CHAPTER SIX

EVACUATION

6.1. General remarks

There are many instances where an area known to be at risk from mudflows is already populated—in some cases heavily populated. Ideally, all such areas should be permanently evacuated. In practice, this is often impossible. Apart from major logistical problems, the density of the existing population in neighbouring safe areas may simply preclude the permanent resettlement of a large number of additional people. Moreover, their arrival could well create problems of employment and social integration. Therefore, evacuation is usually effected only when it becomes evident that a disastrous mudflow is about to occur. When the danger has passed, the evacuees normally return to their original homes.

In most cases, mudflows are sudden events for which little or no warning can be given. Despite the existence of preventive measures which may be planned and taken, in many cases the real situation is aggravated by the reluctance of the population at risk to evacuate unless they themselves see an immediate reason for doing so.

6.2. Human factors influencing evacuation

Natural disasters are characterized by great uncertainty. This is especially so in the case of a threat of mudflow—an event which is unforeseeable and sporadic in most cases. Unless the imminence of a mudflow is clearly evident, people may be understandably reluctant to abandon their dwellings and their livelihood for an unfamiliar environment and for an indeterminate period of time. In many cases, there is a chance, and hence a persistent hope, that the feared mudflow will not materialize. Thus, the decision-making process concerning the need for an evacuation inevitably requires good judgement by a number of people. This requirement, in turn, is subject to various human factors which influence the behaviour of those decision-makers in the face of imminent danger, and which are discussed below:

(a) *Hazard experience*

Those who have suffered from recent disasters have high hazard awareness. They usually react sensitively to unusual situations, may detect impending danger before it occurs, and evacuate quickly and effectively. The more recent the prior experience and the heavier the damage suffered, the higher is the awareness of the risk which may encourage prompt evacuation. On the other hand, since a mudflow disaster is an infrequent event and the memory of past disasters is usually short, mudflow hazard awareness is often low.

(b) *Time of onset*

If the order to evacuate comes late at night when most people are in bed, the reluctance to do so is that much greater. This is unfortunate when account is taken of the increased difficulties which must be overcome at such an hour by those responsible for the decision to issue the warning and for ensuring its effective dissemination. In Japan, it has been observed that casualties due to mudflow disasters occurring after 2200 hours are about three times as high as those due to mudflows which occur in the daytime.

(c) *Character of the community*

Readiness to evacuate is often influenced by the character of the endangered community. In mountain areas where the population is only too familiar with mudflows, people generally have the will to do everything possible to protect themselves through their own efforts. Lessons learned have often been handed down from generation to generation. As a result, warnings have sometimes been efficiently disseminated and mass evacuation successfully carried out. In urbanized areas, by contrast, various adverse conditions can impede evacuation efforts.

(d) *Leadership*

Effective mass evacuation practice can be carried out if a capable and influential leader of the group or community—such as a policeman, a schoolteacher, the village headman or the chief of a fire brigade—is available. In case of an emergency, people pay attention to, and are influenced by, the actions of others. As a result, every individual can (and should) set an example.

(e) *Family context*

A family facing danger is likely to act collectively. In many societies, family members are likely to follow the decision made by the eldest or the most respected member.

(f) *Age*

Old people are usually more reluctant to leave their homes. Therefore, they are more likely to disobey an evacuation order.

(g) *Security*

In some areas, people fear that their homes, once they are left unattended, may be looted. Local police forces must ensure the protection of evacuated villages from pillagers, arsonists, etc., until the last moment before the event occurs, and afterwards until the inhabitants return.

Community leaders and officers in charge of disaster management must keep these human factors in mind when dealing with issues of evacuation.

6.3. Evacuation planning

The evacuation process is based on: (i) identification of possible risk, (ii) analysis of precursors, the degree of potential danger/urgency at a given location, and (iii) recognition of the approaching hazardous event. Long-term planning and last-minute preparations for evacuation require the following activities:

1. Mapping of the hazard zones.
2. Creating/maintaining registers of population and valuable movable property in each zone.
3. Selecting safe refuge zones to which people will be evacuated.
4. Selecting evacuation routes and providing for their maintenance and clearance
5. Identifying assembly points for persons in need of transportation for evacuation.
6. Ensuring availability of means of transportation for evacuation, and traffic control
7. Providing shelter and accommodation in the refuge zones.
8. Ensuring availability of hospital and medical services for the treatment of injured persons
9. Providing security in the evacuated areas.
10. Establishing disaster alert procedures.
11. Establishing emergency communication procedures.
12. Providing for evaluation, revision and updating of the evacuation plan.

