Natural Hazards **9**: 197–213, 1994.

Characteristics and Mitigation of the Snow Avalanche Hazard in Kaghan Valley, Pakistan Himalaya

FES A. DE SCALLY
Department of Geography, Okanagan University College, 3333 College Way, Kelowna, British Columbia, V1V 1V7, Canada

and

JAMES S. GARDNER
Room 202, Administration Building, University of Manitoba, Winnipeg, Manitoba, R3T 2N2, Canada

(Received: 20 December 1991; in final form: 20 July 1992)

Abstract. Snow avalanche hazards in mountainous areas of developing countries have received scant attention in the scientific literature. The purpose of this paper is to describe this hazard and mitigative measures in Kaghan Valley, Pakistan Himalaya, and to review alternatives for future reduction of this hazard. Snow avalanches have long posed a hazard and risk to indigenous populations of the Himalaya and Trans-Himalaya mountains. Land use intensification due to population growth, new transportation routes, military activity and tourism is raising levels of risk. The history of land use in the study area is such that investigations of avalanche hazard must rely on different theoretical bases and data than in most industrialised countries. Despite the intensive use of valley-bottom land which is affected by avalanches, a number of simple measures are currently employed by the indigenous population to mitigate the hazard. Out-migration during the winter months is the most important one. During the intensive use period of summer avalanche-transported snow provides numerous resources for the population. In Kaghan the avalanche hazard is increasing primarily as a result of poorly located new buildings and other construction projects. The large scale of avalanche activity there rules out any significant improvement or protection of the currently difficult winter access. Instead, future mitigation of the hazard should focus on protecting the small number of winter inhabitants and minimising property damage.

Key words: Snow avalanche hazards, Kaghan Valley, Pakistan Himalaya.

1. Introduction

Snow avalanche hazards have been the focus of considerable research effort in mountainous industrialised nations since the 19th century (for summaries, see Fraser, 1978; Armstrong and Williams, 1986). This effort has been in response to the risks posed to transportation, mining, habitation and, in the last few decades, recreation. Avalanche hazards facing high mountain inhabitants of the developing world and the adjustments by them to these hazards have received relatively little attention (Rao *et al.*, 1987). Apart from its impact on high-altitude mountaineering, little literature exists on avalanche hazard in the mountains of south-central Asia.

The objectives of this paper are to describe: some of the geophysical aspects of avalanche activity in Kaghan Valley in the Pakistan Himalaya; the mitigation of the hazard by the local population, including the exploitation of beneficial aspects of the avalanche activity; the difficulty of employing North American and European avalanche hazard identification and evaluation procedures in this environment; and some alternatives for future hazard mitigation in Kaghan Valley. This research was carried out as part of the Snow and Ice Hydrology Project (1985–89), a collaborative undertaking between the Water and Power Development Authority (Pakistan), the International Development Research Centre (Canada) and Wilfrid Laurier University (Waterloo, Canada). The purpose of the project was to carry out research on the hydrological and hazard aspects of snow and ice cover in the Upper Indus River Basin, Pakistan.

2. Research Area

Kaghan Valley transects the front ranges of the Himalaya to link the foothills of North-West Frontier Province with the mountainous Northern Areas in Pakistan (Figure 1). Its importance as an access route to the north has diminished with the introduction of regular air services to Gilgit and Skardu and the construction of the all-weather Karakoram Highway through the Indus gorge. Nevertheless, the valley remains densely populated and is now experiencing the rapid development of summer tourism.

Kaghan Valley ranges in elevation from 800 to 5300 metres, with maximum valley-slope relief on the order of 2500 metres. Vegetation in the middle and upper valley where avalanche activity occurs consists of coniferous and deciduous forests up to treeline at approximately 3600 metres elevation. Above this, most areas have a cover of stunted juniper, alpine scrub, meadow and bare rock. All vegetation zones have been significantly altered by logging, agriculture, livestock grazing and fuelwood gathering. Valley bottoms up to 3000 metres elevation are intensively cultivated and occupied by villages.

The climate of Kaghan Valley is relatively humid, in contrast to the extremely arid valleys to the north and northeast, a fact attributable to its location on the south slope of the Himalaya and exposure to both winter westerlies and the summer monsoon. Winter (November to April) precipitation ranges from 580 to 1080 millimetres and is produced by disturbances associated with a high level westerly airstream. Precipitation in this season increases significantly with distance up-valley as well as with increasing elevation. At elevations above 1500 metres most of the winter precipitation falls as snow, although heavy rain often accompanies the snowfalls in the valley bottoms. Between storms the skies are generally clear and very large diurnal variations in air temperature are common.

