Each of the channelized paths can be subdivided, for purposes of analysis and comparison, into 3 parts. The upper part of each path is called the starting zone, or area in which unstable snowslabs fracture, avalanches begin, additional snow is rapidly entrained into the moving snow, and avalanches accelerate. In channelized paths, such as the Creek Slide and Division Gulley, the areas of the starting zones are closely related to the total volume of snow set into motion during a large avalanche event. The larger starting zones produce the larger, higher velocity, and longer running avalanches. This is reflected in the mapping of the avalanche paths on Map 2, where it can be seen that the runout zones are longer below the channelized paths.

In each of the channelized paths the avalanche tracks consist of shallow gullies which confine and efficiently convey the large volumes of snow released from above to the valley floor. This channelization increases the flow depths, velocities, and runout distances.

Avalanches decelerate and stop in the runout zone which is the level or gently sloping floor of the valley of Warm Springs Creek. Design avalanches will reach the top of the runout zone (where the slope becomes less steep) at maximum velocity. The distances they will flow across the valley is of prime interest when evaluating the hazard and developing an avalanche zoning plan. This runout distance depends primarily on the depth of flow, the velocity, and on the type of avalanches, all factors considered in avalanche calculations.

In addition to the channelized paths discussed above, extensive areas in the Warm Springs area are also subject to unconfined avalanche activity. These avalanches can occur on open faces, in very shallow gullies, or on subdued ridges separating the gullies. Because the flow is not confined to gullies in these cases, the avalanches will move at lesser velocities and will flow shorter distances into the runout zones. Nevertheless, these avalanches can produce substantial pressures on objects located in the runout zones. Therefore, it should not be assumed that a building is safe from avalanches because it is located between major gullies. As stated, both gullies and open faces and ridges can produce avalanches which can reach the valley floor and impact structures.

V. TYPES OF AVALANCHES AFFECTING WARM SPRINGS

Mixed dry-flowing/powder avalanches constitute the design avalanche type throughout the Warm Springs area. These avalanches result from fracture and release of dry, soft new slabs. During design avalanche conditions, fractures can be both deep and extensive, possibly extending several hundred meters in length and connecting several of the major avalanche paths in the area. However, even if such extensive fracturing did occur, the runout distances in each path would be affected only by the topography and snow conditions in that particular path.

Regardless of the length of the fracture, each avalanche path would react independently of the others. The soft, dry snow would become rapidly entrained within each starting zone, and as the avalanche accelerates, air would also be entrained into the flow. The resulting avalanche would be a combination of dry flowing snow moving close to the ground and a deeper, low density powder cloud suspended well above ground level. The powder avalanche portion, because of its greater flow height and velocity will travel the longest distance into the runout zone, thus separating from the denser, slower-moving snow near the ground. This results in a "powder blast" area and is most pronounced below Division Gully, Creek Slide, and Sage Road Slide (see Map 2).

It should be pointed out that although powder avalanches are expected to flow at the highest velocities and travel the longest distances into the runout zones, they produce much smaller dynamic pressures than the denser flowing avalanches. However, these pressures will, in general, be in excess of pressures for which buildings are usually designed and must be considered in building design and location. The relationships between powder avalanches and flowing avalanches are illustrated in Figure 1.

Wet snow avalanches also occur in these paths but will involve less mass and will flow at lesser velocities than the design dry snow avalanches. Therefore, the runout zones of the wet snow avalanches are shorter than the dry snow avalanche runout zones.

VI. ANALYTICAL APPROACH USED TO DEFINE THE HAZARD ZONES

Ideally, an avalanche zoning plan should be based upon (1) study of several centuries of detailed records, (2) study of the climate and weather, (3) terrain analysis, (4) vegetation damage and debris distribution, and (5) avalanche dynamic equations. Unfortunately, in the Warm Springs area, as well as in other areas within the United States, a long historical record is not available, and weather and climate records are relatively short. In addition, at Warm Springs there is little evidence of avalanche activity reflected in vegetation damage because the avalanche slopes are almost completely unforested. Because of these difficulties the avalanche hazard zones shown on Maps 1, 2, and 3 have been based on application of terrain analysis and dynamic equations. These results have been checked through comparison with the short historical record of avalanches.

