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SNOW-AVALANCHE HAZARD ZONING IN BRITISH COLUMBIA, CANADA

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Abstract. Many developed areas in British Columbia are exposed to snow-avalanche hazards. Avalanche-hazard zoning has been undertaken by the British Columbia Ministry of Transportation, Communications, and Highways during the past five years. Recommendations from these zoning studies are forwarded to those agencies responsible for land-use zoning and development approval. Existing and possible legislation are described, as well as problems associated with implementation of the legislation. Technical considerations are outlined; interpretation of vegetation is a very important factor in evaluating each avalanche site. Calculation of run-out distances and consideration of other factors serve as a check on the vegetation interpretation. A special safety factor has been developed.

Socio-political considerations with respect to British Columbia are described. Existing developments have the most wide-ranging implications.

Résumé. *Zonage des risques d'avalanches en Colombie-Britannique, Canada.* Beaucoup de secteurs développés du territoire de la Colombie-Britannique sont exposés à des risques d'avalanches de neige. Un zonage des risques d'avalanches a été entrepris durant les cinq dernières années par le Ministre des Transports, Communications et Routes de la Colombie-Britannique. Les recommandations résultant de ce zonage sont transmises aux agences responsables de l'aménagement et du développement du territoire. On expose la législation existante et celle possible ainsi que les problèmes que pose la mise à jour de cette législation. On esquisse les considérations techniques: l'interprétation de la végétation est un facteur très important de l'évaluation de chaque site d'avalanche. Les calculs de distance d'arrêt et les considérations d'autres facteurs servent de contrôle à l'interprétation de la végétation. On a mis au point un facteur spécial de sécurité.

Des considérations socio-politiques spéciales à la Colombie-Britannique sont exposées. Les développements existants ont les plus vastes implications dans l'aménagement.

Zusammenfassung. *Zonen der Lawinengefährdung in British Columbia, Kanada.* Viele besiedelte Gebiete in British Columbia sind lawinengefährdet. Während der letzten fünf Jahre wurde vom British Columbia Ministry of Transportation, Communications and Highways eine Einteilung in Zonen der Lawinengefährdung vorgenommen. Empfehlungen, die aus dieser Zoneneinteilung resultieren, werden an jene Behörden weitergegeben, die für Landnutzungs- und Entwicklungspläne verantwortlich sind. Die bestehenden und möglichen gesetzlichen Grundlagen sowie die mit deren Ergänzung verbundenen Probleme werden beschrieben. Technische Gesichtspunkte werden umrissen; die Berücksichtigung der Vegetation ist ein wesentlicher Faktor bei der Beurteilung jedes Lawinenhanges. Die Berechnung der Reichweiten und die Betrachtung anderer Faktoren dienen als Kontrolle für die Vegetationsanalyse. Es wurde ein spezieller Sicherheitsfaktor entwickelt.

Sozialpolitische Überlegungen für British Columbia werden dargestellt. Bestehende Entwicklungen führen zu den weitest reichenden Folgerungen.

Introduction

The province of British Columbia in western Canada encompasses an area of 949 000 km^2, 80% of which is mountainous terrain. This terrain, together with the climate which produces average annual snow-falls of 700–2 000 cm, is ideal for the production of snow avalanches. As might be expected, man's developments have invaded the mountains with the resultant need for avalanche-hazard zoning. The purpose of this paper is to describe snow-avalanche hazard zoning in British Columbia.

Snow avalanches have affected development in British Columbia from its earliest days. The first major development in the British Columbia mountains came during the 1800's as a result of mining exploration. Table I shows the number of people known to have died in avalanches. In addition, an unknown number of buildings have been destroyed.

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TABLE I. DEATHS FROM SNOW AVALANCHES IN BRITISH COLUMBIA

Year	*No. of deaths*
1800–99*	75
1900–09	24
1910–19	107
1920–29	13
1930–39	26
1940–49	5
1950–59	6
1960–69	39
1970–79	47

* Records are incomplete.

After a peak of mining activity during 1890–1900, other developments took over in British Columbia during the early 1900's. Farming, logging, and other industry was carried on primarily in the valleys and there were few problems from snow avalanches. The exceptions were roads and railways which proceeded through the mountains encountering snow avalanches and other hazards.