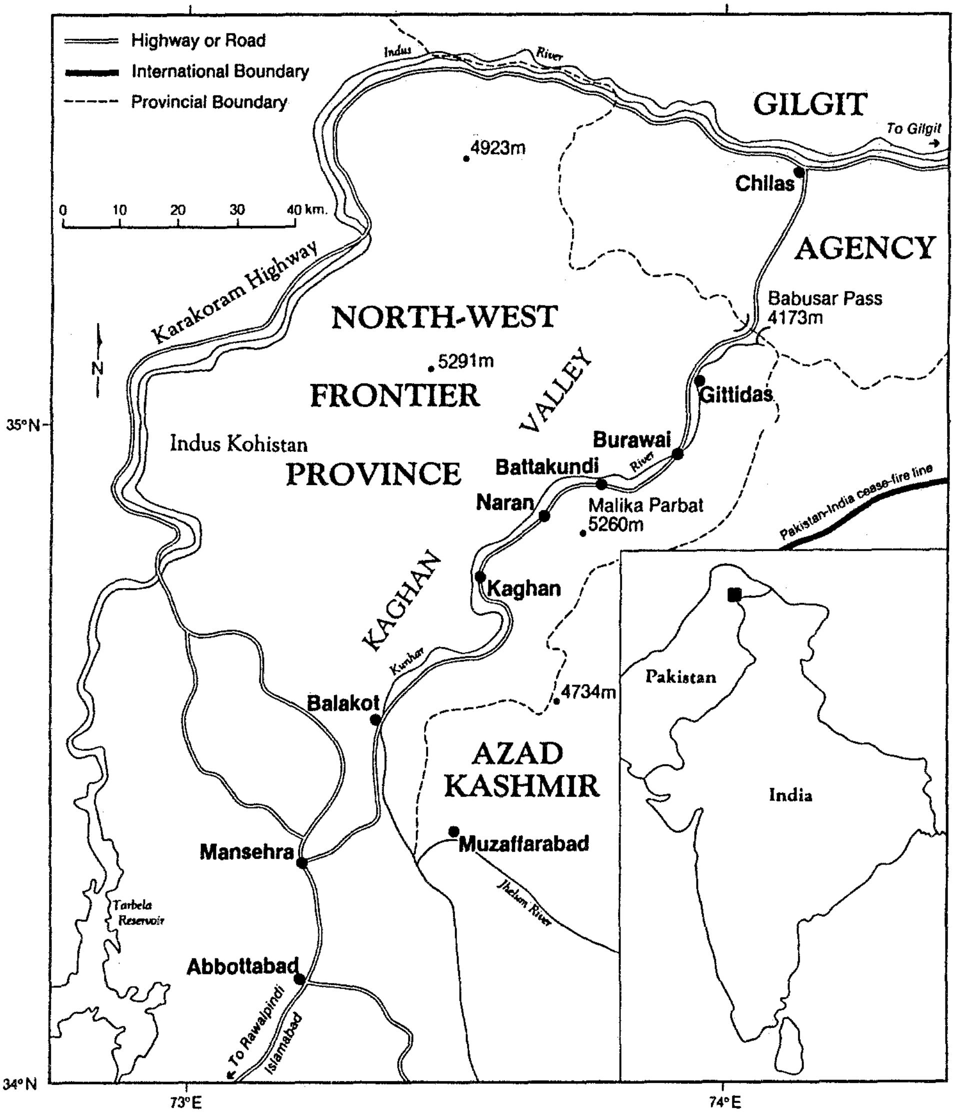

Fig. 1. Location of Kaghan Valley, Pakistan.

January is the coldest month with a mean daily temperature of −2.1°C at Battakundi (2600 m a.s. l.), with December and February also having below-freezing mean temperatures (de Scally, 1989).

A winter snowcover develops in Kaghan Valley above approximately 1500 metres elevation. Snowcover water equivalents reach a maximum in February or March (April at higher elevations) and range from 990 to 2650 millimetres in the Naran area. The large range reflects a sharp increase in snow depth with elevation and distance up-valley; analysis of data from WAPDA (1969) indicates that on average the annual maximum of snowcover water equivalent increases 160 percent over a vertical rise of only 760 metres. The snowmelt period in Kaghan Valley generally lasts from March to July, and varies depending on elevation.

3. Avalanche Characteristics and Generation

Large-scale avalanche activity in Kaghan Valley begins approximately 50 kilometres up-valley of Balakot and continues to Babusar Pass (Figure 1). The greatest concentration of dangerous avalanche paths is in the section between Kaghan and Battakundi villages. In addition, most higher tributary valleys experience very intense avalanche activity. The avalanche season begins in early December and generally ends by mid-May except at higher elevations, where melt-triggered avalanches continue into June.

The size of avalanche paths in Kaghan Valley is highly variable with vertical falls ranging from 100 to as much as 2000 metres (de Scally and Gardner, 1986b). The largest paths in the trunk valley, from Kaghan village to a point 5 kilometres up-valley, are located on east-facing slopes. Up-valley from this point they are situated almost exclusively on west- and northwest-facing slopes. Generally, slopes in the upper valley have greater snow accumulations in the avalanche starting zones and hence the potential for larger avalanches and greater avalanche travel distances.

Much of the land surface area in Kaghan is prone to avalanching. Along a fifty-kilometre stretch of the trunk valley 63 percent of the total slope area (all aspects) is affected by active or potential avalanching (Figure 2). This proportion for the Saiful Maluk valley, a 15 kilometre-long tributary valley southeast of Naran, is 73 percent (Figure 2). These figures are very high in comparison to estimates from other mountain ranges (e.g. Sosedov and Seversky, 1966).

Small avalanche paths in Kaghan Valley are generally situated on unconfined slopes or in shallow basins (Figure 3). The starting zones are generally below treeline and covered with a mixture of bare rock, brush and immature conifers. The track zones are rarely deeply gullied or markedly confined. Runouts usually extend only a short distance onto the valley floor or terminate in the Kunhar River, although on some paths (e.g. #14 in Figure 2) the runouts are disproportionately long relative to the size of the starting and track zones.

