# CHAPTER FIVE

# MUDFLOW DISASTER MITIGATION PLANNING

## 5.1. Awareness of mudflow hazards

However terrifying and dramatic mudflow occurrences may be, they are essentially caused by elements of nature, ranging from volcanic eruptions to rainfall, aggravated in some cases by human activities. The adverse effects of mudflows would be largely eliminated, of course, if it were possible to avoid settling people in exposed areas or establishing economic activities there. However, the realities of population pressure and the need to put all available land to agricultural use or to exploit it for other economic activities often preclude such a possibility. On the other hand, rational forethought and detailed planning, backed by adequate financing and effective education of the population at risk, can do much towards limiting the hazards of mudflows in specific locations and alleviating their consequences when they do occur.

Community leaders and most long-term residents of a region may have some local experience of the need to avoid sites which are dangerous because of their exposure to mudflows. Again and again, however, new settlers and new employers arrive, and a new infrastructure is set up without the requisite experience and knowledge of local natural hazards. Such hazards will naturally be less known if the last catastrophe took place far in the past.

Cooperation between scientists, administrators and community leaders in identifying past events and potential dangers is essential for working out a mudflow disaster prevention plan. Scientists should identify the modes of flow, assess morphological changes and analyse the topographical distribution of discharged materials Administrators of either the central or local government should take the lead in securing budgetary and institutional support.

The realistic awareness of existing hazards at the national and local levels, is a prerequisite for the successful implementation of a mudflow disaster prevention plan. In other words, policy-making in terms of hazard reduction is possible only if all the dangers are identified. It is essential to ascertain the accurate, quantitative facts required for taking economically correct decisions about the structural and non-structural measures to be instituted against mudflows.

A prevention plan against mudflow disasters should take into account the following key elements:

- Causes and physical characteristics of mudflow hazards;
- Nature and magnitude of expected damage;
- Cost-effectiveness of disaster prevention and mitigation;
- Public demand for an environment without hazards.

## 5.2. Planning objectives

The objectives of a mudflow disaster-prevention plan are to:

(*a*) Delineate hazardous areas to be avoided;

(*b*) Provide warnings to the public, as far in advance as possible before a mudflow occurs but at the latest as soon as it begins, and evacuate the people at risk to safe areas;

(*c*) Plan relief measures in advance;

(*d*) Stabilize slopes in the hazardous area and design structural measures against mudflows in order to reduce their frequency and destructive power;

(*e*) Design additional structural measures to deflect or arrest mudflows by lateral and vertical diversions, in order to avoid a direct hit and resulting damage to structures along its path;

(*f*) Ensure that the appropriate policy decisions are taken and the requisite funds are made available;

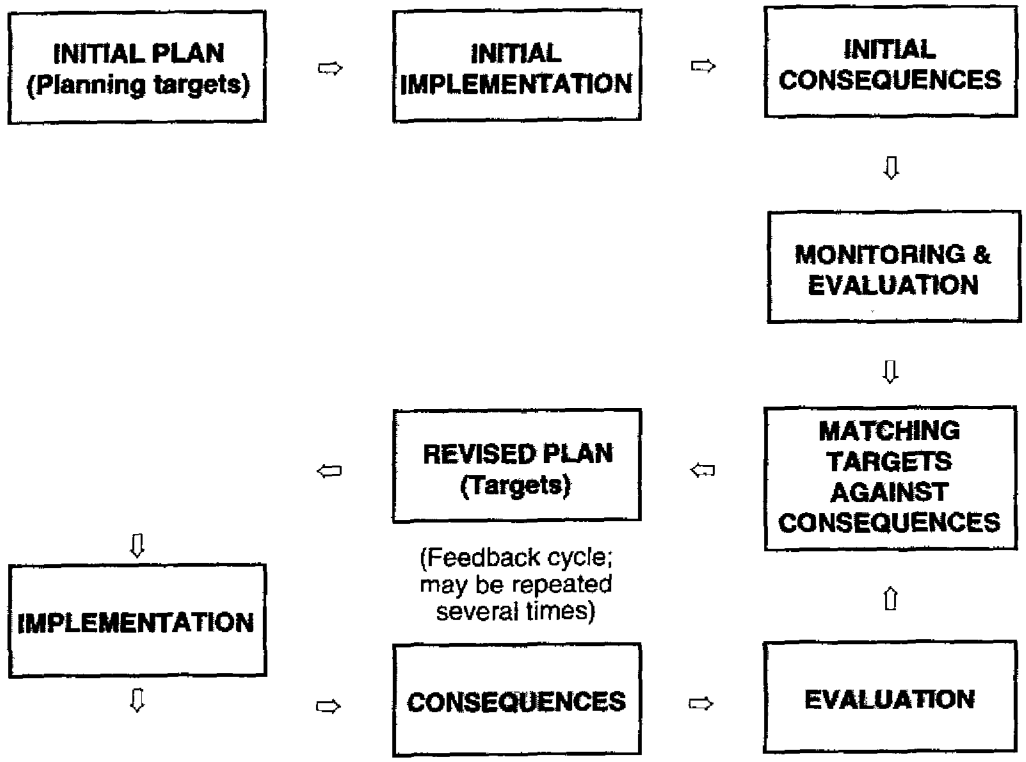
(*g*) Carry out field surveys and prepare a detailed plan in consultation with all concerned;

