Chapter 7

Eruptions and lahars of Mount Pinatubo, 1991 to 2000

C.G. Newhall and R.U. Solidum

Mount Pinatubo (Philippines) – asleep for ~ 500 years – began to stir in mid-March 1991, and produced a giant eruption on 15 June 1991, second largest of the twentieth century. Only that of remote Katmai-Novarupta, Alaska in 1912 was larger. About 20,000 indigenous Aeta lived on the volcano, and ~1,000,000 lowland Filipinos lived around it. Two large American military bases, Clark Air Base and Subic Bay Naval Station, added about 40,000 Americans to those at risk. With centuries' of volcanic gas (supply) accumulated in tens of cubic kilometres of molten rock (magma), and with so many innocent people nearby, a disaster was waiting to happen.

Thick deposits from pumice-rich pyroclastic flows formed the lower slopes of the volcano and told a history of infrequent but very large eruptions - larger than any eruption in the history of modern volcano monitoring. Scientists warned that a giant eruption was possible, perhaps even likely, but none had ever been monitored, much less successfully forecast. For two months after the volcano began to stir, small earthquakes and other signs fluctuated without clear, systematic trends. The volcano was teasing the scientists, and the public was profoundly sceptical.

Against the odds, a team of scientists from the Philippine Institute of Volcanology and Seismology (PHIVOLCS), assisted by the US Geological Survey, correctly forecast a giant eruption. Evacuations that had been recommended earlier were now enforced and expanded. Over the course of a few days, small precursory eruptions escalated to a spectacular climax on 15 June that swept the whole volcano, killing virtually everything in its path. Avalanches of searingly hot ash and pumice (pyroclastic flows) filled valleys and swept over ridge crests. Tens of centimetres of ash, with weight nearly doubled by rain from simultaneous Typhoon Yunya, caused many roofs to collapse. Loss of life was relatively modest considering the population at risk and the enormous size of the events (~400 died during the eruption, and ~500 Aeta children died in evacuation camps from measles). Warnings, coupled with strong visible clues from pre-climactic eruptions, had saved nearly all of the Aeta population, plus an unknown number of lowlanders. Some damage was unavoidable, but much was also averted, especially damage to military assets and commercial jets.

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What factors worked for successful mitigation of the eruption risk?

- Pinatubo, and other long-dormant volcanoes, give plenty of warning signs. The challenge is to read them correctly, and to time the warnings to be early enough for evacuation but not so early that people give up and return home. With no precedent monitoring of such a large eruption elsewhere, and no prior monitoring of Pinatubo, the scientific team just barely managed to install enough instruments, collect and interpret the data, educate those at risk, and to give the right warnings at the right time. Fortunately for all, the volcano gave scientists two months in which to work and in early June gave signs that the eruption was just days away.
- PHIVOLCS had a quick-response team that started work at Pinatubo in earliest April, and captured critical early data. The US Geological Survey also had a team of volcano scientists and technicians, experienced, fully equipped and ready to help. The latter team had been formed after the disaster at Nevado del Ruiz in Colombia just a few years earlier, and was supported by USAID's Office of Foreign Disaster Assistance. Together, the two teams accomplished what neither team by itself could have accomplished. When Nature presents an enormous challenge, rapid, joint, international responses may be necessary.
- Although public and even official scepticism was a huge challenge, trust between key scientists and officials offset that scepticism. The longer a volcano has been quiet, the less people know about it, and the more sceptical they will be. Scientists (led by the late Raymundo Punongbayan of PHIVOLCS) and officials – some who had known each other for years and some who were new-found friends – prepared for the crisis as a team and developed the trust that was needed for critical mitigation decisions. Trust in other circles – e.g. between missionaries and the indigenous people – also helped greatly.
- That the Philippines already had protocols and procedures for evacuations ahead of typhoons and floods, and even for volcanoes elsewhere in the Philippines, also helped to offset local unfamiliarity and scepticism about Pinatubo. The hierarchy of national, regional, provincial, municipal, and village civil defence worked well. A similar hierarchy of command and hazard preparedness within the military had equally beneficial effects.
- Especially because of Pinatubo's long quiescence before 1991, very few people around Pinatubo understand anything about volcanoes and their hazards. The same had been true in Armero, downriver from Nevado del Ruiz, and unfamiliarity with volcanic hazards cost residents of Armero their lives. A hard-hitting video made by the late Maurice Krafft for the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI) was wonderfully graphic, showing quickly in images what words could not describe. This video saved many lives. Video worked where words would have failed. *(Ironically and at the same time, Maurice and his wife Katia, dissatisfied with the footage of pyroclastic flows in this video, stopped by Unzen Volcano to get better footage, and they and 41 others were sadly killed.)*
- Scientists are by training cautious about making forecasts. Invariably, they wish for more data. But during a crisis, advice must be given no matter how high the uncertainties. Ray Punongbayan and his colleagues set aside their normal caution, explained the uncertainties, and gave their best guesses. They made forecasts where others might have feared to tread. Obviously, caution and an all-out search for reliable data are important, but when Nature signals that a hazard is imminent, scientists must speak out.
- Those at risk can be diverse, and require an equal diversity of communication approaches. Some of those at risk responded best to "Trust me. Follow me". Others challenged us to convince them of the hazard. Military officers and engineers understood probability trees; others drew more from the IAVCEI video.