Large avalanche paths are frequently the sites of other hazardous processes such as debris flows and floods and therefore the hazard period is not limited to winter. Such multiple-process sites have been identified in other mountain areas (e.g. Aulitzky, 1974; Desloges and Gardner, 1984). The starting zones of the large paths are usually above treeline and may be composed of a number of steep gullies or basins (e.g. #7, 12 and 20 in Figure 2). The vegetation cover generally consists of heavily grazed alpine tundra. The track zones are in all cases confined by deep gullies and interrupted by cliffs (Figure 4). The runouts are usually located on

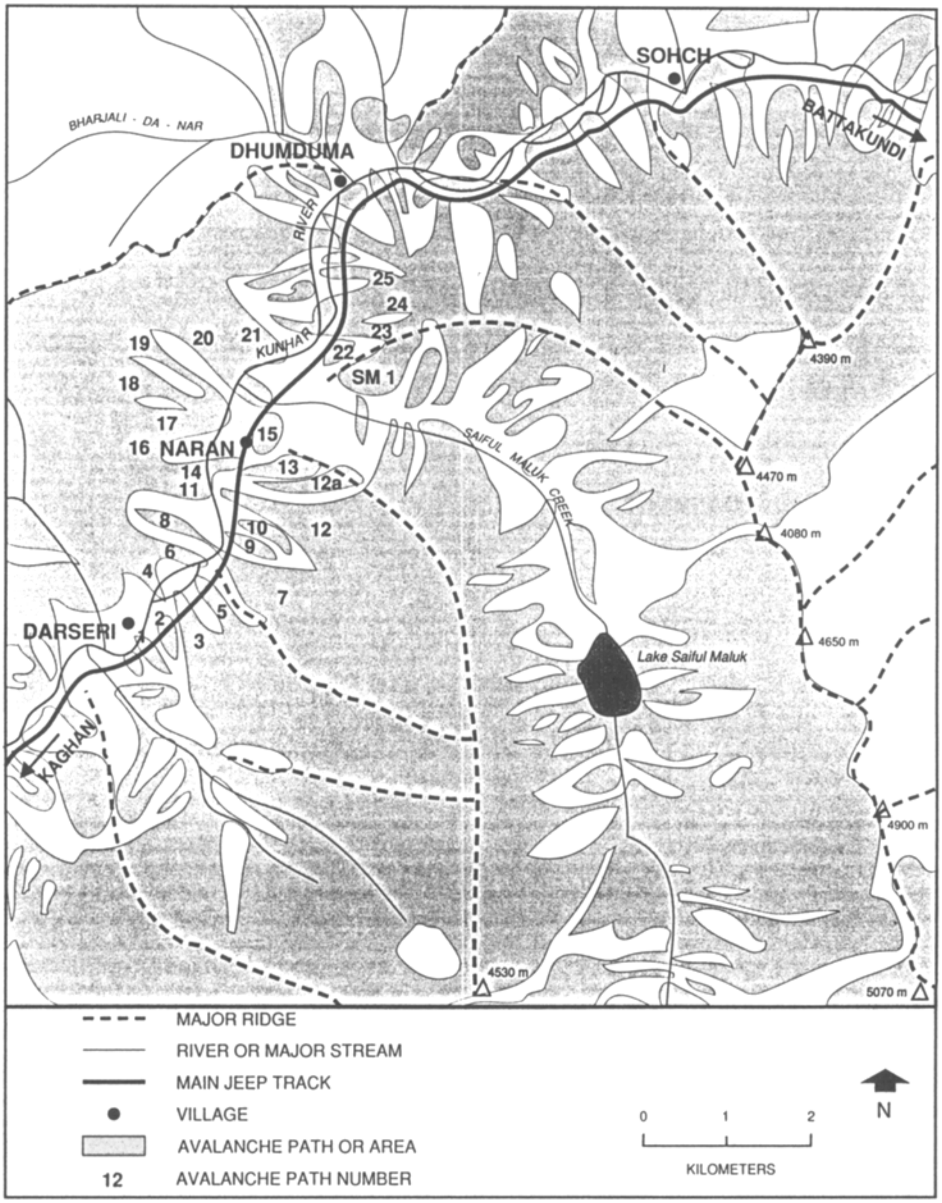

Fig. 2. Potential and active avalanche areas surveyed in middle Kaghan Valley and Saiful Maluk Valley. Numbered paths refer to those described in de Scally and Gardner (1986b).

Fig. 3. 'Chappran Nala' avalanche path, illustrative of small to moderate sized paths in Kaghan Valley (#3 in Figure 2). The jeep track to Naran bisects the runout zone. The houses in the runout are part of the village of Chappran.

alluvial fans or debris fans and extend across the valley bottom (Figure 4). On some runouts large impact pits or avalanche tarns such as described by Corner (1980) and Fitzharris and Owens (1984) have developed, indicating an abrupt transition in gradient between the track and runout zones, with accompanying loss of avalanche kinetic energy.

The lack of avalanche records hinders an analysis of avalanche generation in Kaghan Valley, but avalanche and weather data collected during the 1985–86 winter provide some valuable insights (Figure 5). The relatively high winter temperatures and heavy snowfall produce a deep snowpack which is generally well settled and mechanically strong except during and possibly after periods of thawing. Spontaneously triggered 'climax' avalanches resulting from gradual construc-