(*h*) Inform and educate the public about mudflow hazards.

## 5.3. Planning parameters

It is important that planning targets be clearly defined and kept constantly in mind throughout the preparation of a mudflow disaster-prevention plan. Past disasters in a given mudflow-prone area or in neighbouring regions provide valuable information relevant to the attainment of the objectives described in Section 5.2. Planners and officers in charge of disaster prevention should identify public needs realistically in the light of past experiences.

A disaster-prevention plan should be considered as an ongoing basis, in that it should be monitored and evaluated after every occurrence of a disaster, and revised as necessary. This cyclic process is illustrated in the following diagram.




The planning work for disaster prevention and the design of protective structures must take into account appropriate target values of the following planning elements or parameters:

(*a*) Frequency of mudflows;

(*b*) Volume of mudflow,

(*c*) Peak discharge,

(*d*) Material size;

(*e*) Flow velocity;

(*f*) Channel alignment;

(*g*) Level of channel bed

The characteristics of mudflows vary from place to place and from time to time depending on such factors as geological and topographical conditions, drainage patterns, vegetation, precipitation, slope stability, etc., in the catchment basin. However, the characteristics specific to a particular basin can be ascertained either by a field survey or from past experience (see Chapter 3).

An initial plan for the prevention of a mudflow disaster may be improved in the light of data and information obtained through monitoring during and after construction, and careful evaluation after a disaster has occurred. Sometimes additional structures are needed to meet the target, a different type of structure may have to be built if the existing type does not bring about the expected results, and certain non-structural measures might also need to be taken. (*See Section 5 5.3.3 below, for an example of this type of monitoring, evaluation and consequent revision.*)

## 5.4. Planning points

For systematic mudflow disaster-prevention planning and monitoring, the following planning points or locations must be determined:

(*a*) The *primary planning point* is usually located at the point where a torrent in question emerges from a gorge or valley. The primary planning point is characterized by the following elements:

- Height of the channel bed;
- Acceptable mode of flow;
- Acceptable peak mudflow discharge;
- Acceptable size of transported material.

Each element should be fixed in such a way that no hazardous condition occurs in any reach of the channel bed.

(*b*) Secondary planning points consist of important locations such as towns, villages, bridges, irrigation intakes, confluences, etc. The flow conditions permissible at these points should be taken into account in the plan. The consequences of the development of a structural plan should be monitored at these points.

(*c*) Tertiary planning points can be set up at other locations to ensure close monitoring.

The type, number and locations of engineering structures for mudflow control should be decided upon in such a way as to satisfy the demands at the primary and secondary planning points.