Building occurred mainly in the valleys until approximately 1960 when an expansion in recreational activities led to the development of residential properties in more mountainous terrain. Inevitably, buildings and other structures were constructed within snow-avalanche areas. In January 1974, a gas station–motel–restaurant complex near Terrace was destroyed and seven people were killed. This incident prompted the formation of an Avalanche Task Force to study snow avalanches in British Columbia and to propose measures to safeguard highways and other development. The Task Force completed its report in October 1974, and since that time a Snow Avalanche Section has been operating within the Highway Maintenance Services Branch of the British Columbia Ministry of Transportation, Communications, and Highways. This section is implementing an avalanche-management programme for the Ministry's operations, as well as conducting avalanche studies for the purpose of avalanche-hazard zoning throughout the province. This hazard zoning is done on behalf of other agencies involved in land-use zoning and the development approval process.

THE DEVELOPMENT APPROVAL PROCESS

The land-use zoning procedure in British Columbia depends on who administers the land and on the type of planning which has taken place. In any case, an Approval Officer, of either the provincial or local government, reviews the development and submits the application to a referral system for canvassing the views of other agencies. This referral system gives local officials the opportunity to point out possible avalanche hazards and request a detailed study by the Snow Avalanche Section.

The aim of the approval process is to answer the question: Is the proposed development compatible with the proposed site in terms of public health, *public safety* (including natural hazards), public services, resource management, and effect on amenity of the area?

The approval process is divided into four phases (Fig. 1):

(a) Preliminary administrative investigation: Who administers the land?
(b) Designation (zoning): Is it suitable for the proposed development?
(c) Servicing: How can it be serviced?
(d) Development: Are the construction and operation compatible with local regulations?

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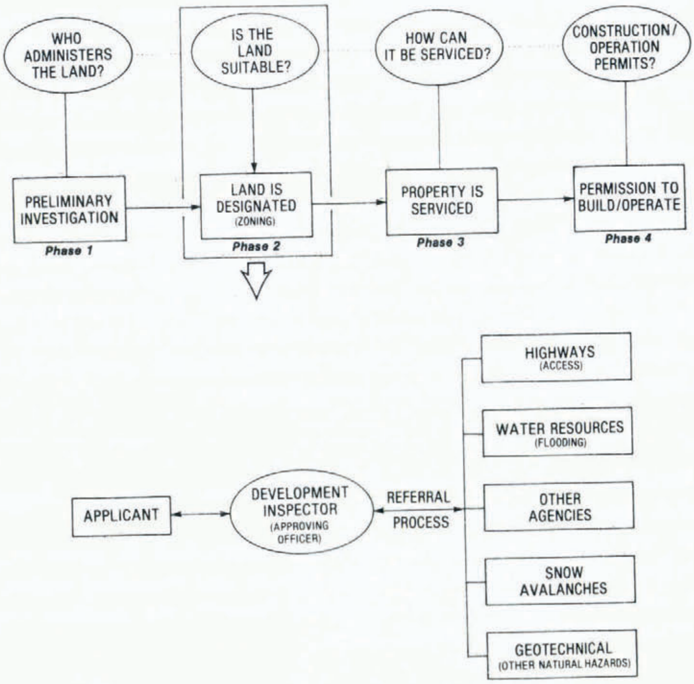

Fig. 1. The development approval process in British Columbia.

Legal considerations

Existing legislation

Although no legislation has been established to deal specifically with snow avalanches, there are some existing acts which are presently used to control development.

About 90% of the land in British Columbia is owned by the Crown or Provincial Government. Control of Crown land is reasonably simple and if avalanche hazards are noted, reserves can be designated through the *Land Act* which states that "The Lieutenant-Governor in Council may, for *any purpose* . . . in the *public interest* . . . reserve Crown land from disposition . . ." (British Columbia. *Laws, statutes.* 1970). The Act refers only to land owned by the government and does not apply to privately owned land.

Land within municipalities is zoned by them under the *Municipal Act* (British Columbia. *Laws, statutes.* 1960[b]) which results in different zoning by-laws for each municipality.

Some land use is controlled by Regional Districts, a type of government similar to counties in other jurisdictions. The Regional Districts, supported by the Provincial Government, may enact zoning and building by-laws.