The avalanche hazard zones are defined analytically in terms of zones of avalanche dynamic pressures and avalanche types. The calculations utilize our knowledge of fluid dynamics and basic physics, thus the pressure zones are calculated rather than assumed. However, it should be stated that our knowledge of avalanche dynamics is at present rather incomplete. Because of this the pressure zones have been defined conservatively. Details of the equations used in the analysis and related applications are discussed in Voellmy (1964); Sommerhalder (1967, with 1978 revisions); Mears (1976); and Leaf and

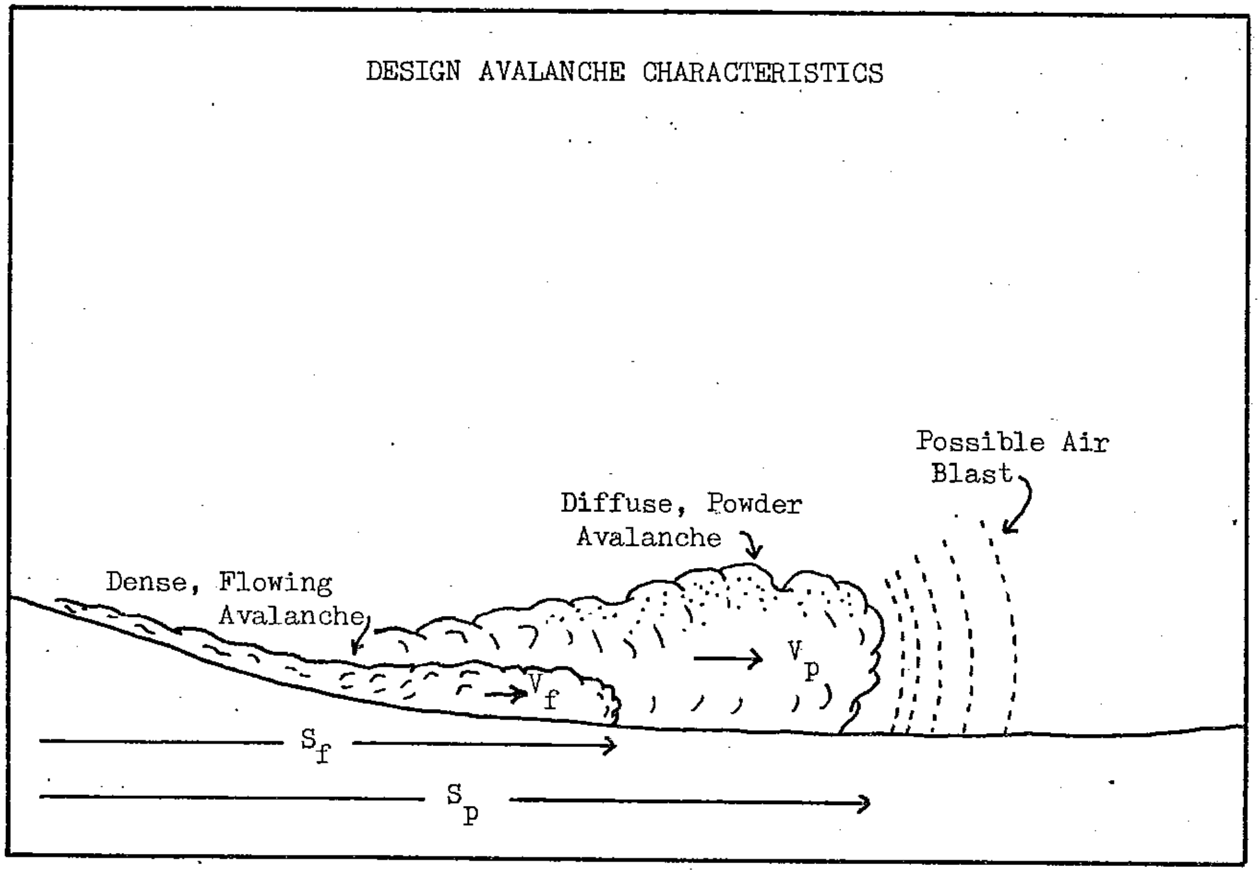

FIGURE 1. The characteristics and relationships between types of avalanches which have been considered in evaluation of the avalanche hazard at Warm Springs are shown above. The following points were considered in the analysis:

a. Powder avalanches are deeper and flow at higher velocities than flowing avalanches. This enables powder avalanches to flow longer distances into the runout zone so that $S_p > S_f$.

b. The densities and dynamic pressures of powder avalanches are considerably less than those of flowing avalanches.

c. An air pressure wave, or "air blast" may precede powder avalanches but will produce less intense pressures.

The avalanche hazard zones shown on Maps 1, 2, and 3 correspond to these avalanche types as well as dynamic pressures and estimated frequencies. Thus Red and Blue Zones are affected by flowing and powder avalanches (where they occur), but the Yellow Zone will be affected primarily by powder avalanches and air blast.