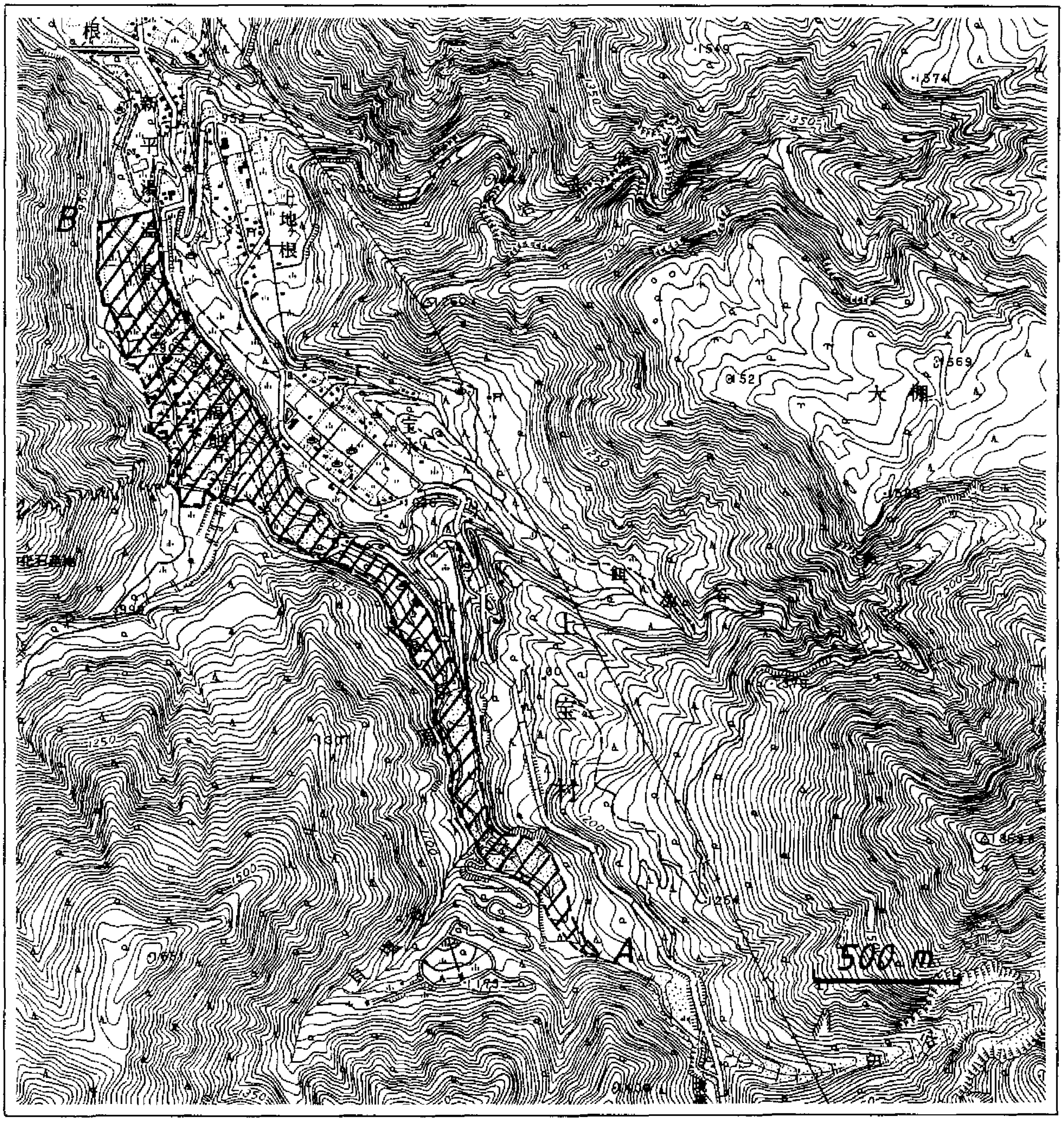



FIGURE 5.1 Typical mudflow hazard map for a river valley in Japan.

## 5.5. Hazard zoning

### 5.5.1. General remarks

In a mudflow-prone region, a hazard map should be prepared in which the areas are divided into a number of zones with different risks of mudflow disasters. From the experience of people living in the area, documentation, topographical and geological surveys and aerial photographs, the areas exposed to the mudflow hazard can be identified (Varnes, 1984). A guideline for hazard zoning is the fact that a mudflow normally comes to rest once the slope is less than 10° However, depending on various factors, such as its velocity, the volume and the grain size of the flowing debris, a mudflow can reach a place with a gradient as low as 3° (see Chapter 2, *Fig. 2.2*).

