FIGURE 8.45 Mt. Pinatubo. Erosion features in the pyroclastic deposits of the watersheds of the Pasig, Abacan and Sacobia rivers. *Photo: M. Watanabe, 1992.*

the year 2010, predict a significant negative impact on all of the river systems draining Mt. Pinatubo.

According to the Office of Civil Defence, a total of 847 persons died, 184 were injured and 23 were declared missing. Of the people who perished, 537 succumbed to diseases at evacuation centres. Most of these were Aetas, semi-nomadic tribal aborigines who lived on the slopes of the volcano. The eruption has displaced about 56,000 Aetas. Ashfall and first-year lahars completely destroyed 40,809 houses, while 67,395 were partially destroyed. The disaster caused more than 270,000 people to leave their homes. Evacuation camps absorbed more than 100,000 people. In total, the eruption and its accompanying first-year phenomena affected more than 249,000 families of about 1.18 million people. This corresponds to 19 per cent of the total population of central Luzon (Tayag, 1992).

Mitigation measures

Mitigation of the effects of lahars in the post-eruption phase requires the management of the sediment yield. In the case of Mt. Pinatubo this is a nearly impossible task. There is a dramatic change of the landscape affected by the lahars after every monsoon season, and the character

Basically, there are several possibilities to minimize the impact of lahars. Some of those which have been considered are:

(*a*) Stabilizing the sediments at the source by a series of check dams;

(*b*) Arresting the lahars near the apex of the fan where there is a break in the river gradient, by constructing sediment traps, debris-flow breakers to remove water from the flow, or sediment-retention dams;

(*c*) Diversion of lahars to less valuable land by constructing training dykes;

(*d*) Accumulation of lahar deposits in a sand pocket in the upper part of the fan, and prevention of further spreading by constructing dykes in the lower parts;

(*e*) Desilting of river channels to provide space for new material;

(*f*) Protection of highly valuable land, including towns and villages, by constructing ring dykes.