Martinelli (1977). For details of the use of the equations, the reader should refer to these publications, which are listed in the references at the back of this report.

Table 1

Calculated Avalanche Dynamics

Path Name	A_s	α	β	U_t	h'	Q	S
Creek Slide	11.2	26	4-17	33	10	7000	200
Division Gully	11.7	24	0-12	32	10	8000	210
Duplex Lot	----	29	1-11	31	3	----	190
Animi Face	----	33	2	27	2	----	90
Sage Road	----	27	2	29	3	----	120
East Face	----	32	1-5	33	3	----	80
West Face	----	26	1-2	18	2	----	50
Far West	----	36	10	25	1.5	----	50

A_s : Starting zone area, ha; 1ha = 2.47 acres

α : Average track inclination, degrees

β : Range of runout zone inclinations, degrees

U_t : Maximum track velocity, m/sec; 1 m/sec = 2.24 mph

h' : Flowing avalanche flow height, meters

Q : Channelized avalanche discharge, m^3/sec; 1 m^3/sec = 35.3 cfs

S : Runout distance, meters; 1 meter =3.28 feet

Note: Powder avalanche dynamics are not summarized on Table 1 and some of the smaller avalanche areas are not included here.

Table 1 summarizes the results of the calculations of the assumed design avalanche conditions. The avalanche hazard zones, discussed in the next section of this report, are based on these calculated results.

Figures 2, 3, 4, and 5 on the following pages illustrate locations in the Warm Springs area which are presently developed within avalanche runout zones. Structures within these areas will probably be reached by avalanches in the future.