Step-by-step planning well in advance of the disaster event is essential The areas to which evacuation is envisaged must be carefully selected and, where necessary, steps taken to make and keep them readily accessible. The population must be properly briefed concerning these areas and how to get to them. The roles of all local officials and of the various organizations, both official and voluntary, which are responsible for various aspects of disaster management prior to, during and after the onset of the event must be decided in advance and made known to all concerned, including the public at large in particular. Officials should be trained in advance for all possible scenarios, so that they are capable of taking the right decisions and giving proper instructions in case of an emergency.

Emergency supplies and equipment such as sand bags, wooden piles, rope, wire, shovels, jacks, wooden boards, etc., should be properly stored and regularly examined to ensure that they will be in good condition when needed. Heavy-duty equipment should be available in the district in advance. It is essential to make arrangements for emergency support from outside the affected area in the case that damage exceeds local precautionary measures. The transportation capacity of roads, railways and airports, should be identified and notified in advance to the higher authorities concerned.

6.4. Evacuation areas

Since mudflows are deposited in relatively low-lying areas when their kinetic energy is spent, places such as valley floors, plains and alluvial fans are potential hazard areas. Places higher than a hazard area can serve as evacuation areas. In some cases, simply moving up the nearest valley slope or hillside can be enough to escape the consequences of a mudflow emergency and, if feasible, is the most straightforward and simplest means of doing so (see *Fig. 6.1*). Although the height needed to escape from a mudflow will vary from place to place depending on the width, slope, alignment and discharge of the flow, in most cases it does not exceed 10 m.

A valuable by-product of mudflow hazard zoning and mapping of an area as described in Section 5.5, is the resulting identification of safe areas appropriate for evacuation during mudflow events. Places of worship and cemeteries situated above (i.e., on high ground) but close to residential areas may serve as appropriate evacuation centres. Natural and artificial mounds or hills may also provide safe refuge during mudflows.

The impact of a mudflow in an area where its speed is decreasing may easily be resisted by a reinforced concrete building of sufficient strength, which can serve as a shelter during a mudflow. A building supported on columns with an open ground floor may be especially suitable for this purpose, since mudflows may then be able to pass through the spaces between the columns. The distribution of previous deposits also provides good clues for identifying safe locations during a mudflow.

At the head of an alluvial fan, a height of some 10 m above the valley floor might be needed to avoid being overwhelmed by a mudflow. On the other hand, at the lower end of a fan where the gradient is smaller, a height of just a few metres might be sufficient for this purpose.

6.5. Monitoring and warning

Successful evacuation requires early detection of an approaching mudflow and rapid dissemination of relevant information through a warning system. Mudflows triggered by earthquakes, volcanic eruptions and dam breaches allow very little lead-time for warning and evacuating the endangered population. In the case of