A hazard zoning map is used for the planning and design of structural measures, for land-use regulations and for the delineation of refuge areas and evacuation routes. A well-prepared hazard map is an invaluable aid for minimizing damage caused by mudflows.

People, including those living in high-risk areas, often discount the likelihood of personally experiencing a disaster. They may consider warnings provided by hazard maps as too scientific to be understood and, therefore, irrelevant. Furthermore, post-disaster memories are often surprisingly short. Strict land-use regulation based on hazard zoning may be highly unpopular with developers and individuals who might feel that such measures interfere with their freedom of choice, for example, but the same citizens often tend to blame inadequate government involvement after destructive mudflows have occurred.

Hazard zoning depends primarily on the causes of potential mudflows, as described below:

(a) *Heavy rainfall*

Heavy rainfall is the most frequent cause of mudflows. Such mudflows are likely to occur simultaneously in several neighbouring valleys. Valleys susceptible to mudflows during heavy rainfall are those

- situated in geologically unstable mountains where landslides frequently occur;
- in which the gradients of the bed slopes in the upper reaches exceed 20°,
- in which the valley floor is covered with a large amount of debris; and
- in which the courses of rivers are sinuous and varying in width

(b) *Volcanic eruptions*

The hazard due to a volcanic mudflow is limited to the area surrounding an active volcano. The hazardous areas exposed to volcanic mudflows can be identified relatively more precisely than those of other types of mudflows. In the case of ice-capped volcanoes or those which have a crater lake at their summit. the hazard can extend over a large area because mudflows occurring there can travel considerable distances. For example, the 1985 mudflow originating from the Nevado del Ruiz volcano travelled more than 60 km from its source. A high proportion of fine ash also renders low viscosity to a volcanic mudflow, enabling it to travel far and at high speed. The lahars of Mt. Pinatubo in 1991, which were triggered by heavy monsoon rains, reached a distance of up to 50 km from the crater (Details on Mt. Pinatubo in Chapter 8).

(c) *Earthquakes*

An earthquake-triggered mudflow can occur quite suddenly, and can travel at very high speeds and over long distances. Consequently, in unstable mountainous areas with frequent strong earthquakes, the mudflow hazard may cover large areas, as was the case of the Mt. Huascaran mudflow in 1970, and the Mt Ontake mudflow in 1984 (Details on Mt. Huascaran and Mt Ontake in Chapter 8).

### 5.5.2. Hazard zoning on alluvial fans

Alluvial fans result from repeated deposition of debris and are highly vulnerable to mudflows. Because they provide a flat area suitable for human settlement, hazard zoning is quite important for reducing mudflow damage at such sites. The town of Armero, destroyed by the Nevado del Ruiz mudflow in 1985, was situated on a large alluvial fan

The mudflow risk on the surface of an alluvial fan depends on the location and degree of dissection (erosion by the stream). At the fan head (apex), a mudflow has greater depth and velocity than at its lower end. Therefore, the mudflow risk is higher at the fan head. In general, the deeper the dissection of the fan surface, the less frequent is the mudflow discharge. The spreading of a mudflow over an alluvial fan is usually confined to a certain sector of the fan. The horizontal angle of the spreading may vary from 30° to 70°. This angle can be determined from past records and experimental models.

### 5.5.3. Some examples

#### 5.5.3.1. *Hazard zoning in Japan*

A typical mudflow hazard map prepared for a river valley in Japan is shown in *Figure 5.1*. It is assumed that the debris transported by a mudflow will come to rest at the point in the channel bed having a bedslope of 8° (point A), but may reach the point having a bedslope of 3° (point B). The mudflow hazard area, therefore, covers the entire area between point A and point B. The depth of sediment deposited by a mudflow can be expected to vary from 5 m to 10 m, depending on the volume of the mudflow discharge and the width of the channel.

*Figure 5.2* illustrates the case of an alluvial cone or fan, in which case it is assumed that the mudflow will come to rest on reaching the fan head or a point where the slope drops to 10° (point A in the figure). The mudflow hazard zone extends up to the curve B in the figure, where the slope decreases to 3°.