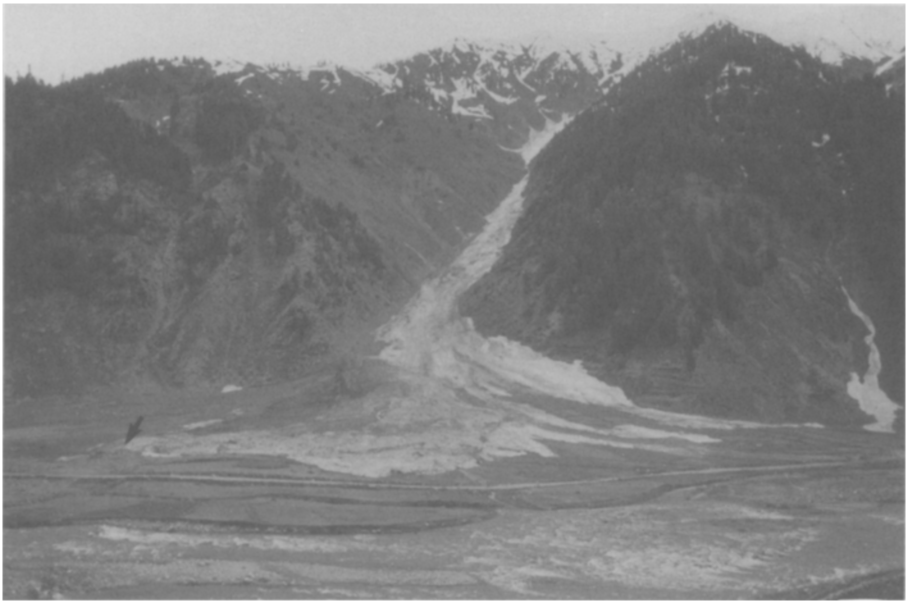

Fig. 4. 'Kapan' avalanche path, illustrative of very large paths in Kaghan Valley (#12 in Figure 2). The large snow deposit is typical for late May conditions. The jeep track to Naran bisects the runout zone which extends across the Kunhar River to the bottom of the photo. The arrow indicates the location of a large stone building destroyed by an avalanche (see text).

tive metamorphism (i.e. the formation of noncohesive faceted crystals) are probably uncommon, and most mid-winter avalanches are of the 'direct action' kind triggered by snowfall loading during storms. Figure 5 shows a strong association between snowfalls and avalanche events, with 64 percent of the 196 events recorded occurring during or within 24 hours of a snowfall (storm snowfall totals ranging from 10 to 160 centimetres).

Rain and high temperatures are also important triggers of avalanche activity, probably reducing cohesion in the snowpack until failure occurs. The precise significance of each is not clear since they frequently occur together and, in addition, the rain often accompanies snowfalls, at least at lower elevations. A sharp rise in air temperature is associated with 19 percent of the recorded avalanches. In 89 percent of these rises the mean daily air temperature is above 0°C. High winter-time levels of insolation between storms appear to be responsible for these temperature rises, the importance of which in producing snowpack instability in the Himalaya also has been noted by Schaerer (1986). Rain or high temperatures followed by refreezing can create ice-crusts, which when buried by subsequent snowfalls may provide a significant source of snowpack instability. Lastly, Figure 5 shows that 23 percent of the recorded avalanche events are not related in any direct way with snowfall or high air temperatures.

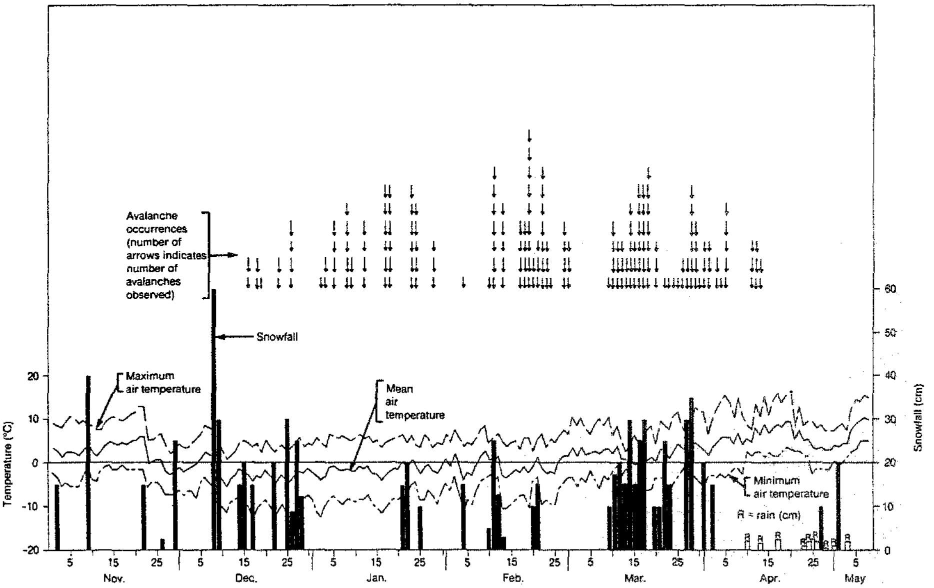

Fig. 5. Avalanche and climate record for the 1985–1986 winter in the Naran-Battakundi area.

The mass and volume of avalanche snow in Kaghan Valley was investigated by de Scally and Gardner (1989) who found avalanche deposits at the end of the winter on some large paths to exceed one million tonnes (which may explain why these deposits are locally referred to as 'glaciers'). Their results also show that prediction of avalanche mass is difficult and uncertain, particularly in a poorly known mountain region such as the Himalaya. They demonstrate that an equation based on the size of the starting and track zones, total winter precipitation and an empirically derived snow yield coefficient does provide some estimate of expected annual avalanche snow mass and volume.