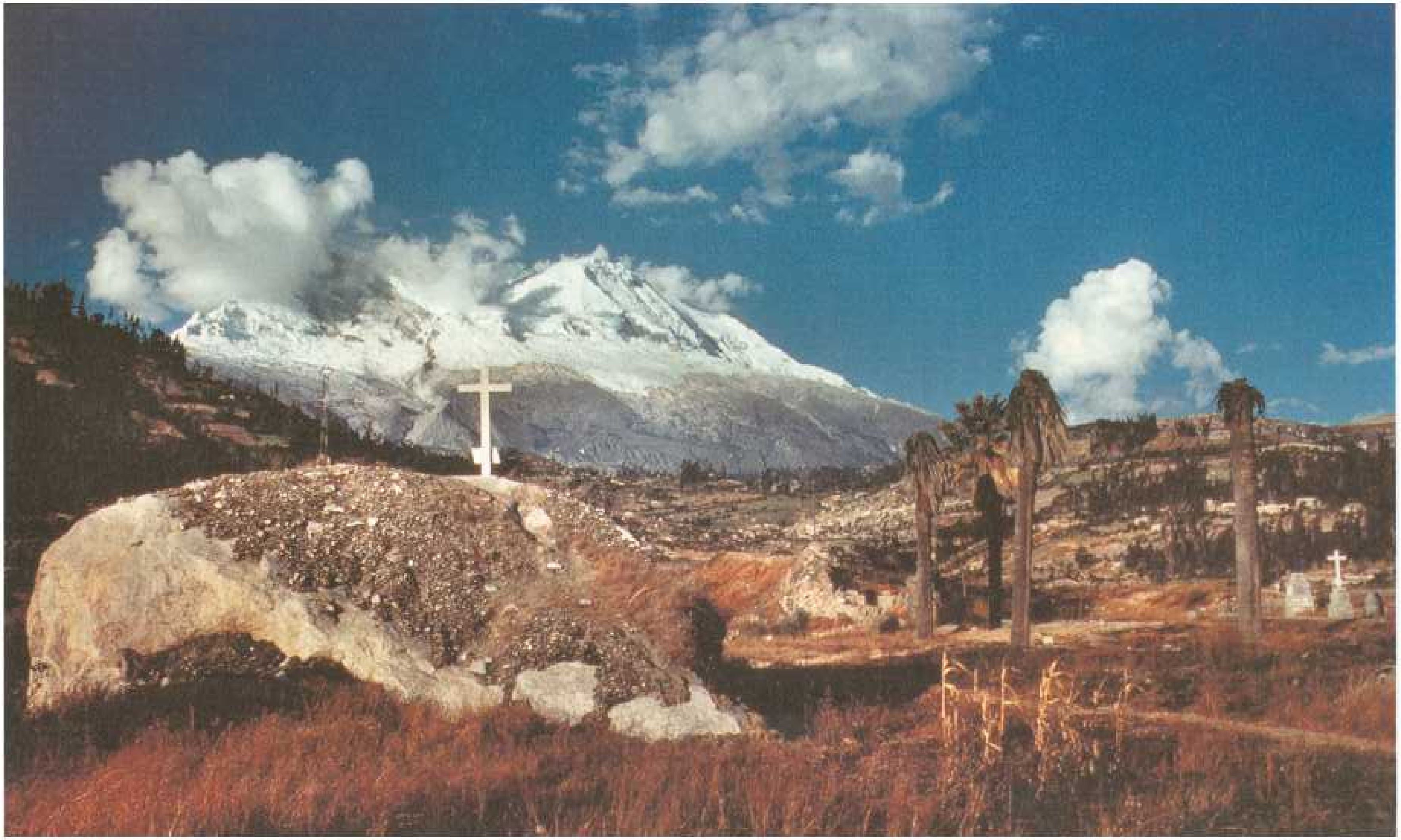

FIGURE 6.1 Cemetery Hill, Yungay, Peru. Those people who were able to reach the hill were among the few who survived the Mt. Huascaran mudflow of 1970. Location: Huascaran, Peru. *Photo: National Geographic.*

continued heavy rainfall, there is a better chance of predicting a mudflow and evacuating in time.

Local authorities in charge of disaster prevention should continuously monitor intense rainfall which might initiate a mudflow. For instance, a ten-minute cloudburst following a period of steady rainfall could well trigger a mudflow. Rainfall should be monitored within the source area where a mudflow is most likely to originate. The critical values of the total rainfall and the intensity at which mudflows are likely to occur can be estimated based on past experience. However, it is not easy to decide to evacuate simply because rainfall has become intense.

Figure 6.2 shows various mudflow monitoring devices. A simple device consisting of a wire stretched across the path of a possible mudflow can be used as a sensor (*Fig. 6.2 (b)*). A mudflow would cut such a wire and, a little later, other wires downstream, setting off electrical signals for warning purposes. Such a warning system should be installed far enough upstream to allow sufficient time for evacuation. (It must be noted that a wire sensor sometimes fails, due to unforeseen causes such as wind, fallen tree branches and interference from humans and/or wild animals.)

The occurrence of the following precursory phenomena might indicate that a mudflow is imminent:

- sudden muddiness in the stream;
- deep rumbling sound (roaring) from upstream;
- sudden rise or fall of water level;
- unusual smell in the water;
- increased volume of driftwood.

Since the warning period is usually very short, it is crucial that these precursory phenomena be perceived as early as possible and the information disseminated as quickly as possible to the responsible authorities. Therefore, a good communication network should be set up in advance. Contact persons and the hierarchical order for disseminating warnings and information should be decided upon and notified to all those concerned. In many cases, door-to-door visits may be necessary to convey the warning and instructions for evacuation to the population at risk. In mountain villages where closely knit communities exist, losses have been reduced by quick detection, warning and evacuation. In particular, mudflows due to heavy rainfall are local phenomena and, hence, a system of evacuation at the community level works well.

There are typically *three levels of alert* for mudflows: the *first* should be announced as soon as precursors are recognized, such as intense rainfall in steeply sloping ground of known high hazard. The *second* level of alert, corresponding to imminent danger, arises if a potential triggering event such as an earthquake or a violent cloudburst then occurs within this area and greatly increases the probability that mudflows will occur. The *third* level of alert begins with the recognition that one or more landslides have already occurred. In the case of an earthquake in particular, there may be hundreds of landslides, many of which will liquefy and transform themselves into debris flows capable of descending even gently sloping valleys.