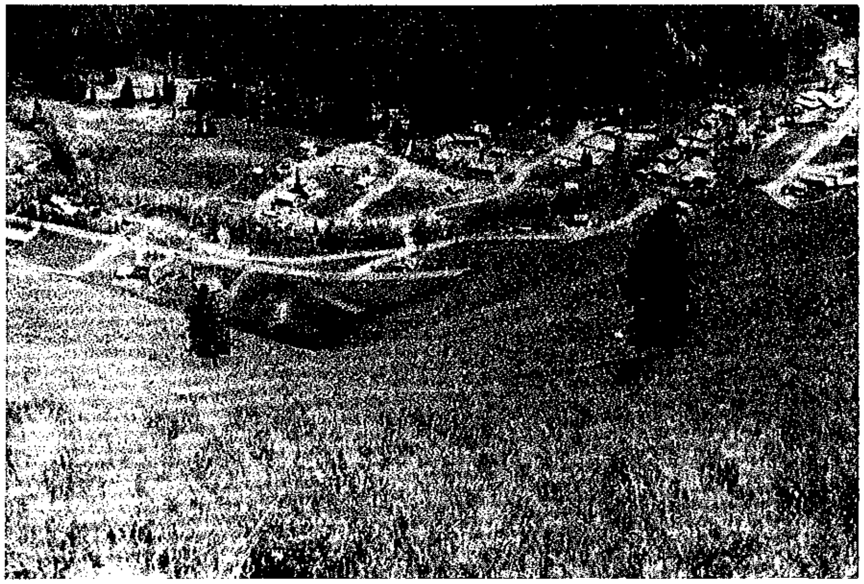

FIGURE 2. View looking down from the upper track in Creek Slide. Trees in foreground show damage from avalanche impact.

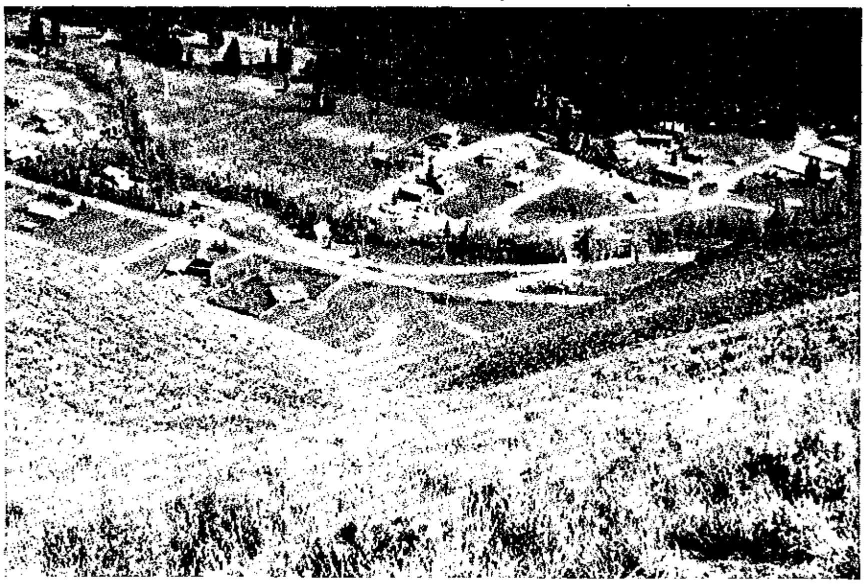

FIGURE 3. View looking down from mid track in Creek Slide. Runout zone (Map 2) extends across Warm Springs Creek.

FIGURE 4. Houses exposed to avalanches in Warm Springs area. Some buildings are exposed to small, unconfined slope avalanches, others, such as illustrated in Figures 2 and 3, to major channelized avalanches.