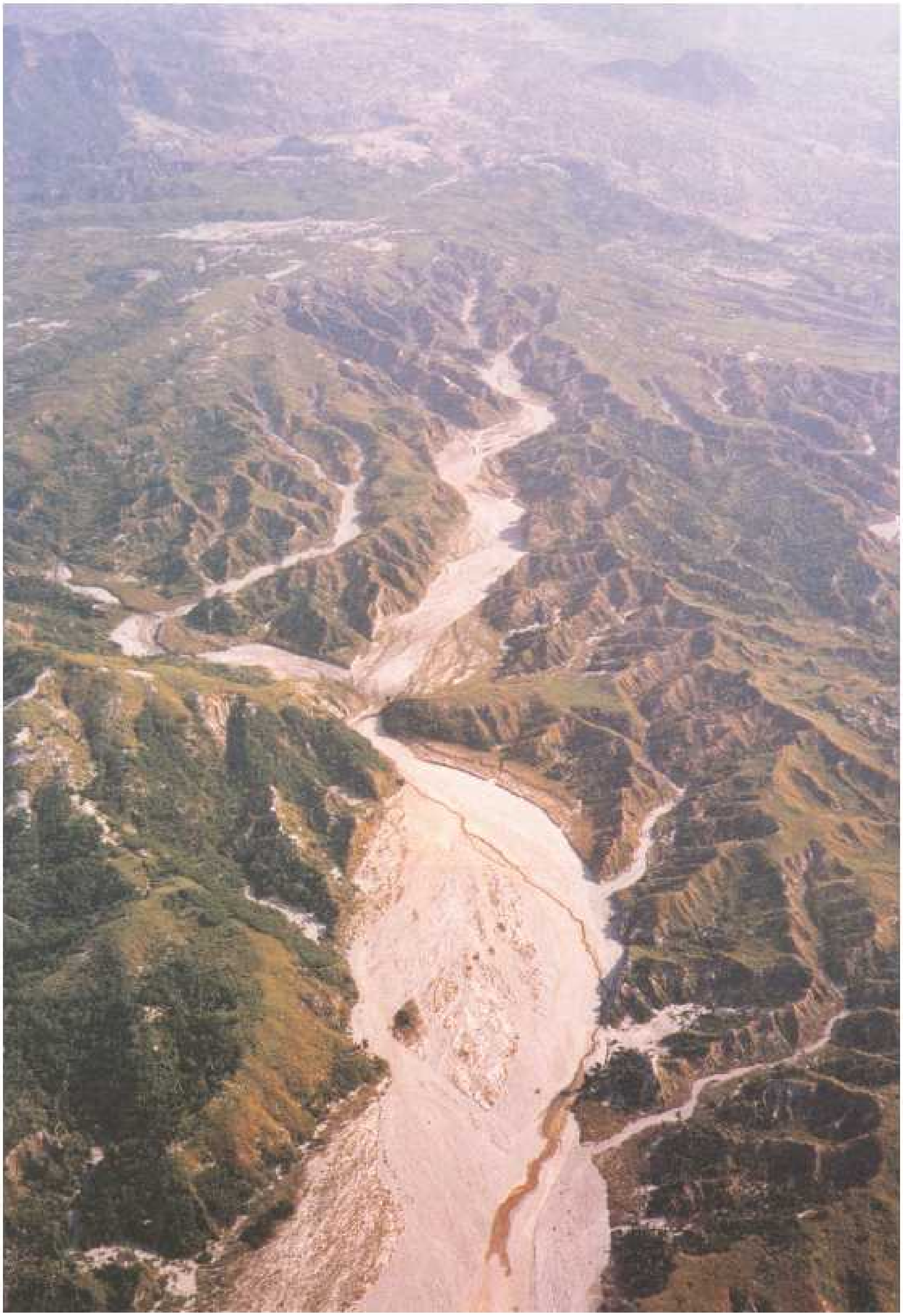

FIGURE 8.46 Mt. Pinatubo. Typical first-year lahar in the upper reaches of one of the rivers draining the western side of the volcano. *Photo: R. P. Brenner, 1992.*

FIGURE 8.47 Mt. Pinatubo. Lahar in the lower reaches of the fan causing widespread damage to the infrastructure. *Photo: M. Watanabe.*

FIGURE 8.48 Upstream side of Capaya bridge over Abacan River at about km 80 from the Manila-Mabalacat Expressway. The lahar has filled the river channel up to the underside of the bridge deck.
Location: Central Luzon, Philippines. *Photo: R. P. Brenner, 1992.*

1lof the natural processes taking place is not yet fully understood.

The Government of the Philippines, through its Department of Public Works and Highways, has divided rehabilitation work into immediate, intermediate and long-term phases. Some of these mitigating measures have been implemented to various degrees and with varying degrees of success. However, with the many constraints prevailing in the Mt. Pinatubo area, such as the huge volumes of sediments, the high population density, the patterns of land use, the ever-changing morphology of the river basin, the cost/benefit ratio of protective works, and the economic situation, it appears that only the building of sand pockets and dykes (alternative (*d*), p. 114) has a chance to yield substantial success in the coming years. In the long-term, a major problem will be to predict the impact of the slow transfer of sediments to the rivers in the low-lying areas.

8.4. Mudflows caused by dam failures or glacial lake breaches in high mountains

- **Basin of Lesser and Greater Almatinka Rivers, Kazakstan, 15.07.1973 .... glacial lake failure.**
- **Stava, Italy, 19.07.1985 .... failure of a dam.**

8.4.1. Mudflows in the Basins of the Lesser and Greater Almatinka Rivers, Kazakstan

Disaster events

The central region of the Pamir mountains near Almaty City in Kazakstan, is subject to violent mudflows, which have been observed since 1920. Some of the mudflows have been particularly destructive, claiming large numbers of human lives and causing heavy material losses. Among the main causes of these mudflows have been heavy rains, breaches in glacial lakes, snowmelts, large amounts of unstable moraine deposits, and sharp increases in runoff due to deforestation in the highlands.