Unlike disaster events such as cyclones or river floods, mudflows triggered by volcanic eruptions typically exhibit a very long period of low-level precursors, often lasting months and sometimes years. This, in turn, gives a special characteristic to alerts for such mudflows. That is, the passage from a first, low-level alert status based on precursor activity, to a destructive climax often takes place instantly or with no more than a few hours' notice. This highly variable time span of precursors to volcanic eruption means that evacuation plans must be correspondingly flexible In particular, local authorities and populations in zones of high hazard risk should be suitably informed, so that they are ready to accept the occurrence of one or more false alerts without loss of confidence in future calls to evacuate.

It should be emphasized that in UN-DHA's view, the decision to evacuate should be a *two-step process* involving two different groups of actors. The *first step* is for the specialists to restrict their judgements to their fields of established professional expertise; namely, to describing the various significant hazards in probabilistic, *quantified* terms. An example of this would be to declare a consensus on the part of all specialists that there is a probability of one third that mudflows affecting certain hazard zones already defined on the appropriate reference map, will occur within the next 12 hours. Only at the *second step* should a decision be taken on whether or not to evacuate—this can then be done by consensus of those authorities (normally the political leaders) who are best qualified to judge on the part of the population as a whole, where the limit of acceptable risk should be set.

It is established practice in certain Asian countries that the specialist-in-charge recommends when to evacuate, and that government leaders normally accept such recommendations. This has the advantage of eliminating any delay over the second half of the two-step process described above. It also implies that any specialist with responsibility for giving an opinion on the need for evacuation should take steps to acquire expertise in the socio-economic consequences of evacuation.

6.6. Training and simulation exercises

Evacuation will not work in a real disaster emergency if it has not been rehearsed by responsible officials, emergency organizations and the population at risk. An evacuation exercise in a simulated emergency situation can provide invaluable knowledge to the local people of the steps to be taken in a real disaster emergency. An exercise involving the personnel of the various emergency organizations is useful for pinpointing any faults in the emergency plan, checking the warning dissemination and evacuation systems, as well as training the personnel concerned.

The advance training of young people, especially those who have joined community organizations such as the Junior Red Cross or Red Crescent and/or Boy Scouts or Girl Scouts, can prove to be of vital importance when a crisis occurs. They can assist in various emergency operations and in instructing the public, and they form a pool of potential human resources for the future person-

FIGURE 6.2 Monitoring devices for mudflow warning: (*a*) Current gauge.

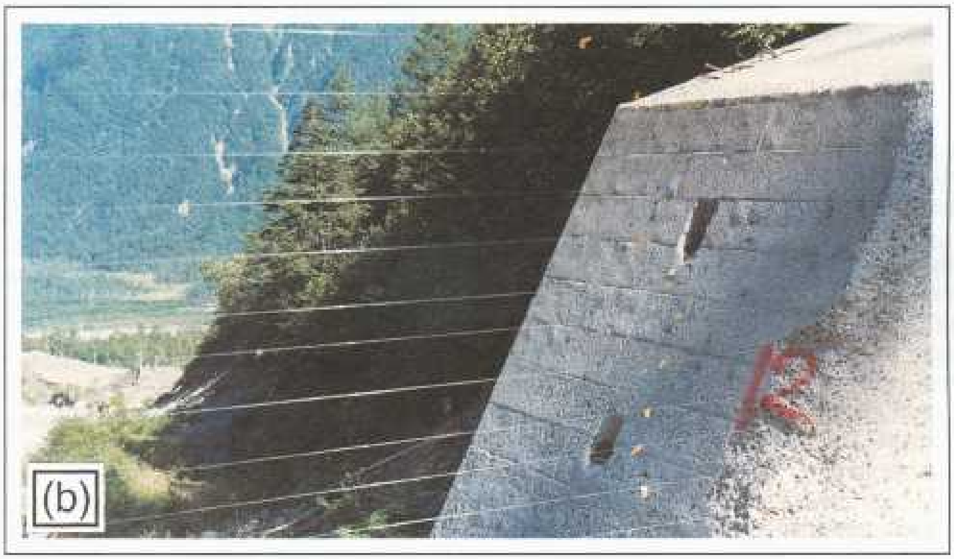

FIGURE 6.2 (*b*) Wire sensor.