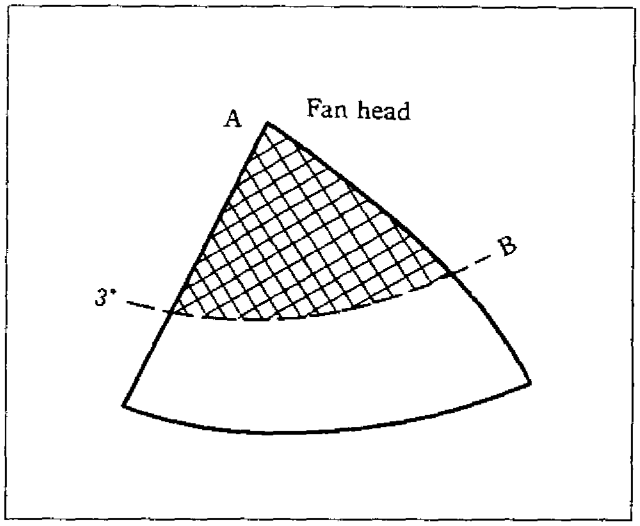



FIGURE 5.2 Scheme for hazard zoning in the case of an alluvial cone or fan The deposition area is bounded by the curve B, where the slope decreases to 3 degrees.

### 5.5.3.2. *Hazard zoning in Indonesia*

An example of a mudflow hazard map in the area around Mt. Kelut is shown in *Figure 5 3*. Volcanic hazard maps such as this are prepared on the basis of an analysis of historical data concerning past disasters in the areas around potentially dangerous and active volcanoes (see Mt. Kelut case history in Chapter 8 for details). In the figure, three types of zones having different hazard levels are noted:

(*a*) The *forbidden zone* is the zone which may be affected by a pyroclastic flow or other phenomena associated with an eruption. This zone should be completely abandoned at all times;

(*b*) The *first danger zone* is the zone around the volcano summit. This zone may not be affected by pyroclastic flow, but may be hit by large blocks ("bombs") thrown up from the vent in the crater;

(*c*) The *second danger zone* is the zone which may be affected by mudflows and floods during the rainy season. This zone may be subdivided into an alert zone situated at a high altitude above a potential mudflow, and a zone from which no escape is possible during a mudflow invasion and which, therefore, should be abandoned once a mudflow warning has been issued.

### 5.5.3.3. *Hazard zoning in Austria*

A hazard zoning map for Gendorferbach in the Drau valley of Carinthia, Austria, is shown in *Figure 5 4* (a). This map proved to be unreliable during a destructive mudflow in 1983. Several ground sills and a high restraining wall along the right bank of the river were constructed following the mudflow, modifying the hazard situation. Therefore, the revised hazard zoning map shown in *Figure 5.4* (b) was prepared. All hazard zoning maps should be similarly reviewed and revised in the light of new information and changes in flow conditions.

In preparing the above hazard zoning maps, all geological hazards such as mudflows and landslides with return periods of less than 150 years were taken into account. The varying degrees of danger are differentiated by three colours (colours are indicated on the maps by hash marks). In the red danger zone (R), the regular use of the terrain for settlement and traffic is prohibited. In the yellow danger zone (Y), settlements are allowed under certain conditions. In the green zone (not shown in the figures), there are no restrictions. A comparison of the two maps clearly shows that the structural measures for torrent control resulted in a significant reduction of the red danger zone, the zone of highest risk.

## 5.6. Priority decisions

**The cost of preparing and implementing a mudflow disaster prevention plan is by no means negligible, and may necessitate compromises between what is ideally desirable and what is practically affordable. In any case, economic considerations have to be abandoned if human lives are threatened.**

**Following is a practical priority order for the major measures to be taken in mudflow disaster mitigation planning:**

1. ***Careful land use* and strict limitation of further settlement in hazardous areas.**
2. ***Simple protective measures*, buffer zones and erosion control works in catchments.**
3. ***Structural measures*, systematically planned and implemented for protection against local mudflow hazards and supplemented by non-structural measures such as afforestation, risk mapping and public regulations.**
4. ***Regular monitoring and maintenance* of all structural measures by establishing a permanent office for doing so.**
5. ***Ongoing analysis and revision* of disaster prevention plans.**