No precise information is available on the destructive power of very large avalanches in Kaghan Valley. However, on one of the largest and most dangerous avalanche paths in the Naran area (#7 in Figure 2) a large boulder had, according to local inhabitants, been transported about 700 metres into the runout zone by an avalanche. By noting the lithology and dimensions of the boulder (14 by 12 by 10 metres) and the terrain over which it travelled, an estimate was made of the minimum impact pressure required to move it. The calculated pressure ranges from 135 to 148 kN m^{-2} (friction coefficient = 0.7 and slope angle = 15°), with a much larger range (54 to 231 kN m^{-2}) when the friction coefficient is taken to range from 0.5 to 0.9 and the boulder is assumed to have originated in the steepest part of the runout (slope angle = 18°). These impact pressures are well within the maximum of 290 kN m^{-2} recorded or calculated for avalanches with flow velocities up to 40 m s^{-1} (Lang and Brown, 1980), and are not equivalent to the very high pressures recorded in Kurobe Canyon, Japan (Shimizu *et al.*, 1973). This seems to indicate that while exceptionally large masses of snow can be entrained by avalanches in Kaghan Valley, impact pressures generated are not exceptional, perhaps as a result of lower velocities in these (usually) wet-snow avalanches.

Deep snow and intense avalanche activity make winter access into Kaghan Valley difficult, and Babusar Pass connecting the valley to Chilas on the Karakoram Highway is open to cargo jeeps for only three to four months of the year (Figure 1). Naran, the main tourist and market centre of the valley, is generally accessible to vehicles from early May until November.

4. Current Hazard Levels and Mitigative Measures

The low-gradient fans which serve as the runouts of avalanche paths are choice locations for agriculture and habitation in the densely populated valley bottoms of Kaghan. Such land use is particularly intense on the same side of the trunk valley as most large avalanche paths, owing to larger areas of level land, better developed soils and timber, a more reliable water supply, and the location of the jeep track. Consequently, the most significant avalanche hazard exists in these large valley-bottom runouts where inhabitants, travellers and buildings are placed at risk. Avalanche accidents caused by the victims themselves triggering an avalanche appear to be rare in Kaghan Valley since few people venture above the valley bottom in winter. In this respect the hazard differs significantly from that in most industrialised nations where the majority of avalanche related deaths result from self-triggering by winter recreationists.

In low-lying areas of Kaghan Valley localised flooding caused by avalanche blockage of the Kunhar River presents an additional hazard. These winter-time snow dams can be extremely large in some cases. However, downstream flooding is rarely catastrophic since river flows are low at this time of year and the snow dams are usually breached in one or two days, before a significant volume of water can accumulate behind them. A spring-time hazard results from avalanche snow covering agricultural land, leading to delays in sowing and even failed harvests if the snow is deep or melting is delayed.

Despite the intensive use of the valley-bottom land, a number of simple mitigative measures reduce the avalanche hazard in Kaghan Valley. Fatalities are minimised by avoidance; most of the land-owning as well as transhumant Gujar populations of the middle and upper valley take up winter residence in lower hill towns such as Balakot, Mansehra and Abbottabad, and on the plains closer to Rawalpindi (Figure 1). Property damage is minimised by sound locational decisions for construction; the local population possesses a detailed knowledge of hazardous areas which is reflected in the fact that every large or dangerous avalanche path is named (de Scally and Gardner, 1986b). However, there appears to be little recognition of long return-period avalanche events. And, many summer dwellings are forced to locate on avalanche slopes due to lack of space. These usually are

Fig. 6. Indigenous dwellings in an avalanche runout at 3300 metres elevation in upper Saiful Maluk Valley. The construction is of stone and timber. Building the uphill wall flush with the slope reduces damage from avalanches.

designed with roofs that are level with the slope on the uphill side, and sometimes apparently constructed with sufficient strength to withstand the dynamic and static loads imposed by avalanches (Figure 6). The roof profile is similar to the profile of engineered snow sheds (Schaerer, 1965). Small pedestrian and vehicle bridges are removed in winter from the upper valley if they are subjected to avalanche hazard, since their timber is difficult to replace if destroyed. Larger permanent bridges which cannot be removed are frequently damaged by avalanching.

The greatest avalanche risk is faced by the small portion of the population which is forced to winter in the valley above Kaghan village (Figure 1). Accidents and fatalities are most common during severe avalanche periods. For example, during the winter of 1985–1986 five people were killed in a single avalanche in Battakundi (Figure 1). Most recently in the winter of 1991–92, 29 people were killed in a large avalanche in the valley, prompting a major enquiry by government authorities. The most significant damage from avalanches is usually sustained by the largest and strongest stone buildings (Figure 7). These are usually bungalows, rest houses or administrative offices built by non-local entrepreneurs, land owners or administrators with little knowledge of the avalanche hazard and apparently little willingness to listen to local advice. As a case in point, a large stone building was constructed by a government agency in Naran in the runout of a major avalanche path, despite the warnings of local inhabitants. During the winter

Fig. 7. Heavily damaged restaurant building in the runout zone of 'Rahi' avalanche path (#14 in Figure 2), with the confined track zone visible in the background. Several buildings in this runout are periodically damaged and rebuilt. A mosque and another building were completely destroyed at this site during the 1983–1984 winter.

following completion of construction the building was destroyed by an avalanche (Figure 4).