Mudflows on the Malaya Almatinka River

8 July 1921. This was one of the largest mudflows which occurred during the entire period of observation. It began on the night of 8-9 July, after a heavy rainfall (exceeding 100 mm). The total volume of the flow was estimated to be 3.2 million m^3 and the maximum discharge rate was between 900 and 1,000 m^3/sec. Approximately 1.2 million m^3 of mud was deposited within the Almaty City limits, which was responsible for 500 deaths. Similar disastrous mudflows on the Malaya Almatinka river occurred on 8 July 1950, 20 August 1951 and 7 August 1956.

15 July 1973: This event was caused by the breaching of a glacial lake dam near Central Tuyuksa glacier. The average temperature was also higher than usual by 4° to 7° C. The water level of the lake fell by 5.8 metres after the failure of the dam. The volume of the drained water was 220,000 m^3 and the maximum discharge rate was 350 m^3/sec (as opposed to the normal discharge rate of about 2.0 m^3/sec). At a height of 3,000 m, the flow destroyed a check dam (designed for an intake of 30,000 m^3) which was overwhelmed by the immense volume of water, which burst through some moraine layers as a result. These facts contributed to the creation of a catastrophic mudflow with a discharge rate of 10,000 m^3/sec and a total volume of 3.8 million m^3 with an average density of between 2,350 and 2,400 kg/m^3.

This mudflow completely destroyed a steel cell dam 10 metres high, as well as bridges, roads and engineering structures, and claimed several human lives. The dam at Medeo, which at that time was built to a height of 110 m, stopped the mudflow. The water discharge tunnel of the dam was blocked by the mudflow, which resulted in a drastic increase of the water level in the reservoir behind the dam to the 50 metre level. The danger of overtopping and the start of a secondary mudflow was neutralized by a month of around-the-clock emergency work at the dam crest. Some 1,500 workers as well as powerful pumps, and special earth-moving and other equipment, were mobilized.

Some specialists ascertained that if the Medeo dam had not been constructed, the central part of Almaty City with a population of more than 200,000 people would have been badly affected by this mudflow. After this event, a second stage of construction was carried out at the Medeo dam, raising its height to 150 m and its capacity to 12.6 million m^3. Other important mudflows near Almaty City were also observed in 1975 (100,000 m^3), in 1977 (between 3 and 8 million m^3), on 28 June 1988 (0.2-0.5 million m^3), and on 3 June 1994 (70,000 m^3).

Mudflow disaster reduction

In light of the hazardous location of the city of Almaty, the capital of Kazakstan, with 1.35 million inhabitants and the high potential for mudflow occurrence, a complex of protection and mitigation measures was developed and realized with the aim of enhancing the disaster preparedness capacity of the city. These measures were carried out in several phases. The first phase, prior to 1960 involved the strengthening of the river banks and the construction of small engineering structures (such as dykes, gabions and retaining walls). The second phase was the adoption, in the 1970s, of a protection plan for the city, calling principally for the construction of several important mudflow protection structures. The first such project was the construction of a large dam at Medeo, realized by the use of pinpointed explosions (which required a total of 10,000 tons of explosives). In the third phase, apart from the continuing construction of engineering structures, the implementation of important disaster mitigation projects and the organization of a network of required specialized services was programmed. To date, projects worth US$ 200 million have been carried in the implementation of the city's protection plan.

Scheme for the Protection of Almaty City from Mudflows

VULNERABILITY OF HEALTH, EDUCATION AND DWELLING FACILITIES TO NATURAL DISASTERS (EARTHQUAKES, MUDFLOWS, FLOODS) IN ALMATY, KAZAKHSTAN.

Structures	Resistant	Vulnerable	To be removed	To be Strengthen		Reserve
		Structures	Total M²	Structures	Total M²	
Hospitals	14	17	75,600	13	96,000	
Clinics	16	8	33,500	3	19,300	
Schools	29	66	65,300	54	93,300	
Kindergarten*	25	68	74,700	55	88,600	
Dwelling houses	1735 (20.6%)	5020 (59.6%)	173,800	1675 (19.8%)	55,700	750,000 m

Note: * Construction cost: Ruble 750,000 (prices 1991). Reinforcement cost: Ruble 123,000 (prices 1991).