Natural hazards, specifically floods and landslides but not snow avalanches, are mentioned in legislation that deals with the development approval process. An example of such legislation is the *Land Registry Act* which states that "the approving officer . . . may refuse to approve the plan if . . . the deposit of the plan is against the public interest; the land is subject to, or could reasonably be expected to be subject to, flooding, erosion, or land slips" (British Columbia. *Laws, statutes.* 1961). Other sections of the *Land Registry Act* state that application for development can be refused if it is against the public interest. This has been upheld in the Courts on a natural-hazards case involving rockslides (British Columbia. Supreme Court, unpublished).

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In 1979, the *Land Registry Act* (British Columbia. *Laws, statutes.* 1961) will be replaced by the *Land Titles Act* which includes avalanches in the list of natural hazards.

The Provincial Government, under the *Municipal Act* and under the *Local Services Act* both of which state that "... no subdivision shall be approved unless it is suited to the configuration of the land ..." (British Columbia. *Laws, statutes.* 1960[a]), assists in the zoning of land controlled by municipalities and Regional Districts. This statement encompasses all natural hazards, including avalanches.

The legislation described above applies only to proposed developments. Existing developments present special problems with regard to the law. If a housing development has been approved, but access roads and buildings are not yet constructed and an avalanche hazard is discovered *post facto*, several avenues of control are available. In some cases, driveway permits have been withheld as their issuing was not considered to be in the public interest. If the access has been granted, certain building by-laws could be used to prevent the issue of building permits for buildings proposed in avalanche-hazard areas.

Proposed legislation

The current legislative provisions described above have not been altogether successful, particularly in lands governed by municipalities.

Alternatives to the current legislation are being considered in order that the law may more effectively reflect the policies of hazard avoidance and remedial action. More specific statutes will give the municipalities and Regional Districts the explicit responsibility and authority to control development in hazard areas.

Technical considerations

Technical studies of snow avalanche hazards in British Columbia are similar in scope to those in other countries. For this reason, this section does not detail the methodology generally available in the literature (Perla and Martinelli, 1975) but describes its application in British Columbia. Presently, two types of studies are undertaken: the preliminary study and the detailed study.

Preliminary study

The *preliminary study* is similar in scope to the Swiss cadastral survey (Frutiger, 1970), although not as detailed due to the large areas generally involved. The study is usually carried out in preparation for municipal- or regional-planning map compilation, large developments such as strip mining, or broad transportation and utility corridor studies. The purposes of the study are:

(1) to identify avalanche sites for land-use planning;
(2) to provide the technical background required for deciding whether a detailed study is necessary;
(3) to serve as an educational tool for personnel involved in land-use planning and zoning.

The preliminary study is usually carried out in the following sequence:

(1) *Interpretation of aerial photography* with respect to avalanche paths, their extent and run-out zones.
(2) *Identification of avalanche paths* on topographical maps (1 : 50 000 scale).
(3) *Limited field studies* to eliminate gross errors.
(4) *Observation of avalanche deposits* during seasons when there is a possibility of large avalanches. These observations usually consist of one or two trips in the spring to observe obvious evidence of maximum avalanches.

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The preliminary study provides an early-warning system for the user. Because the field studies are restricted in scope the preliminary study has its limitations, and this is made known to the user. A typical note on mapping would be as follows:

> "This map shows active snow-avalanche sites as interpreted from aerial photographs. Some discrepancies may be noticed in the field, particularly with sites of very infrequent activity. Potential avalanche sites (i.e. slopes covered by dense forest) have not been delineated, and developments proposed near any inclines of significant magnitude should be carefully studied."

Preliminary studies of sixteen developed and potential development areas in British Columbia have been completed. It is intended to continue these studies as time and staff permit, developed areas first and, subsequently, potential development areas.

Detailed study

A detailed study is an investigation of one or more avalanche paths, and its purpose is to establish areas safe from snow avalanches so that specific developments can proceed in those areas. It is usually initiated by the referral of a development application to the Snow Avalanche Section by an approval officer from the Provincial Government, Regional District, municipality, or another agency involved in the approval process (Fig. 1).