While avalanches are a winter-time hazard in Kaghan Valley they also provide significant resources to the population during the intensive use period of summer. Timber uprooted at higher elevations by avalanches is collected in the valley bottom for fuelwood, a valuable commodity since most forests in the valley are protected to some degree by law. The associated organic debris transported into the runouts builds the organic component of the agricultural soils, with the result that the runouts are prime sites for the cultivation of corn and potatoes. On some paths, avalanches are used to purposely transport cut logs from high elevation forests. The larger avalanche snow deposits, which frequently extend from the runouts all the way to the starting zones, provide relatively easy access between the valley bottom and the high pastures and villages. Melting avalanche snow provides an important summer source of irrigation water which is channelled from the paths to cropped fields and pastures beside or on the runout fans. The high-density snow also is manually quarried and trucked out of the valley for refrigeration purposes in the plains areas. On balance, avalanche activity may provide greater resources than hazards for the local population.

5. Hazard Identification and Evaluation

Methods for avalanche hazard identification and evaluation developed in North America and Europe (for example, see Martinelli, 1974) are difficult to apply to the Himalayan environment, in large part because of its alteration through centuries of intensive land use. This is especially true of dendrochronological (Potter, 1969; Burrows and Burrows, 1976; Föhn, 1979) and other geobotanical techniques (Schaerer, 1972; Madole, 1974; Butler, 1979) of investigating the periodicity and extent of avalanche activity. Botanical identifiers such as forest trimlines along the margins of avalanche paths are frequently missing due to deforestation or because the avalanche paths are situated above treeline. The runout zones are particularly difficult to delineate because of the intensity of human activity there. In these areas geomorphological identifiers such as boulder tongues, debris tails and perched rocks (Luckman, 1978) are usually missing because they are cleared annually as the land is cultivated following the disappearance of avalanche snow. Broken timber entrained by avalanche snow is quickly gathered for fuelwood. Other vegetation damage resulting from avalanche activity (snapped limbs, scarring, etc.) is frequently difficult to distinguish from damage done in the process of fuelwood collection and browsing by livestock. Written historical records of avalanche activity which have provided an invaluable source of information in many countries (e.g. Armstrong, 1977; Fitzharris and Schaerer, 1980; Hestnes and Lied, 1980), are not available for Kaghan Valley.

The hazard identification and evaluation in this study relied on diverse sources of information including: topographic characteristics such as slope gradients suitable for avalanche release and movement; the presence of open basins and gullies which act as starting zones and tracks respectively; the presence of alluvial or debris fans which serve as runout zones; the presence of late-lying avalanche snow deposits; local knowledge; and damaged or destroyed buildings.

Each of the above sources of information presents some problems of interpretation. For example, topographic indicators alone are not sufficient to determine the presence or absence of avalanche activity. Consequently in the mapping (Figure 2) there may have been some tendency to overestimate the extent of active avalanche sites in deforested or above-treeline areas in order to err on the side of caution. Late-lying avalanche snow deposits are reliable indicators of avalanche activity but they usually greatly underestimate avalanche travel distances and extent. This is due to the fact that the shallow, low-density snow deposits of high-velocity powder snow avalanches quickly melt in the spring, leaving behind only the high-density deposits of wet snow avalanches which usually do not travel as far. This problem may help to explain some of the poor locational decisions for new construction in the valley. In several instances during this study, spring-time avalanche deposits greatly underestimated the travel distances of actual observed avalanches. This can be further complicated by the fact that many deposits are rapidly eroded and truncated by the Kunhar River during high spring runoff.

Local inhabitants who winter in Kaghan Valley were the best source of information on avalanche activity in this study (de Scally and Gardner, 1986b). However, the subjectivity of some of the observations creates problems for the accurate interpretation of event dates and magnitudes. In addition, interpretation from one language to another causes some problems. Damage to buildings provides good evidence of avalanche activity and permits estimation of magnitude parameters such as impact pressures (Figure 7). The absence of damage does not necessarily indicate a lack of avalanche activity since many of the indigenous dwellings are designed so that avalanches pass over them with minimal effects (Figure 6).

Remote sensing techniques such as aerial photography and satellite imaging have been used successfully for delimiting avalanche areas in industrialised countries (Ives *et al.*, 1976; Knepper, 1977; Kienholz, 1978). In the Pakistan Himalaya, aerial photography is not readily available to civilian users. Satellite imagery is available from agencies abroad but is costly and, without computer-aided image manipulation, it lacks the spatial resolution necessary for mapping avalanche paths. An even more fundamental problem is the lack of suitable large-scale topographic maps. Without these, the measurement of avalanche path gradients, vertical falls, starting zone areas, runout distances and other relevant terrain parameters requires time-consuming field surveys.

6. Future Mitigative Measures

The avalanche hazard facing the indigenous population of Kaghan Valley appears to have remained more or less constant over the last several years. Increasingly at risk are the poorly located construction projects built or planned to serve the growing summer tourist industry. Tourism also is chiefly responsible for the growing demand for earlier and easier jeep access in spring to the Naran area, which remains difficult and dangerous in most years due to the blockage of the road by numerous large avalanche deposits. Thus far the response to this demand has been to excavate jeep tracks through the deposits in spring using manual labour or heavy road-building machinery. Efforts to improve access will undoubtedly continue as tourism becomes an increasingly lucrative source of revenue for the indigenous population and outside entrepeneurs.