FIGURE 6.2 (*c*) Touch sensor.
Location: Nagano, Japan. *Photo: M. Watanabe.*

FIGURE 6.3 Demonstration to the public of the destructive power of a mudflow by means of a simple test model. Location: Nagano, Japan. *Photo: Ministry of Construction, Japan.*

nel of emergency organizations. Instructions and demonstrations in easily-understood language can be given to young people by schoolteachers or local authorities in the schools or at local gatherings. Demonstrations are very useful as well for the general population at risk for purposes of awareness-raising (*Fig. 6.3*).

Exercises should cover the handling of incoming and outgoing messages containing relevant information and instructions during a disaster emergency, which are disseminated through both public and private communication networks. Every individual who will deal with such communications should be made familiar with the equipment to be used and the format and possible content of such messages.

Flood-fighting exercises should include the protection of houses, roads, railways and other important facilities from mudflows and floods. Emergency material such as sandbags, stones and rolls of wire for making gabions should be taken from storage and put to actual use. The number of persons and the time needed to complete the various phases of the exercise, as well as the quantity of materials required, should be carefully determined and monitored. Exercises should also be carried out to ensure the timely and fair distribution of emergency food and appropriate shelter facilities.

As mentioned previously, rehearsals of evacuation procedures (*Fig. 6.4*) are invaluable. In such rehearsals (and of course during an actual emergency), particular attention must be paid to the following:

(*a*) Persons selected to lead the evacuation must be identified;

(*b*) Each leader must check the number of injured, aged, handicapped persons and children assigned to him/her. He or she must keep a careful watch for persons falling behind the others during evacuation, and ensure that proper attention is paid to all in need as far as resources allow;

(*c*) Medical supplies, including stretchers, should be held in readiness on the assumption that there will be sick and injured people;

(*d*) People should be encouraged to move in groups so as to be able to help each other;

(*e*) People should follow the directions of the leaders and take shelter at the designated places calmly and promptly;

(*f*) Each person should carry basic necessities, such as food for one or two days and two litres of drinking water. If possible, other items such as medicines, an electric torch, a raincoat, spare clothes, slip-resistant footwear, a portable radio, batteries, matches, candles, cooking and eating utensils, a helmet, etc., should also be carried;

(*g*) In order to prevent looting or arson, tight security should be ensured.

These considerations may well be transcended by the realities of the situation when a mudflow actually occurs. No matter how seriously an evacuation exercise is carried out, in all likelihood there will be some gaps between the exercise and the ultimate reality. For example:

(*a*) Among the inhabitants there may be some who are determined to defend their houses and property at all costs, and who will not obey an evacuation order;

(*b*) When a disaster occurs, rumours all too readily gain currency. Officials in charge must provide correct details so as to give factual information and to calm the situation generally;

(*c*) In tourist areas, many of the visitors will not have sufficient knowledge of the neighbourhood. The managers of accommodation facilities, of camping sites and villas should be briefed in order to direct tourists to places of safety.

6.7. Comparative study: Emergency evacuation examples and lessons learned

6.7.1. Armero, Nevado del Ruiz mudflow, Colombia (1985)

The largest debris flow disaster to date in the present century was the 1985 catastrophe at the Nevado del Ruiz volcano in central Colombia. In that event, small hot volcanic pyroclast flows shaved off and melted between 5 per cent and 8 per cent of the large ice cap on the summit of the volcano, which generated debris flows which travelled up to 90 km down-valley. This led to the loss of over 24,740 lives, including the burial of more than three-quarters of the town of Armero which is located 45 km down-river from the summit area where the flows were generated, and from where they took 2.5 hours to converge upon the town.

In theory, this should have allowed ample time to issue the necessary alert and to evacuate the population of Armero. In practice, however, even though the responsible scientists had clearly identified two previous early historical disasters of similar magnitude which destroyed the same areas, the local authorities were not convinced that history was about to repeat itself for the third time. No alternative accommodation such as temporary shelters on neighbouring hillsides had been made, and alert procedures had not been sufficiently well-established or practiced, in order to make a rapid evacuation possible. This was, most regrettably, a missed opportunity to alert and evacuate the many ultimate victims. In turn, this led afterwards to a new and greatly increased commitment, up to the highest national level, to set up the much more comprehensive and systematic local risk-assessment and reduction studies which are currently underway in Colombia, and which have made excellent progress to date.