Before 1974, few avalanche-hazard zoning studies were conducted in British Columbia. During 1974–79, fifteen detailed studies have been completed by the Ministry of Transportation, Communications, and Highways.

The detailed study includes the following factors. These factors do not have equal importance, but generally would be given the following approximate weightings:

Evaluation of terrain	30%
Evaluation of vegetation	20%
Study of climate	15%
Collection of historical data	10%
Calculation of run-out distance	10%
Comparison of avalanche paths	10%
Application of experience	5%
	100%

The initial stages of the detailed study involve extensive research into the availability of topographical mapping and aerial photography.

Topographical mapping for most of British Columbia is restricted to scales of 1 : 50 000 and smaller, which have insufficient accuracy for detailed avalanche studies. Occasionally, larger-scale mapping (e.g. 1 : 12 000) may be available for special projects.

The lack of large-scale mapping in British Columbia has led to the extensive use of aerial photography for the identification and evaluation of snow-avalanche sites. Aerial photography of the province began during the 1930's and many areas have been photographed five or six times since. Available scales include 1 : 63 000, 1 : 32 000, and 1 : 16 000. Special project photographs at larger scales (e.g. 1 : 5 000) are also available for some areas.

Careful interpretation of terrain configuration, vegetation patterns, and avalanche- or wind-deposited snow shown on aerial photographs enables the investigator to identify and become familiar with the avalanche sites before a field examination. This familiarity enables the investigator to develop theories as to where maximum avalanches have travelled or could travel. As the field work progresses, these theories are put to the test.

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Evaluation of terrain

Observations of the terrain include slope inclines, configuration, aspect of starting zones, cross-section of the track, and character of the run-out zone (Martinelli, 1974). Many of these factors can be easily determined from aerial photographs. Remnants of avalanche- or wind-deposited snow are often visible on photographs taken in late spring or early summer. The wind-deposited snow observed on the leeward side of ridges indicates the direction of the prevailing wind and the aspect of the avalanche slopes.

Evaluation of vegetation

The evaluation of vegetation in and near the avalanche paths plays an important role in the detailed studies. The majority of avalanche sites affecting development in British Columbia are located below the tree line, and, because the province is blessed with extensive and dense forests, the identification of avalanche paths is relatively easy.

The evaluation of vegetation includes:

(a) *Vegetation type mapping* of all species within the study area; this includes shrubs, as well as deciduous and coniferous trees.

(b) *Dendrochronology*, determining the age of various types of vegetation as assistance in establishing the frequency of large avalanches.

(c) *Examination of damaged trees, branches, and debris* on the ground, all of which may be indications of past avalanche occurrences.

Aerial photographs are used extensively in the evaluation of vegetation. Openings in the forest or sparsely forested slopes are usually the first patterns that can be recognized on the aerial photograph. Detailed vegetation patterns, including species and different age groups within and between species, can often be determined within each avalanche path. Often vegetation damaged or destroyed by avalanches is recognizable, for example, trees leaning downhill or lying on the ground.

The evaluation of the vegetation is often confused by man's developments such as power lines, farms, and logging, as well as by fires, and great care must be taken in excluding such influences.

Study of climate

Long-term observations of the climate close to the avalanche areas usually include only the depth and water equivalent of the snow-pack, the daily precipitation, and the daily maximum and minimum temperatures. Often it is necessary to extrapolate these data for long return periods and for the avalanche paths under study.

The climate data are analysed with respect to:

(a) the 30-year maximum water equivalent of the snow-pack with the objective of determining through empirical relations the mass of a maximum avalanche (Schaerer, [1975]);

(b) the maximum amount of snow deposited during a storm with the objective of determining the maximum depth of a slab avalanche;

(c) the frequency of weather patterns that led to major avalanches, such as a combination of sustained snow-fall and high temperatures.

Collection of historical data

Information on the frequency and magnitude of avalanche occurrences in the past can be found in various sources including:

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(a) *Avalanche occurrence records* maintained by local highway or railway maintenance staff, or ski-area personnel. Such records usually cover short time periods only.
(b) *Aerial photographs* taken during different years which reveal changes of vegetation caused by avalanches. Older photographs sometimes show trim lines in the forest which have since melded with surrounding vegetation.
(c) *Newspaper accounts and old photographs.*
(d) *Interviews with long-term local residents* (Armstrong, 1976).