The choice of other realistic mitigative measures against avalanches in the future for Kaghan Valley is limited. This is partly due to the intensity and magnitude of the avalanche activity and partly to the fact that the valley no longer provides an important route to Gilgit. Structural measures for avalanche defense and other significant improvements in winter-time access do not appear to be economically justifiable or feasible. Any future developments in mitigation should therefore focus on protecting the winter inhabitants and minimising the risk of damage to future construction. For these purposes it is imperative to develop techniques of hazard identification and evaluation which are appropriate to the physical, cultural and economic conditions of Kaghan Valley specifically, and densely populated mountain environments of the developing world generally. Simple transfers of information and technology from industrialised nations will be of limited use in Kaghan Valley. It may also lead to a decreased reliance on indigenous, intuition-based, yet relatively sound methods of hazard assessment. For example, Indian experience has shown that when avalanche hazard forecasting becomes possible the local population will demand official warnings to be issued during hazard periods (Schaerer, 1986).

One of the most critical immediate requirements in Kaghan Valley is to begin avalanche record-keeping by trained local observers. Such records should include regular observations of weather and snowpack conditions as well as avalanche occurrence data including location and time, injuries or damage, size, snow water content, travel distance, deposit volume and any blockage of rivers (for guidelines see Canadian Avalanche Association, 1986). They would prove invaluable in studies of avalanche generation, calculations of avalanche masses, runout distances and impact pressures, land-use planning, and eventually even statistical avalanche forecasting. Various problems of data collection, such as the difficulty of patrolling and observing avalanche paths on foot in winter and the adverse conditions under which the observers would have to carry out their work, would have to be overcome. Proper training and equipment including skis and snowshoes would alleviate some of these problems. An efficient, accurate and readily accessible data archiving system would also have to be developed.

In order to facilitate the development of an avalanche monitoring programme Pakistan might benefit from the establishment of an avalanche research group such as the Snow and Avalanche Study Establishment in Manali, India. The group should be encouraged to develop local expertise based on both scientific research and existing indigenous knowledge of avalanches. A civilian organisation would be preferable in order that research results and knowledge can be disseminated without restriction. An appropriate agency might be the Hydrology and Investigations Directorate within the Water and Power Development Authority which has previous training in snow hydrology and avalanche hazards (Hewitt, 1988; Snow and Ice Hydrology Project, 1990), or the Forest Department of one of the northern provinces. Avalanche data collection could be combined with the basic snowcover and meteorological data collection which is necessary as well for hydrological forecasting.

7. Conclusion

The terrain and winter climate of Kaghan Valley combine to produce intense avalanche activity both in terms of the sizes of individual avalanches and the proportion of slopes potentially affected by avalanches. The avalanche hazard is mitigated by the indigenous population with a number of simple but effective strategies including out-migration in winter and careful siting and construction of buildings. During the intensive-use period of summer, avalanche snow and the debris contained within it actually provide important resources for the inhabitants. The hazard presently is increasing as a result of development related to the growing summer tourism business. Such development is frequently carried out by outside agencies and individuals who have little knowledge of avalanches and therefore make poor locational decisions for new construction.

Traditional European and North American methods for avalanche hazard identification and evaluation are difficult to apply to the Himalaya due to the continual removal or disturbance of geobotanical indicators of avalanche activity. Instead, hazard investigations have to rely on diverse information sources including topographic conditions, late-lying avalanche snow, damage to buildings and other structures and local knowledge. The intuitive knowledge possessed by the indigenous population provides valuable and readily collected data but it is frequently difficult to interpret accurately.

The choice of additional mitigative measures in the future in Kaghan Valley is limited owing to the intensity and magnitude of avalanche activity and a lack of available resources. Efforts should be concentrated toward protecting the small number of winter inhabitants and improving locational decisions for future construction. In order to accomplish these it is imperative that techniques of avalanche hazard identification and evaluation be developed which are appropriate to this region. A critical first step is to begin the collection of winter meteorological, snowpack and avalanche observations by trained local observers.

Acknowledgements

The financial and logistical support of the International Development Research Centre (Canada), Water and Power Development Authority (Pakistan), Snow and Ice Hydrology Project (Wilfrid Laurier University, Waterloo, Canada), Department of Geography, University of Waterloo (Waterloo, Canada) and Okanagan University College is gratefully acknowledged. The field assistance of H. Afzal, M. Mohammad and M. Anwar (WAPDA) is appreciated. A. Swati (WAPDA Gauge Reader) and other inhabitants of Naran provided much valuable information on avalanches. Winter climate data were supplied by the Seed Potato Research Farm, Battakundi.

References

Armstrong, B. R.: 1977, Avalanche hazard in Ouray County, Colorado, 1877–1976, Institute of Arctic and Alpine Research Occasional Paper 24, University of Colorado.

Armstrong, B. R. and Williams, K.: 1986, *The Avalanche Book*, Fulcrum Press, Golden.

Aulitzky, H.: 1974, *Endangered Alpine Regions and Disaster Prevention Measures*, Nature and Environment Series 6, Council of Europe, Strasbourg.

Burrows, C. J. and Burrows, V. L.: 1976, Procedures for the study of snow avalanche chronology using growth layers of woody plants, Institute of Arctic and Alpine Research Occasional Paper 23, University of Colorado.

Butler, D. R.: 1979, Snow avalanche path terrain and vegetation, Glacier National Park, Montana, *Arctic Alpine Res.* **11**, 17–32.

Canadian Avalanche Association: 1986, Guidelines for Weather, Snowpack and Avalanche Observations, National Research Council Canada, Associate Committee on Geotechnical Research Technical Memorandum 132, Ottawa.