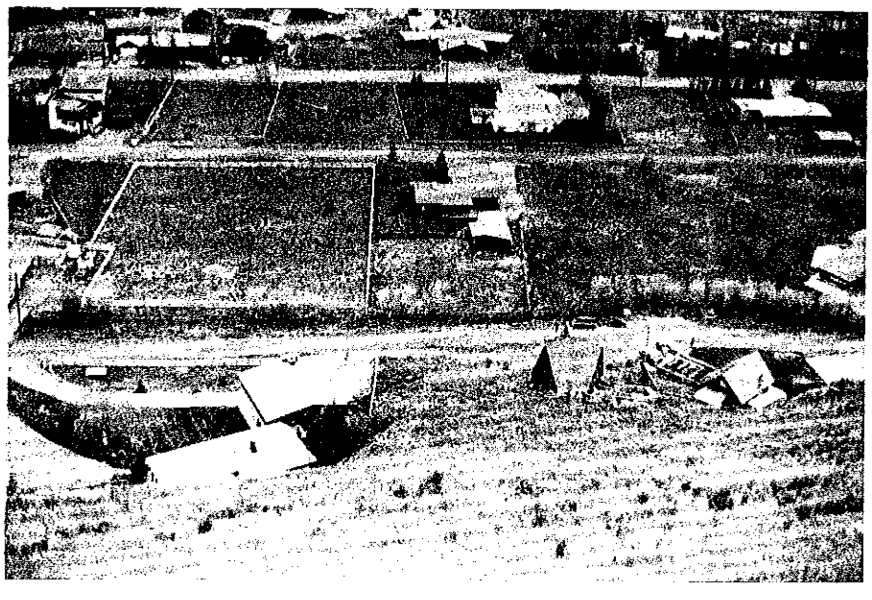

FIGURE 5. Houses at lower left are located below a 35-degree slope and are exposed to hazard from unconfined slope avalanches.

VII. AVALANCHE ZONING AND RELATED LAND-USE RECOMMENDATIONS

An avalanche zoning plan is necessary in the Warm Springs area to ensure that future property development considers the potentially hazardous avalanche condition. Such a zoning plan must (1) recognize and define the natural avalanche condition, and (2) be applied objectively and fairly to all affected property owners. Although there is little experience with avalanche zoning in the State of Idaho, experience in other areas can serve as models for zoning in the City of Ketchum.

The Swiss avalanche zoning recommendations, which are based on calculations of avalanche dynamic pressures and estimated frequencies such as those used in preparation of this report are followed closely here. The following zone definitions can serve as models for avalanche zoning in the City of Ketchum. The Red, Blue, and Yellow Zones discussed below are shown on Maps 1, 2, and 3. The only minor modification to the Swiss recommendations is in the return period affecting the Blue Zone. The Swiss recommend that avalanches with return periods of up to 300 years be included in the Blue Zone. This is possible in Switzerland because they have a long historical record of avalanches. Specification of such a long return period is not possible in Blaine County, Idaho because the historical record is much shorter (roughly a century). Thus, it is recommended that the Blue Zone, as defined here, include avalanches with return period of up to approximately one to two centuries. The pressure requirements in the Blue Zone remain the same as those recommended by the Swiss.

Three zones of avalanche hazard intensity are recommended. Hazard intensity diminishes progressively in the Red Zone, Blue Zone, and Yellow Zone as discussed below.

Red (high hazard) Zone. This zone includes terrain exposed powerful avalanches that satisfy either of the following:

1. Any avalanche with a return period of less than 30 years, regardless of its impact pressure potential.
2. Any avalanche with an impact pressure potential of $3.0\ t/m^2$ ($600\ lbs/ft^2$)* or more and with a return period of roughly "one to two centuries."

*Exact conversion is $1\ t/m^2$ = 1 metric ton per square meter = $205\ lbs/ft^2$. Conversions in zone definitions are rounded to same number of significant figures.

The Red Zone will be affected by wet and dry flowing avalanches and by powder avalanches.

Blue (moderate hazard) Zone. This zone includes terrain exposed to avalanches which are infrequent or produce moderate pressures as follows:

1. Avalanches produce dynamic pressures of 0.5 to 3.0 t/m^2 (100 to 600 lbs/ft^2) with average return period of 30 years to "one to two centuries."

The Blue Zone will be affected by dry flowing and powder avalanches, but wet flowing avalanches will rarely, if ever extend this far into the runout zone.

Yellow (very low hazard) Zone. This zone includes terrain exposed to powder avalanche blast and air blast and very rare flowing avalanches satisfying the following:

1. A powder avalanche or air blast producing a stagnation pressure less than 0.5 t/m^2 (100 lbs/ft^2) with a periodicity of more than 30 years.
2. An extremely rare flowing avalanche with a return period of more than one to two centuries.

