- lack of public awareness (attitudinal and motivational vulnerability);
- limited access to political power and representation (political vulnerability);
- certain beliefs and customs (cultural vulnerability); and,
- weak buildings or weak individuals (physical vulnerability).

A systematic approach to the consideration of vulnerability issues is rare in relation to glacial risks, but has been considered during the Cordillera Blanca pilot study in this project. The study object was to evaluate the perception of both inhabitants and authorities of their vulnerability (in accordance with the above definitions) with respect to natural threats (with emphasis on glaciers). The ultimate aim is to achieve the commitment of entities, organisations and authorities in the management of natural hazards and risks and to communicate this information in order to create a culture of prevention.

Emphasis was placed on determining the perception of risk issues by the local population, specifically in respect to their vulnerability. Information was obtained through the use of focus groups/workshops with community members, and interviews with authorities, entities and key officers involved in risk management and civil defence. Throughout the exercise, common concepts investigated were those of hazard, vulnerability and attitude to the relevant communities and institutions with regard to each or their roles in the issue.

The findings highlighted that the people of the Cordillera Blanca region are vulnerable to glacial hazards from a social and economic point of view. They lack the logistics and capacity for an organised response to natural disasters, and have neither the information nor the institutional support to deal with the issue. Within organisations and authorities there is a positive interest in glacial hazards, yet their activity is not included within civil management schedules. Other priorities, limited budgets, lack of appropriately skilled staff and training, poor communication, and a lack of technical and management tools were highlighted as barriers to reduction of physical and human aspects of vulnerability. Recommendations arising from the study are being incorporated within the design of a regional management plan (see section 7.4.2).

7 RISK MANAGEMENT

7.1 Introduction

In order to reduce risk it is necessary to reduce either hazard or vulnerability, or both. Mitigation of glacial hazards has typically been achieved by reducing the level of hazard at source or by installing engineering protective measures downstream to lessen their impacts. Social-centred approaches, focussing on the factors that determine people’s level of vulnerability (the social, economic and political factors affecting the resilience of their livelihoods and their ability to prepare for hazards) are far less common.

7.2 Hazard reduction

Reducing glacial hazards in high mountain environments is technically and logistically challenging. Published examples of mitigation works tend to be restricted to reducing the hazard posed by glacial lakes rather than those directly from glaciers. Essentially this involves reducing the susceptibility of the lake to failure, either by reducing water levels to increase freeboard and reduce the differential head across the dam, by raising the level of the dam and building a protective covering, or by a combination of the two (Figure 15). Lowering the water level has the added benefit of reducing the magnitude of the potential hazard. Commonly used approaches include:

- *Water lowering by tunnel.* Where lakes are constrained, at least in part, by natural rock bars, a tunnel can be driven through bedrock. Examples include Lake 513 (Reynolds *et al.*, 1998) and Laguna Parón in the Cordillera Blanca, Peru. There are no known cases where the lake level has been lowered by tunnelling through moraine or other unconsolidated deposits. Tunnels have been constructed through moraine sediments, but above the water line in order to limit any rise in lake level (e.g. Safuna Alta, Cordillera Blanca, Peru). It remains to be seen if a tunnel could be successfully driven at a position below the water table in a location as remote as many of the potentially hazardous lakes.

- *Water lowering by culvert or spillway.* Enclosed culverts and open spillways are cut into the moraine crest, normally at the lowest point to keep excavation volumes to a minimum. Construction often, but not exclusively, occurs in the dry, by means of a cofferdam to isolate the site from the lake. Culverts historically tend to be constructed from cast sheet metal or reinforced concrete. Concrete channels, gabion mattresses and geotextile liners have been used to line channels and protect the floor, sides and exit portal area from erosion. Spillways are sometimes left open, but it is preferable to install a gate system to regulate the flow to control downstream erosion, particularly during the initial period of draw down (e.g. Tsho Rolpa, Nepal, Rana *et al*., 2000; e.g. lakes at Grubengletscher, Swiss Alps, Haeberli *et al*., 2001). The techniques are ideal for larger lakes. Cutting through a moraine needs care to prevent an uncontrollable and dangerous discharge. Adequate design of the temporary works is essential for both approaches to ensure the safety of the workforce.