Corner, G. D.: 1980, Avalanche impact landforms in Troms, North Norway, *Geografiska Annaler* **62A**, 1–10.

de Scally, F. A.: 1989, The Role of Avalanche Snow Transport in Seasonal Snowmelt, Himalaya Mountains, Pakistan, Unpub. Ph.D. thesis, University of Waterloo.

de Scally, F. A. and Gardner, J. S.: 1986a, Avalanche hazard in Kaghan Valley, Himalaya Range, Pakistan, in *Proceedings of the International Snow Science Workshop*, 22–25 October 1986, Lake Tahoe, U.S.A., pp. 21–28.

de Scally, F. A. and Gardner, J. S.: 1986b, Avalanche hazard in Kaghan Valley, Pakistan, Working Paper No. 2, Snow and Ice Hydrology Project, Wilfrid Laurier University.

de Scally, F. A. and Gardner, J. S.: 1989, Evaluation of avalanche-mass determination approaches: an example from the Himalaya, Pakistan, *J. Glaciology* **35**, 248–252.

Desloges, J. R. and Gardner, J. S.: 1984, Process and discharge estimation in ephemeral channels, Canadian Rocky Mountains, *Canad. J. Earth Sci.* **21**, 1050–1060.

Fitzharris, B. B. and Owens, I. F.: 1984, Avalanche tarns, *J. Glaciology* **30**, 308–312.

Fitzharris, B. B. and Schaerer, P. A.: 1980, Frequency of major avalanche winters, *J. Glaciology* **26**, 43–52.

Föhn, P. M. B.: 1979, Avalanche frequency and risk estimation in forest sites, in *Mountain Forests and Avalanches*, Swiss Federal Institute for Snow and Avalanche Research, Davos, pp. 241–254.

Fraser, C.: 1978, *Avalanches and Snow Safety*, John Murray, London.

Hestnes, E. and Lied, K.: 1980, Natural-hazard maps for land-use planning in Norway, *J. Glaciology* **26**, 331–344.

Hewitt, K.: 1988, The Snow and Ice Hydrology Project: research and training for water resource development in the Upper Indus Basin, *J. Canada-Pakistan Cooperation* **2**, 63–72.

Ives, J. D., Mears, A. I., Carrara, P. E., and Bovis, M. J.: 1976, Natural hazards in mountain Colorado, *Ann. Assoc. Am. Geogr.* **66**, 129–144.

Kienholz, H.: 1978, Maps of geomorphology and natural hazards of Grindelwald, Switzerland: scale 1:10,000, *Arctic Alpine Res.* **10**, 169–184.

Knepper, D. H., Jr.: 1977, Application of LANDSAT data to delimitation of avalanche hazards in Montane, Colorado. Final Report Feb. 28–Apr. 28, 1977, Institute of Arctic and Alpine Research, University of Colorado.

Lang, T. E. and Brown, R. L.: 1980, Numerical Simulation of Snow Avalanche Impact on Structures, U.S.D.A. Forest Service Research Paper RM-216, Fort Collins, Colorado.

Luckman, B. H.: 1978, Geomorphic work of snow avalanches in the Canadian Rocky Mountains, *Arctic Alpine Res.* **10**, 261–276.

Madole, R. F.: 1974, Quaternary research methodologies applied to delimiting natural hazards in mountainous Colorado, in W. C. Mahaney (ed.), *Quaternary Environments*, Geographical Monograph 5, York University, pp. 79–98.

Martinelli, M., Jr.: 1974, Snow avalanche sites: their identification and evaluation, *U.S.D.A. Forest Service Agricultural Information Bull.* 360, Fort Collins, Colorado.

Potter, N., Jr.: 1969, Tree ring dating of snow avalanche tracks and the geomorphic activity of avalanches, northern Absoroka Mountains, Wyoming, in S. A. Schumm and W. C. Bradley (eds), *U.S. Contributions to Quaternary Research*, Geological Society of America Special Paper 123, pp. 141–165.

Rao, N. M., Rangachary, N., Kumar, V., and Verdhen, A.: 1987, Some aspects of snow cover development and avalanche formation in the Indian Himalaya, in *Avalanche Formation, Movement and Effects*, 1986 Davos Symposium. International Association of Scientific Hydrology Publication 162, pp. 453–462.

Schaerer, P. A.: 1965, Snowshed location and design, in *American Society of Civil Engineers Transportation Engineering Conference*, Minneapolis, U.S.A., Conference Reprint 215.

Schaerer, P. A.: 1972, Terrain and vegetation of snow avalanche sites of Rogers Pass, British Columbia, in H. O. Slaymaker and H. J. McPherson (eds), *Mountain Geomorphology*, Tantalus Research, Vancouver, pp. 215–222.

Schaerer, P. A.: 1986, Avalanche problems in India, Unpub. paper, Avalanche Center, National Research Council Canada, Vancouver.

Shimizu, H., Huzioka, T., Akitaya, E., Narita, H., Nakagawa, M., and Kawada, K.: 1973, Study on high speed avalanche in Kurobe Canyon III, *Low Temperature Science A* (**32**), 126 (English summary).

Snow and Ice Hydrology Project: 1990, *Snow and Ice Hydrology Project, Upper Indus Basin*, Overall Report (Canadian Centre), Wilfrid Laurier University.

Sosedov, I. S. and Seversky, I. V.: 1966, On hydrological role of snow avalanches in the northern slope of the Zailiyusky Alatau, in *International Symposium on the Scientific Aspects of Snow and Ice Avalanches*, April 1965, Davos, International Association of Scientific Hydrology Publication 69, pp. 78–85.

Water and Power Development Authority: 1969, *Snow Surveys of West Pakistan*, 1961–1968, Surface Water Hydrology, WAPDA (Pakistan), Lahore.