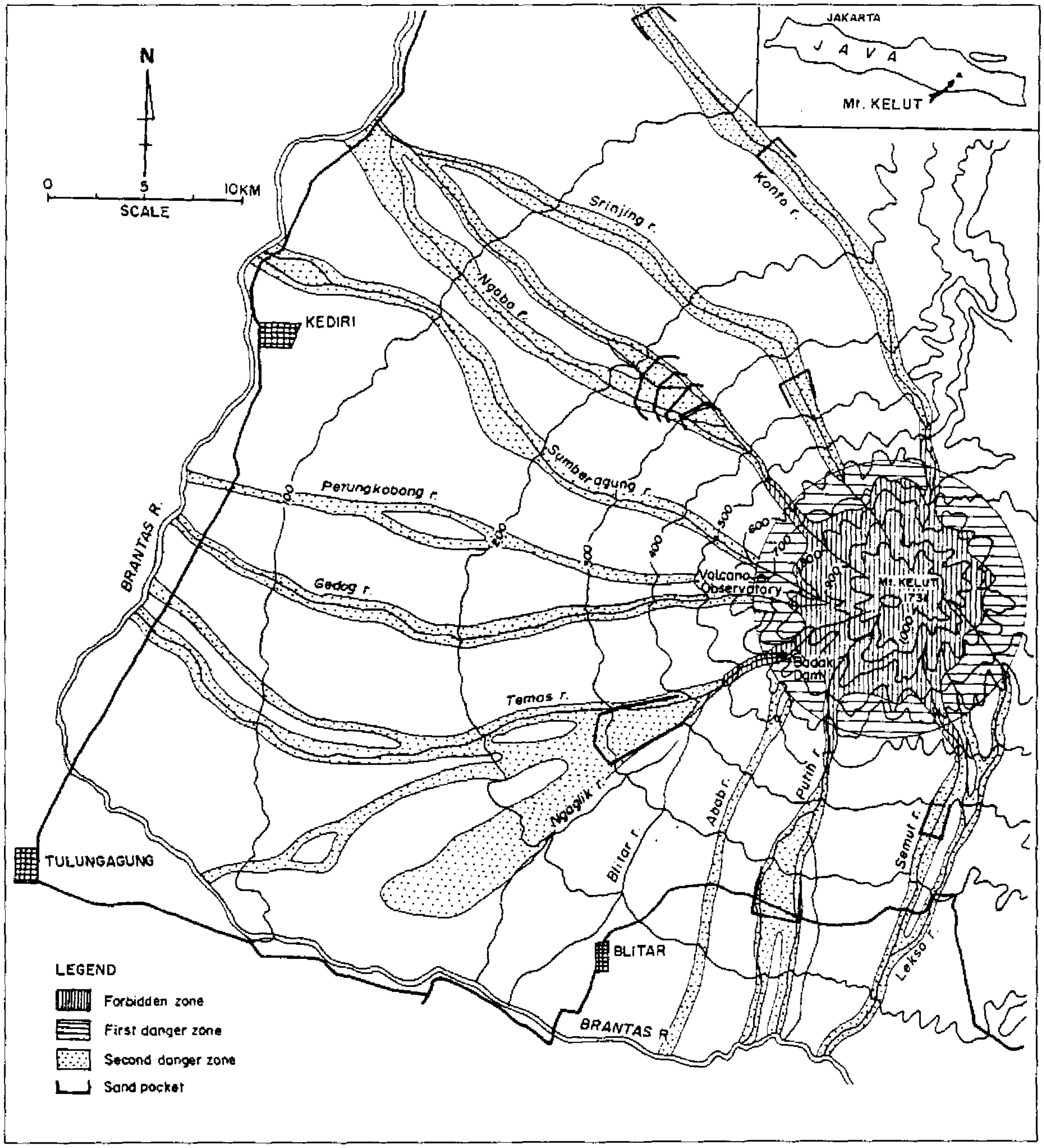



FIGURE 5.3 Volcanic hazard map of Mt. Kelut indicating three danger zones.