Fig. 15: Examples of glacial lake hazard remediation styles. A - channel with control gates, Tsho Rolpa, Nepal; B - Siphons, Tsho Rolpa, Nepal; C - tunnel through bedrock cored moraine dam, Lake 513, Peru; D - channel and reconstructed dam, Cuchillacocha, Peru (photo César Portocarrero).

- *Water lowering by siphons and pumps.* Siphons have been used successfully to remove water from lakes at altitudes of up to 4,500 m (Reynolds, 1992, 1999). The technology has been developed specifically for use in glacial environments using 160 mm diameter pipes (Richardson and Reynolds, 2000a). The technique is normally used as an emergency measure to control rising water levels (e.g. Lake 513, Cordillera Blanca, Peru, Reynolds *et al*., 1998) and is best suited to lakes containing less than a few million cubic metres of water if siphon numbers are to remain practicable. Pumps have also been used in emergency situations (e.g. a supraglacial lake developing on the snout of Ghiacciao Del Belvedere was drained using pumps in 2002; temporary drainage of periglacial lakes at Grubengletscher, Swiss Alps, Haeberli *et al*., 2001).

- *Hazard reduction by dam construction*. The hazard may also be reduced by raising and/or strengthening the natural dam structure by construction of an artificial dam, often used in conjunction with a culvert. There are many examples of this approach throughout the Cordillera Blanca region of Peru (Figure 15). Benefits of the technique include increasing the freeboard and susceptibility to overtopping by displacement waves and protection against regressive erosion should the dam be overtopped. Concrete and masonry construction is typically employed.

7.3 Alternative measures of hazard reduction

Several alternative and, as yet, largely untried strategies suggest themselves in relation to hazard reduction. In the case of moraine dams, remedial works could be aimed at strengthening the natural dam or at removing or restraining the potential trigger mechanism by:

- dam strengthening;
- dam armour;
- tunnelling in unconsolidated deposits; or,
- stabilisation of adjacent (rock) slopes.

Soil nailing and jet grouting techniques, with proven application in non-glacial settings, are potentially viable in situations were dam strength is critical to the likelihood of an outburst. The granular nature of most dams would suit injection of a cementitious material by a technique such as jet grouting. In the case of soil nailing, however, granular sediments could hinder drilling and lead to instability during or after drilling, especially if treatment is to extend below the water table. Facing the dam with some resistant facing, rip-rap or armourstone seems to offer few advantages. Armourstone alone is unlikely to be effective since even the largest of boulders would be carried away by floods of the size observed previously in Nepal, Bhutan and Peru. A concrete or rip-rap facing would be difficult to apply and fix to the very steep and unstable dam faces. To date, tunnels through moraine dams are only known to have been carried out above the water table. It may be possible to construct tunnels through unconsolidated materials below the water table either by grouting in front of the heading or by freezing.

A common problem with these potential methods is the relatively large amount of plant required. Transportation of the equipment and supplies, including drilling and injection equipment, pumping and mixing plant, excavators, tunnel machines, *etc*., could prove difficult and/or prohibitively expensive to mobilise to remote locations. Nevertheless, helicopter transport of heavy plant and their re-assembly at site has been undertaken successfully at Tsho Rolpa, Nepal (Rana *et al*., 2000).

7.4 Vulnerability reduction

Relatively few risk reduction measures employed have attempted to reduce vulnerability. Techniques include constructing physical protective measures such as check dams, flood diversion works or energy dissipating baffles. Alternatively, social measures could be used, such as moving settlements or other targets; or preventing new settlements or targets from being constructed in the most dangerous areas. Also in this category are the provision of early warning systems and education of the local population.

7.4.1 Vulnerability reduction by engineering methods

Check dams and channels of various designs have been used to divert or constrain floods and debris flows, although the techniques are not commonly used to protect from glacial hazards (Figure 16). Examples tend to come from developed nations, possibly because the vulnerability to hazards is considered greatest in monetary terms and where events on the whole appear to be smaller than their counterparts in developing countries of the Andean and Himalaya mountain chains.