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- Many – indeed most – of those at risk waited until the last possible moment before evacuating. Yes, many were sceptical. And yes, few people wanted to evacuate even if they knew they should. Although the plan called for evacuations at Alert Level 4, very few moved because the hazard wasn't yet in their face. Two messages by example helped. First, scientists moved themselves from the centre of Clark Air Base to the far perimeter of the base, and base commanders took notice. Second, when Americans from Clark Air Base left town, Filipinos in neighbouring towns also took notice.

Beginning during the eruption, and continuing for a more than a decade thereafter, rain-triggered volcanic mudflows (lahars) buried large areas around the foot – including many towns up to 40 km away – with an average of 5-10 m of sand and gravel. Unlike floods that come and go, lahars come … and stay. Of roughly 6 million cubic meters of deposit on the volcano slopes, more than half was washed into the surrounding lowlands over the next 10 years. The scale of the hazard far exceeded normal sediment control measures. More than 200,000 people were "permanently" displaced, though by 2014 some have returned and built new homes on top of the lahar deposits. Within just a few years, costs of lahar damage and mitigation exceeded the ~ USD 2B damage from the eruption itself.

Again, in spite of the enormous scale of the lahar hazard, only about 400 were killed by lahars. Scientists set up high-tech warning systems with radio-telemetered rain gauges and flow meters. For lahars, the PHIVOLCS-USGS team was joined by a team from the University of the Philippines and University of Illinois-Chicago. Kelvin Rodolfo of the university team introduced the Indonesian word "lahar" which, because it is foreign, became a good educational tool. Police set up manned lahar watchpoints. More videos were shown. Time and again, warnings were sounded, towns were evacuated, and most people survived. In addition to warning systems, engineers built an elaborate set of levees (dikes) and sediment catchment structures. Early structures were too optimistic, getting filled or overrun quickly, but eventually, the increasing scale of the engineered structures matched the decreasing scale of hazard. Some of the waste was inevitable, as there was public pressure to act even before the full scale of the problem was understood. Some additional waste might be charged to politics and corruption. Debate about whether to spend for dikes or spend for relocation of towns was generally cut short, either by normal human reluctance to abandon one's home, or by lahars themselves. Much of the engineering mitigation was financed by the central government; overseas development aid financed additional studies and construction in selected watersheds.

Estimated costs for the pre-eruption scientific response (mainly, helicopter time and equipment that was destroyed and had to be replaced) were approximately USD 1.5 million; for preparation of scientists over the preceding decade ~15 million and for pre- and syn-eruption evacuations ~USD 40 million. Compare these costs to roughly 10,000 lives saved and hundreds of millions of dollars of damage averted. Clearly, maintenance of quick response teams and the warnings they gave were cost effective.

The cost-effectiveness of lahar mitigation was not as clear. Costs of scientific response were roughly USD 2M and lahar control structures plus temporary and relocation housing cost at least USD 700M of government outlays. Damage to the town of Bacolor, sandwiched by sediment control levees, should also be counted as a cost of mitigation. Savings might include other towns, e.g., Bamban, Guagua, San Marcelino, Botolan, and the large city of San Fernando,

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but saving them from lahars has caused substantial flooding in subsequent years. A proper cost-benefit analysis of Pinatubo lahar mitigation would be of great interest.

Preparation time for the eruption was short, the scientific team was tight and spoke with one voice, and a relatively small number of political, civil defence, and military leaders made most of the decisions. The subsequent lahar crisis was much more complicated, with more scientists, more decision makers, and more time. Before the eruption, there was no time for debate; during the lahar period, there was lots of time for debate – between scientists, among engineers and policymakers, and between citizens of one town and the next. The result was that mitigation measures during the lahar period were more controversial, and probably more expensive than they needed to be, but in the end most people and towns were protected. It wasn't perfect, and some bitterness still remains, but the overriding fact is that most people at risk survived and have been able to rebuild their lives.

Figure 7.1 Mount Pinatubo prior to the paroxysmal explosive eruption of 15 June 1991 (top) and after the eruption (bottom). Much of the edifice disappeared and became a caldera depression with a lake and many active steam vents. (V.Gempis, USAF).

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