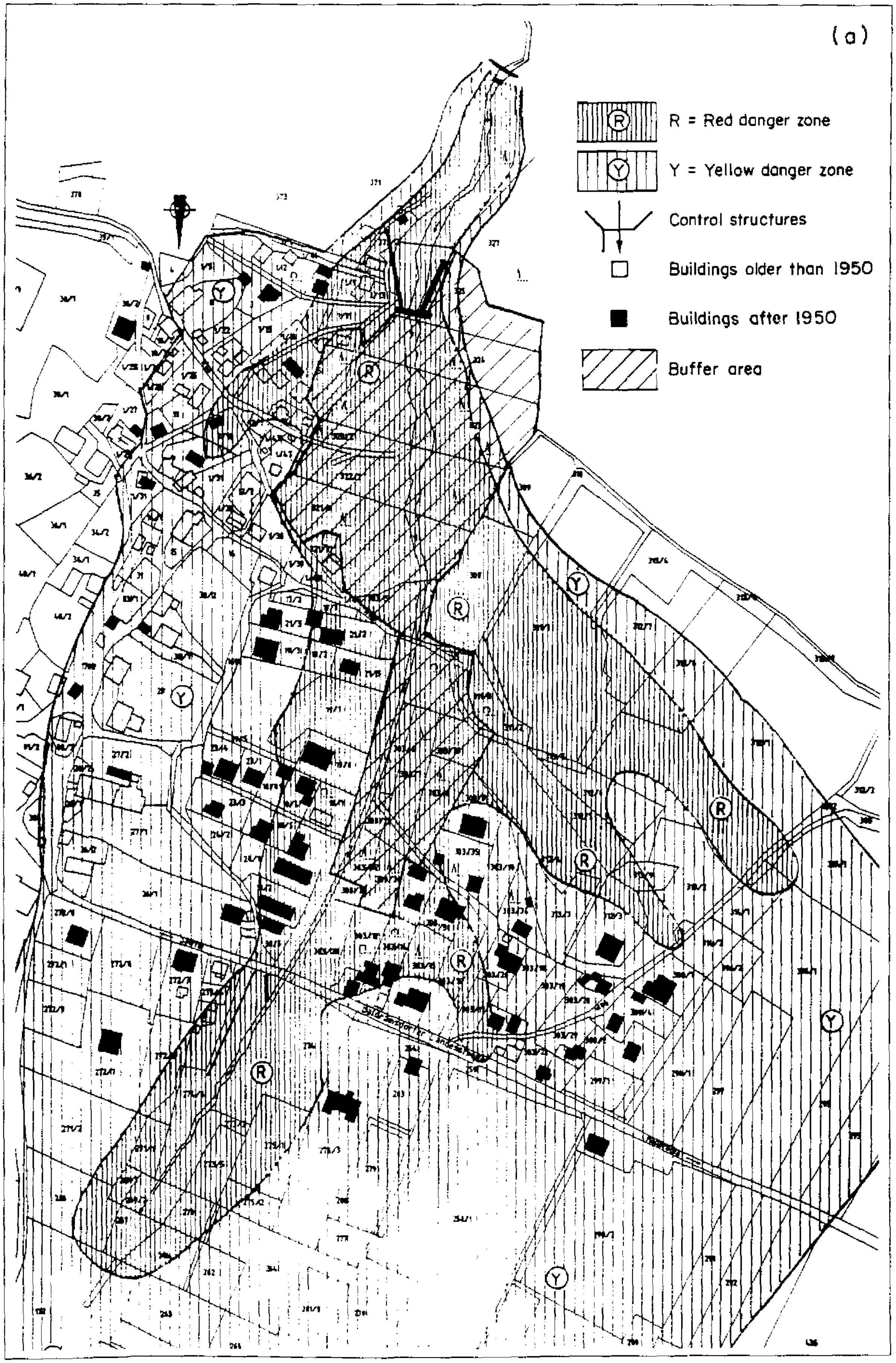



FIGURE 5.4 (*a*) Old hazard zoning map for Gendorferbach, Carinthia, Austria. It turned out to be unreliable during a mudflow event in 1983.