It is known that large check dams have been constructed, and proven, against debris flows in the former Soviet Union. A 40 m high dam was constructed at Medeo, by blasting the right bank of the Almatinka River. It appears that this somewhat drastic action was effective since, soon after it was finished, a huge flow almost completely filled the reservoir and a second huge blasting operation was carried out on the left bank to raise the dam height to 80 m (Figure 16). There are other, smaller, examples from the republics of central Asia including the Small Almatinka River, which was secured by a concrete retaining structure; a concrete dam south of Talgar and a network of concrete structures on the Uzynagash River, west of Almaty.

Obvious difficulties in relation to the design of check dams is prediction of the size and path of the event and the high discharges of thousands of cubic metres per second associated with some of the larger scale floods. Also, depending on the geography of vulnerability, a conscious decision may be needed to sacrifice targets upstream of the main area to be protected.

7.4.2 Vulnerability reduction by social measures

The use of social controls to reduce vulnerability to glacial floods is not well documented and appears not to have been practiced on a significant scale. An early warning system was implemented in the Rolwaling valley of Nepal in relation to a potential flood from Tsho Rolpa. Initially, the system involved soldiers stationed at the lake and connected by radio to settlements and the Khimti hydropower scheme downstream, and an exclusion zone for habitation was imposed within a limit of 20 m above river level. Clearly, such a system is open to human error and difficulties in enforcement. Later, the system was automated using river level sensors linked to sirens in the villages. Such a system is not without technological difficulties such as the design of the triggering criteria and occasional problems with false alarms. However, examples of other floods in the region (Sabai Tsho GLOF, 1998; Chubung GLOF, 1991) indicate that the highland villages can be virtually evacuated in a very short period of time, sufficient to save lives. Even a few hours warning of an outburst flood can be sufficient to evacuate workers and to close water intake valves at hydropower schemes in order to minimise damage.

Another example is that of an integrated remedial and evacuation strategy put in place to prevent a disaster from a lake that developed on Ghiacciao del Belvedere, Italian Alps, in 2001/02. Scientists, municipality politicians and emergency response teams, including the military, worked together to design, communicate and enforce the strategy to safeguard the inhabitants and visitors of Macugnaga (Haeberli *et al.*, 2002). Ultimately, the lake was drained before it burst.