There are two elements of this situation which help to explain why the opportunity was missed. First of all, although the town of Armero was 45 km down-river from the source of the mud/debris flows, and therefore at a distance large enough to allow time for evacuation, this same remoteness from the volcano, and the low awareness of the nature and extent of earlier historical eruptions, apparently created a false impression of safety. Furthermore, because of bad weather and thunderstorms on the evening of the catastrophe, it was not evident to the population of Armero that the volcano had begun a new phase of explosive activity. A second factor was that the volcano had not followed a steady course of escalating activity over the weeks or days preceding its destructive climax Even on the day of the disaster, small vertical explosions causing slight ash fall as far away as Armero, which began six hours earlier, had died down, and there were apparently many people in Armero who were convinced that the new danger signalled by this precursor had already passed.

It is clear that the monitoring and warning system was insufficient A hazard map together with an explanatory text was distributed to the officials concerned a month prior to the disaster, and was also published in local newspapers. However, these measures failed to raise the awareness of the population of Armero to the potential hazard and, consequently, did not promote a call for a pre-disaster evacuation. (See Chapter 8 for additional details.)

6.7.2. Mt. Pinatubo, Philippines (1991)

The 1985 disaster at Nevado del Ruiz just described, which was caused by an eruption very modest in size, but which caught people insufficiently prepared to respond and caused enormous loss of life By contrast, the 1991 eruption of Mt. Pinatubo (see Chapter 8 for details) was enormous in size, and since Pinatubo was a volcano which, unlike Ruiz, had not had any previous historical activity, it had not been identified as especially hazardous. Nevertheless, the initial alert led to a rapid response both by scientists and by the Civil Defence and other preparedness authorities. As a result, during the considerably shorter two-month run-up to the destructive climax, it was quickly established what type and what scale of eruptive activity was to be expected (based primarily on the reconstruction of a 600-year old, prehistoric eruption), and the appropriate preparations for a massive evacuation of more than 300,000 people were made. Thanks to these preparations and in spite of the enormous size and violence of the eruption, only 870 lives were lost. Moreover, most of those killed were members of an indigenous tribe who lived in widely dispersed groups on the upper and relatively inaccessible flanks of the mountain. As a result, it was difficult to locate these semi-nomadic tribespeople and to explain to them the risk of an eruption of a kind that they had never witnessed.

There were several important factors which made alert and evacuation procedures easier to implement at Pinatubo than at Ruiz, as follows:

1. The existence of an experienced national scientific monitoring service which had already learned how to deal with similar but smaller crises at other Philippine volcanoes, as well as Civil Defence, Social Welfare, Red Cross and other national logistics and planning services who were fully aware of the particular needs arising from this type of alert and evacuation, and ready to cope with them.

2. The immediate provision of additional monitoring equipment and support from external sources, in this case principally by the United States which had important naval and air force bases within the area threatened by the volcano.

3. A nationwide appreciation (except among the local tribespeople) of the potential risks at Pinatubo and the need to take them seriously, arising from disasters caused by eruptions in other parts of the country in recent decades.

4. The eruption was a natural event to be expected following the progressively escalating sequence of precursors over the weeks and days leading to its climax This made the scientific and public safety authorities, as well as the population in general, progressively more convinced of what was likely to happen and the need to be ready for such an eventuality.

5. The existence of a very simple and quick-to-engage procedure for determining that an evacuation was required.

6. The constructively informative role played by the national and local media services.

Because of its success, the above requirements should be part of a check-list for evacuation planning in all zones of high mudflow risk.

A particular complication in connection with the Mt. Pinatubo eruption was its very long-lasting consequences, arising from the enormous thickness of pyroclastic flow and ash fall deposits. Indeed, five years after the eruption, these still continue to be washed downslope during typhoons and other periods of heavy rain, on a scale threatening to human life and settlements and destroying cultivated areas (see *Figs 6.5* (a) and *6.5* (b)). The continued destructiveness of these secondary mud and debris flows meant that additional precautions had to be taken. Alert procedures had to be established, and will probably have to be maintained for a total of 10 years or more, in order to detect the onset of new mudflows, issue warnings and, in extreme cases, call for new local evacuations in the low-lying areas likely to be affected by such events.

A particular feature of the Pinatubo eruptive climax is that it coincided with the passage of a typhoon which dumped enormous quantities of rain on the new and very thick mantles of ash fall on the slopes, and on the giant pyroclast flow deposits in the valleys. This resulted in almost instantaneous and enormous mud and debris flows. The advent of the typhoon gave rise to suitable alerts, however, and it was recognized that mudflows would become an immediate problem.

6.8. Conclusions

1. Alert and evacuation plans for mudflow disasters can be effective and are therefore essential in order to reduce loss of life and injury.