Calculation of run-out distance

Mathematically-determined maximum run-out distances of avalanches provide another set of information. In most cases, this information is secondary in weight to the observations of terrain and vegetation, but at locations where avalanches run into open farm land or where the boundaries of previous avalanches cannot be established because trees were cut in recent years, greater importance is attached to the calculations.

Methods for calculating avalanche run-out distances are discussed in other papers of this conference. Because, up to the present, no other methods were applicable, the run-out distances for flowing avalanches were computed as suggested by Voellmy (1955). In doing so, we found the following points important in obtaining realistic values:

(a) In the process of the calculations, the investigator must assess from time to time whether or not the intermediate results, such as avalanche speeds and depths in the track, are realistic by asking himself: "Do the values make sense?" In particular, he must compare the calculated flow depth with evidence of avalanche flow on trees and shrubs.
(b) The run-out zone must be divided into sections of uniform incline, ground cover, and width, and the loss of avalanche speed must be determined for each section. Since Voellmy assumes that avalanches behave similarly to a fluid, energy equations are applied in which the difference of velocity head and elevation head over a section equals the loss due to friction.
(c) The coefficient of turbulent friction is strongly dependent on the roughness of the surface, whether for example the ground is covered with grass, shrubs, or forest. In calculating run-out distances in British Columbia, various coefficients of turbulent friction are applied which were derived from Manning roughness coefficients tabulated in hydraulics handbooks. In some cases, coefficients for turbulent and gliding friction are determined for a given avalanche path by analysing the observed run-out distance of a large avalanche in the same or an adjacent path. By applying the same coefficients to a larger, maximum avalanche, the run-out distance for the avalanche path is found.

Comparison of avalanche paths

The avalanche path(s) being studied should be compared with each other and with those in adjacent areas. Quite often, interpretation of the terrain and vegetation of these comparative areas will assist in determining avalanche run-out distances for those avalanche paths in question.

Experience factor

In the final analysis, all information is brought together and weighed with experience. After the technical elements have been considered one must ask and answer from experience the question, "Could avalanches travel this far; could they travel further?"

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Analysis

The result of the detailed study is an avalanche hazard line that divides hazardous areas from areas free of snow avalanches. The authors wish to stress that the hazard line must not be determined from a single technical consideration such as run-out calculations, but must be established by taking into account all the factors.

This process is similar to day-to-day snow stability analysis where the analyst considers different factors such as snow-pack, weather, avalanche occurrences, and slope tests. Avalanches cannot be predicted successfully on the basis of only one or two factors.

The avalanche hazard line

In British Columbia, the avalanche hazard line is defined as the boundary of large, infrequent avalanches, and development is defined as being either inside or outside of this line. The line corresponds to the boundary dividing the blue and white zones of the avalanche zoning system used in Switzerland.

The avalanche hazard line indicates how far one might *reasonably* expect extreme avalanches to travel, and its establishment does not take into account return intervals of avalanche occurrences and expected impact pressures. The Swiss standards are used as general guidelines but are considered somewhat inapplicable in British Columbia in view of the short-term records of climate and avalanche occurrences (usually less than forty years duration).

Occasionally, several boundaries are established within the avalanche hazard line. This practice was found particularly useful in studies of existing developments when the hazard to individual buildings must be assessed. These boundaries usually include areas of:

(1) frequent flowing avalanches with return intervals shorter than thirty years;
(2) infrequent flowing avalanches with return intervals greater than thirty years;
(3) infrequent powder snow and wind effects.

Snow avalanches are known for their unexpected behaviour and often travel further than might reasonably be expected. In order to cover unforseeable behaviour, inaccuracies of observations, and uncertainties in the state of the art, a safety distance of 50–150 m is added to the run-out distance determined in the analysis. This safety factor is included in the avalanche hazard line and was developed after much discussion and several detailed studies of specific hazard-zoning projects. It is useful in areas where uncertainties exist, but it must be used with care. Small avalanche paths and the flanks of large ones usually require a safety distance of 50–75 m, large avalanche paths a distance of 100–150 m at the extreme toe of the run-out zone.