Source : Kazakh Research and Development Institute of Seismology, Construction and Architecture.

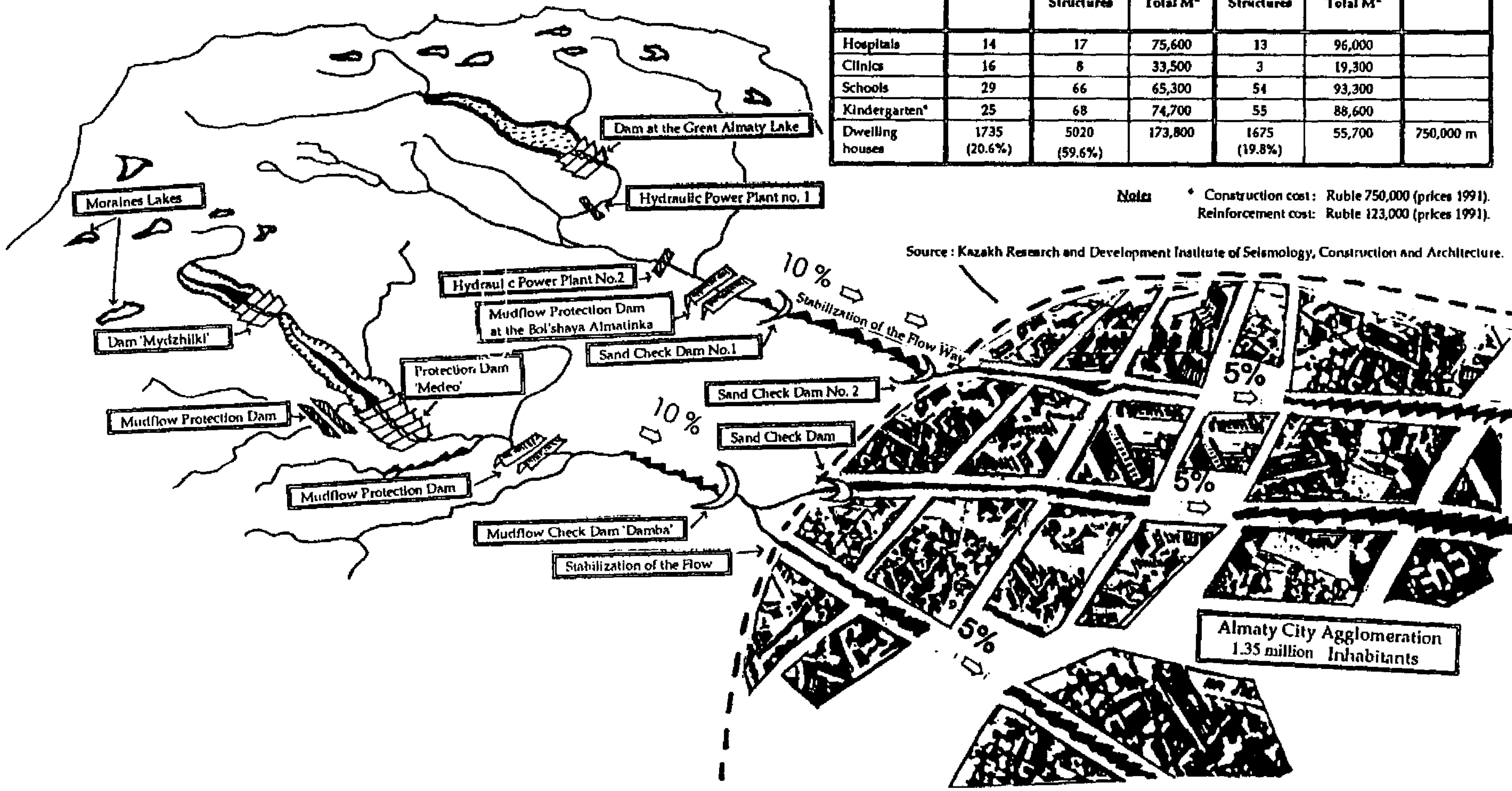

FIGURE 8.49 Scheme for the protection of Almaty City from mudflows.