2. Each disaster type has its own time-scale of typical precursors, but for most disaster scenarios there are *three stages of alerts*. The *first* stage corresponds to the onset of initial precursors, such as local earthquakes, ground inflation or mild eruptive activity. For landslides, the precursors include heavy saturation of the ground after days or weeks of frequent rain A *second* stage of alert comes when there is a rapid escalation of precursors, such as the occurrence of exceptionally intense cloudbursts in landslide-prone zones. The *third* stage of alert corresponds to very short-term notices, following the initiation of mud or debris flows, or their suspected imminent initiation, because of a violent earthquake, for example. In such cases, the alert period is extremely short and evacuation is absolutely essential. At that stage, the only questions remaining are how quickly the destructive phenomenon will reach the vulnerable locations (which may be from a few minutes to a few hours), and whether or not the people in those zones of high hazard risk are ready to take the required emergency measures immediately.

3. Successful evacuation depends upon *two primary factors*. The *first* is how much time remains between the second or third level of alert which triggers the evacuation and the arrival of the destructive phenomenon. *Second*, successful evacuation is a function of how quickly it is initiated and how efficiently it is carried out. This clearly depends on how carefully the required preparedness measures have been designed and practised.

4. The two cases described in Section 6.7 illustrate that there are certain populated areas that are so close to the source of mudflow hazards that there is only a slim chance that the evacuation can be undertaken, even with the fastest and most efficient alert and evacuation procedures possible. In these cases, alert and evacuation plans are not sufficient protection; the only safe solution is not to allow these very high hazard zones to be settled, and to remove existing settlements progressively over time.

5. For locations which are within the zones of high hazard risk but not so critically close to their sources, recent case histories show that it is vitally important to have the best possible alert and evacuation measures in place These measures follow the same basic principles for any disaster type or setting, involving effective monitoring, rapid interpretation, communication and decision-making. The effectiveness with which these basic principles are transformed into practice is a function of how appropriately and carefully they are planned to match the particularities of each expected disaster scenario, including the type of hazard, the local physical geography and the distribution of the vulnerable population.

6. Finally, it should be underlined that good disaster preparedness costs relatively little in equipment or other capital investment. It requires above all a firm commitment to promoting an awareness of the serious nature of the problem by the political and public safety authorities, and the effective coordination of technical and logistics planning services.

FIGURE 6.4 An extract from a leaflet about mudflow hazards distributed in Japan shows an evacuation rehearsal in progress. It advises people to "take heed of early warnings and be brave enough to evacuate".
Location: Yamagata, Miyagi, Nagano, Japan. *Photo: Ministry of Construction, Japan.*