The Yellow Zone is affected primarily by powder avalanches and air blast. Dry flowing avalanches will rarely extend this far into the runout zone.

It should be noted that the Red, Blue, and Yellow hazard zones differ from one another in terms of (1) dynamic pressure potential, (2) return period, and (3) avalanche type. These zones define in a quantitative way what is intuitive: the severity of avalanche effects decrease progressively with distance from the bottom of the track. Thus a certain point exists in which the potential hazard from avalanches becomes small enough so that certain types of construction are acceptable.

In the United States, the Town of Vail, Colorado has adopted as part of its land-use plan the following avalanche hazard definitions. These are also modeled after the Swiss Plans:

(A) Avalanche - Red Hazard Area. A red hazard avalanche area shall mean any area impacted by a snow avalanche producing a total static and dynamic pressure in excess of 600 pounds per square foot on a flat surface normal to the flow and/or a return interval of less than 25 years. No structure shall be built in any red avalanche hazard area.

(B) Avalanche - Blue Hazard Area. A blue hazard avalanche area shall mean an area impacted by a snow avalanche producing a total static and dynamic pressure less than 600 pounds per square foot on a flat surface normal to the flow and/or a return interval in excess of 25 years. Structures may be built in blue avalanche hazard areas provided that proper mitigating measures have been taken.

The following recommendations about land use in the outer fringes of the design avalanche runout zones consider the fact that avalanche hazard decreases with distance into the runout zone. The recommendations, which are similar to those of the Swiss and similar to those of Vail, carefully consider the type of avalanche hazard which could be encountered in each zone in terms of pressures, avalanche types, and encounter probability. Specifically, they are as follows:

Red (high hazard) Zone. Residential construction within this zone should be avoided because of potentially high avalanche pressures and/or short avalanche return periods. The Red Zone may be suitable for certain summer uses only.

Blue (moderate hazard) Zone. Because avalanches here are infrequent and produce moderate pressures certain types of construction are suitable. Buildings here should be located, designed, constructed, or otherwise defended to ensure protection against the moderate pressures of flowing and powder avalanches. Such avalanche defense design will, in general, differ for each specific case depending on the size, shape, and location of the building in the Blue Zone. Avalanche defense is discussed in more detail in the next section.

Yellow (very low hazard) Zone. The recommended land use here is the same as in the Blue Zone, although buildings need be designed only for powder avalanche pressures and/or wind blast.

VIII. AVALANCHE DEFENSES

When man chooses to live in and near avalanche hazard areas such as those of Warm Springs, he voluntarily assumes some risk. As stated in the preceding section, the level of risk is acceptable, according to standards accepted in the Swiss Alps and in Vail, Colorado, provided two conditions are satisfied: (1) that building be restricted to Blue and/or Yellow hazard zones, and (2) that structures are constructed to withstand expectable avalanche forces or that the hazard is otherwise mitigated. I assume that land values and the desirability of living near the Sun Valley Ski Area will lead to development in Blue or Yellow Zones. Therefore, the following general discussion of avalanche defense is appropriate even though no specific recommendations can be made about the most suitable types of defenses without additional information about building location, size and shape.

Various types of avalanche defense alternatives include (1) artificial avlanche release, (2) supporting structures in avalanche starting zones, (3) deflecting, arresting, or retarding structures in the lower track and runout zone, and (4) direct protection of individual buildings.

Alternative (1) is unacceptable in developed areas. Artificial release should be attempted only when the entire avalanche path can be evacuated. This is a useful method of avalanche control on highways and at ski areas but can lead to serious problems when structures exist within avalanche paths, such as in Warm Springs. An example of such a problem occurred in December, 1973 in and near Alta, Utah, as artifically released avalanches crossed Little Cottonwood Canyon, damaged many parked cars and some buildings. This type of avalanche control should be attempted only when the consequences of misjudging the avalanche sizes are not important. This will never be the case in a developed area.