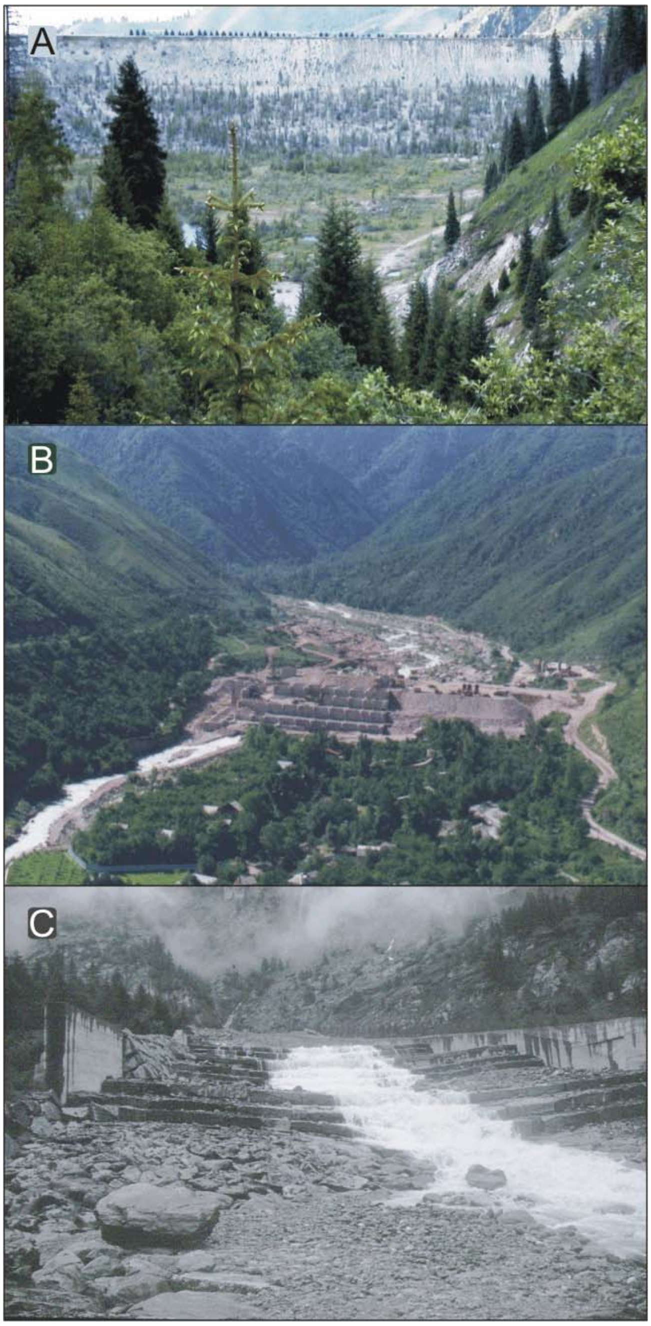

Fig 16: Examples of protective measures to reduce vulnerability. A - an 80 m high earth check dam on the Big Almatinka River, Medeo, Russia; B - concrete dam with periodic 5 m high culverts under construction south of Talgar, Russia; C - stepped and lined channel downstream of Ghiacciaio del Belvedere, Italian Alps. Photos A and B courtesy of J. Hanisch.

There is a viewpoint that stresses that it is unwise to rely on the development of scientific knowledge and technical approaches to reduce vulnerability due to the uncertainties involved in predicting the behaviour of potential hazards, the use of inappropriate technologies for local people, and unreliability of the state in communicating or enforcing social measures (Cannon, 1993). During the current project, therefore, a pilot study was undertaken in the Cordillera Blanca, Peru, to investigate the social methods that could compliment engineering approaches to remediation. Key recommendations arising from the study include:

- Communication. Information to be communicated should be standardised wherever possible. It should be accurate, clear and made available to the authorities and to the inhabitants. It is important that this information is in the public domain (one way could be through local schools, since this is a proven communication channel influencing the family group). Relevant information to be communicated includes:
  - A description of threats and hazards associated with natural phenomena in the area and in the region (characterisation and categorisation);
  - The description of the processes that trigger these natural threats (characterisation and its categorisation);
  - The specification of safety measures, depending on the area and the potential hazards identified.

- Prevention and preparedness is preferable to disaster response, but this concept needs to be incorporated in the national work agendas.

- Technical procedures for risk assessment, monitoring, and emergency response plans should be developed in parallel with social measures of risk reduction. Risk zonation, including the identification of safe areas for development, must be considered a priority. Ranking of the risks will enable scarce resources to be directed towards the areas of highest priority first.

- Training of technical practitioners is critical to enable them to assess hazards and risks accurately. Training should also be adequate for the intended recipients of the technical information, be it the authorities, community representatives, or others.

- The interest of the inhabitants needs to be captured, yet this often can be difficult due to the more frequent occurrence of non-glacial hazard types. Increased education to raise awareness of risks, combined with the natural interest to work with the unpredictable, could be strong elements towards accomplishing a commitment.

7.5 Regional and national risk management strategies

In the past, funding to assess and reduce glacier-related risks has tended to be concentrated on specific projects in order to address an immediate problem. Seldom has any of this funding been allocated for improvements in capability and capacity within national institutions. This is despite a clearly identified need for strategic approaches to management driven by the unknown scope of the problem in many regions, the changing distribution and rates of hazard development at previously studied sites, and calls for adaptive measures to climate change from international organisations such as the OECD and UNEP. If sustainable improvements in national and regional capabilities are to be achieved, specific long-term funding by the donor community is required.

Within an economic framework of longer-term funding, some of the key aspects critical to the potential success of a strategic approach are believed to include:
- political recognition of the issue and responsibility;
- nomination of an apolitical national managing organisation;
- provision of resources - funding, staff facilities, training, *etc*;
- a clear technical strategy, addressing issues of:
  - identification of the scale of the problem through updated glacier and lake inventories;
  - quantitative approaches to assessment to enable prioritisation;
  - monitoring at national scale, according to priorities;
  - focussed site investigations;
  - risk evaluation (i.e. the need for remediation, requiring relative information to aid prioritisation); and,
  - implementation and oversight of necessary remediation works.