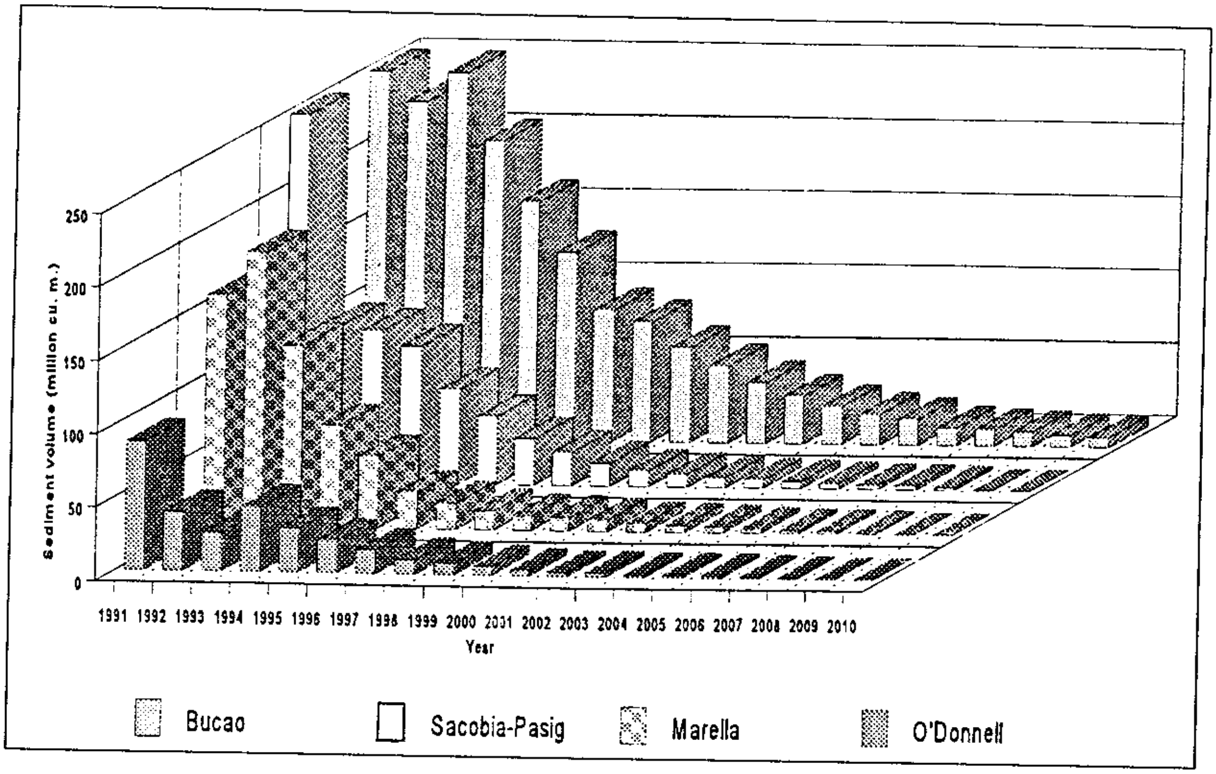

FIGURE 6.5 (*a*) Mt. Pinatubo—Projection of ***annual*** sediment delivery from each of the four major rivers draining the mountain.

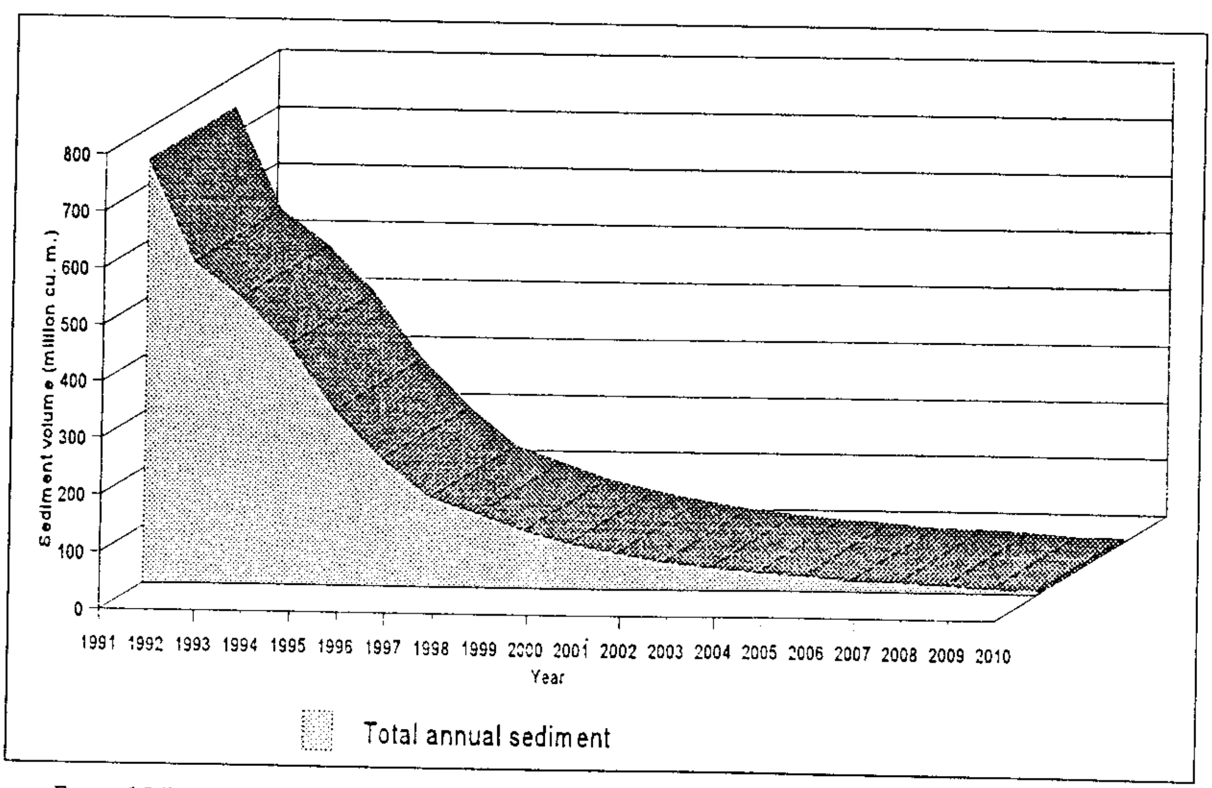

FIGURE 6.5 (*b*) Mt. Pinatubo—Projection of *total* annual sediment delivery from four major rivers draining the mountain.