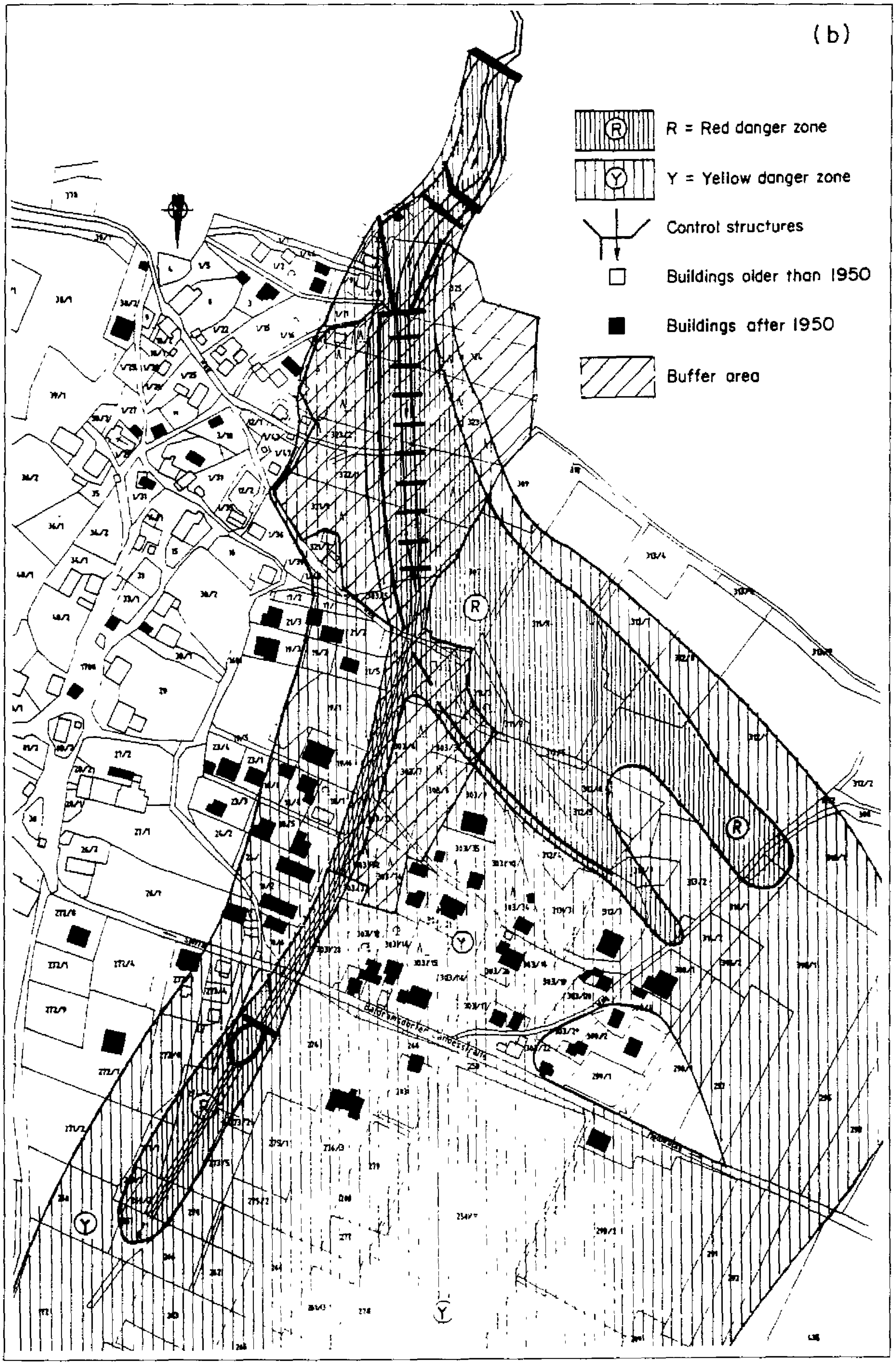



FIGURE 5.4 (*b*) Revised hazard zoning map for Gendorferbach, Carinthia, Austria after the 1983 mudflow event. The "red" danger zone (R) was able to be reduced because of the construction of several structural control measures