The appointed national organisation could:

- act as the focal point for information for all interested parties, regionally, nationally and internationally;
- have clear lines of communication with local government agencies and central government ministries; and,
- be responsible for advising educational policy, to all affected parties.

The above basis for a management model is based on discussions with the national agency responsible for glacial hazard management in Peru (the Unidad de Glaciología y Recursos Hídricos within the Instituto Nacional de Recursos Naturales) and feedback from workshops held in Peru, Nepal and Bhutan.

A recent study by the Asian Disaster Preparedness Centre (ADPC, 2003) outlines adaptation measures to climate change and glacial hazards that could be emplaced at the national level. Findings from a workshop organised during the project, highlight the perceived relative effectiveness, cost and key barriers to implementation of such measures (Table 11). The findings further confirm the need for strategic management plans at a national level such that the scale of the problem can be identified and sites prioritised for monitoring and remediation, allowing scarce resources to be allocated effectively.

Table 11: Measures of adaptation to glacial lake outbursts in Nepal (based on ADPC, 2003).

OPTION		EFFECTIVENESS	COST	IMPLEMENTATION BARRIERS
1	Raising awareness	High	Low	Communication, what form of media?
2	Inventory of glaciers and glacial lakes; monitoring	High	Moderate	Lack of appropriate data, local capacity, funding
3	Vulnerability and risk assessment	Medium-high	Moderate	Lack of appropriate data, local capacity, funding
4	Research for multiple benefits of mitigation measures	High	Medium-high	Funding
5	Land use planning	Moderate	Moderate	Lack of co-ordination between agencies and with communities
6	Developing a national policy and action plan	Medium-high	High	Funds, political will
7	Mitigation (engineering works) and early warning systems	Medium-high	High	Funds, logistics, local capacity, **uncertain priorities (requires options 1 & 2)*
8	Relocation	Uncertain	High	Social acceptance

**not in original ADPC (2003) document.*

7.6 International co-ordination initiatives

The unfortunate incident in Peru in 2003, when a false alarm was raised in the media over a potential outburst from a glacial lake, highlighted shortcomings in the way information is handled at the international level. The incident illustrated how quickly dramatic information is spread by the media, who are in no position to assess the factual validity of the story. It also exposed the isolated position of the few experts, who were unable to respond in time to limit the effects of the press release.

In response, a Working Group of the International Commission on Snow and Ice has been established entitled '*Glacier and Permafrost Hazards in High Mountains*'. This is the first collaborative scientific initiative under the auspices of an international scientific lead body focussing on such hazards. The goals of the Working Group are to:

- improve the international scientific communication on glacier and permafrost hazards;
- compile a state of knowledge related to glacial and permafrost hazards;
- work towards a greater transfer of information and improved communication between the scientific and governmental communities;
- signpost sources of advice to international and national agencies, responsible authorities and private companies; and,
- act as a focal point for international media during relevant crises.

Other initiatives in recent years include a high-level warning launched in spring 2002 by the United Nations Environment Programme (UNEP) highlighting the growth of glacial lakes in the Himalaya. The initiative accompanied their publication of glacier inventories for Nepal and Bhutan through the International Centre for Integrated Mountain Development (ICIMOD; Mool *et al.*, 2001a, 2001b) and shows a willingness to consider these lakes at the national scale, as is needed. Regional organisations such as ICIMOD, however, have no political mandate within the individual member countries within the Hindu Kush Himalaya to become involved with targeted remedial works. This responsibility is normally given to the national implementing agencies as outlined in the above section, allowing them to engage those organisations that they and their funding partners feel will provide the service most appropriate to the specific problem or geographic area (e.g. Reynolds and Pokhrel, 2001).

More recently, the Organisation for Economic Co-operation and Development (OECD) published a report on the affects of climate change through natural hazards, in which outbursts from glacial lakes were considered exemplar (OECD, 2003). The results of this study, incorporating the Nepal country report prepared by the ADPC (2003), were presented at an international meeting in Paris in April 2003. Publicity from events such as this and associated with other awareness initiatives (e.g. the International Decade for Natural Disaster Reduction (Reynolds and Richardson, 1999); and the Year of the Mountains in 2002) helps maintain the profile of glacial hazards within the international scientific, donor and political communities.

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