Investigators from the Snow Avalanche Section, Ministry of Transportation, Communications, and Highways draw the avalanche hazard line. Sometimes, consultants may be retained for a detailed study, but they must have the experience necessary for the evaluation of the terrain and vegetation, the calculation of the run-out distance, and the placement of the hazard line. Persons who determine hazard zones in detail must have an appreciation of the behaviour of avalanches through observation of avalanches in motion and investigation of deposits, run-out distances, and damage. We have found it beneficial to have two persons determine the hazard line independently and then discuss their assessments.

The hazard line is first drawn on enlarged aerial photographs or when available on large-scale topographical maps, then transferred to maps showing the various property boundaries. The maps are part of the technical report submitted to the approval officer. The hazard line and other conclusions of the study are recommendations only and their implementation is at the discretion of the approval officer. If the developer does not agree with the hazard zoning,

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he may appeal to the approval officer and/or to the courts. In this case, the approval officer will normally request a review of the original study and may retain a consultant to provide a third opinion.

Socio-political considerations

Proposed developments

Snow-avalanche zoning of proposed developments has not resulted in serious problems. Meeting the interested parties and explaining the avalanche study and its implications are important so that the developer understands that a reasonable and just approach has been taken. The meetings also allow discussions of alternative use of the land within the hazard area and partial developments outside the hazard line.

Frequently in discussions with landowners and developers the action of large, infrequent avalanches must be explained. The avalanche which occurs almost every year is easily understood, but the ability of avalanches in that path to run a considerable distance on a very infrequent basis is not. This lack of understanding can result in developers asking for "third opinions" by consultants.

Existing developments

Existing developments found in avalanche areas have considerable social and political implications. Property owners and governments are faced with difficult decisions. Several alternatives can be considered:

(1) to require property owners to obtain natural-hazard insurance (not presently in existence); or
(2) to take no initiative and consider damage claims when an accident happens; or
(3) to construct works which would eliminate or reduce the hazard; or
(4) to modify the use of the area by outright purchase of property, compensation for relocation of structures, or compensation for changed uses of property at risk.

Education

The success of an avalanche zoning programme is heavily dependent on the education of all persons involved in the process. This includes the politicians, land-use planners, and approval officers who zone the land and approve its development, and the developers and the public in general who should understand the avalanche hazards.

Avalanche phenomena and land-use problems have been discussed in a short seminar with senior management of the Ministry of Transportation, Communications, and Highways. Their understanding of avalanches and associated problems is appropriate as their advice is directed to senior government officials involved in the approval process.

The importance of education at the initial level of the approval process cannot be overemphasized. This includes education of the land-use planners who can prevent many problems by recognizing them prior to land-use zoning, and of the approval officers who evaluate specific projects.

Avalanche education for land-use planners, approval officers, and other interested parties is available in Canada through one-day seminars sponsored by the British Columbia Ministry of Transportation, Communications, and Highways, and through four-day courses developed jointly by the National Research Council, the British Columbia Institute of Technology, and the Ministry of Transportation, Communications, and Highways. These courses, which have proved to be very successful, are attended by such people as engineers responsible for the location of highways and electric transmission lines and personnel responsible for forest

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management. The course programme includes an introduction to the avalanche phenomena, recognition of avalanche terrain and hazards, and information about available technical assistance.

In addition to offering training programmes, guidelines have been established for the recognition of hazards and the referral of problems.

Developers and the public usually come into contact with avalanche problems when they plan to develop, wish to buy, or have bought land in avalanche areas. Although education of these individuals can be difficult because of their financial and personal interest, the problems are discussed and the reasons for hazard zoning are explained.

Conclusions

British Columbia, compared to many parts of the world, has few developments located in avalanche areas, and with careful study has the opportunity to avoid further cases.

Successful land-use zoning in avalanche areas is keyed to one concept, a firm policy of hazard zoning prior to land-use zoning.

The avalanche-hazard zoning programme must include:

(a) specific *legislation* preventing development in hazard areas;
(b) *education* of land-use planning and development approval personnel;
(c) development of *guidelines* for identifying avalanches in land use and development planning;
(d) development and maintenance of *avalanche-hazard mapping*;
(e) *avalanche-occurrence recording* in conjunction with mapping;
(f) *a technical advisory* service readily available to assist in evaluating avalanche hazards.

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