Alternative (2), supporting structures in the starting zone, has been used with considerable success in the Swiss and Austrian Alps for decades. Supporting structures anchor the snow to the ground in the starting zone, thereby preventing avalanche release.

The method is most applicable when the starting zones are small and well defined and the objects to be protected are numerous and valuable. However, this type of defense has two important disadvantages. First, the cost of structures is so large that in Switzerland the federal government must pay for up to 80 percent of the total construction and engineering cost. Even in Switzerland, where considerable experience has been gained in the design and construction of supporting structures, costs may exceed $100,000 per acre of supporting structures. In the United States costs may run 2 to 3 times this amount because of our lack of experience. Considering the fact that the Warm Springs area avalanche paths involve well over 50 acres of starting zones, it is easy to see that construction costs would well run into the millions of dollars. Secondly, supporting structures, which may exceed 10 feet (3 meters) in height in some areas of deep snow, would probably be visually unacceptable.

Alternative (3) involves massive earthen or engineered structures designed to deflect or stop moving avalanches before they reach buildings. Such structures may be quite useful particularly on long runout zones or on alluvial fans where there is room to stop or deflect an avalanche and store the debris. They may be applicable at some locations in the study area. In order for this to be an effective defense it is imperative that advanced planning consider the best location for the deflected snow and development take place well outside of these areas. This requirement may present serious problems when land has already been subdivided into lots and sold. Furthermore, the location, length, orientation, height, and strength of these structures must be carefully designed by taking into consideration the topography, the avalanche velocity, and avalanche dynamic pressures. Haphazard placement and sizing of these structures may even increase the hazard to adjacent buildings by causing avalanches to be deflected into the air after structures have been overtopped by fast-moving snow.

Alternative (4) is more generally attractive because it involves only modification of individual building design to withstand avalanche forces and prevent overtopping of structures by debris. If such a defense system is required it is important to realize that the design pressures on the direct protection structures will, in general, differ from the 600 lbs/ft^2 figure used to define the Blue Zone or the 100 lbs/ft^2 figure used in the Yellow Zone. These are reference pressure levels only. The actual pressure on a structure depends on location, orientation, and shape. These architectural design parameters are often determined by land-use and aesthetic considerations, thus defense design must be on an individual basis. It is not possible to suggest a single set of design requirements that will resist avalanche loadings on affected buildings in all of Warm Springs.

IX. RECOMMENDATIONS

The City of Ketchum has taken the responsibility to define the avalanche hazard to the Warm Springs area in terms of an avalanche zoning plan. It should be pointed out that the present study follows a similar one prepared by Norman A. Wilson (1977), and although different techniques were used in preparation of these two reports, the defined hazard areas are not substantially different. Maps accompanying both reports, although differing in detail and hazard zone definitions, show extensive areas subject to avalanche hazard. With all of this information at hand the City of Ketchum should determine what moral and legal responsibility it has for disseminating the information to the public and for utilizing it in a workable land-use plan.

The following recommendations consider the findings of this study and the experience of communities exposed to avalanche hazard both in the United States and abroad:

(1) Allow no new construction in the Red Zone.

(2) Allow residential development in the Blue Zone provided that structures have been designed to resist avalanche forces or have been otherwise protected by carefully designed avalanche defenses. Such structural defenses must be designed on an individual basis and should be certified, by state architectural and/or engineering standards to safely accomodate the various static and dynamic forces resulting from avalanche impact and deposition.

(3) Allow residential construction in the Yellow Zone subject to the same design standards as discussed in (2). Note: as discussed in section VII of this report, design pressures in the Yellow Zone are less than those of the Blue Zone.

Several existing buildings are presently located in defined avalanche areas. It is my opinion that these buildings will eventually be reached by avalanches and will probably suffer some damage. Owners should be advised of this fact by the City of Ketchum and they should be encouraged to investigate the possibility of structural defenses.

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Respectfully submitted,

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