Impacts and management of recent volcanic eruptions in Ecuador: lessons for New Zealand

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by G S Leonard, D M Johnston, S Williams, J W Cole, K Finnis & S Barnard

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ABSTRACT

This report summarises the observations and interpretations of a reconnaissance trip to central Ecuador in November 2004. The purpose of the trip was to investigate infrastructural and agricultural volcanic impacts and volcanic hazard emergency management in Ecuador, focussing on lessons for New Zealand. The team included participants from the Institute of Geological and Nuclear Sciences, the Ministry of Civil Defence and Emergency Management, the University of Canterbury and the University of Otago.

In November 2002 a major ash fall from Reventador volcano caused significant impacts on Quito, the capital of Ecuador. Quito airport and most schools closed for almost a week. This followed ash fall from two eruptions in 1999 and many dozens of earlier historic eruptions. Quito is one of few large urban areas to feel the effects of volcanic ash falls in recent times and the scale of the events there provides a unique opportunity to investigate both long and short term impacts of volcanic ash falls on lifelines and urban communities. The town of Baños to the south of Quito has been in danger of proximal (potentially lethal) volcanic hazards from Tungurahua volcano, which has been in eruption since 1999, and on whose flank the town sits. The 25,000 residents of Baños were evacuated for nearly three months in 1999/2000. Towns and agricultural areas surrounding Quito and Baños also regularly experience ash falls and ongoing lahar hazards.

The following key observations resulted from the trip:

- Monitoring staff need to be prepared for high levels of stress, understand what their and their equipments' limitations are, and be rostered for long-term sustainability. Any false alarms may reduce monitoring credibility and place scrutiny and criticism on those agencies. Direct relationships between monitoring agencies and all responding agencies prior to events is essential. The best response occurs where those who need to exchange information in an event have talked to each other ahead of time, and trust each other.

- Clear planning at all levels of emergency management is necessary to pre-determine the division of responsibility, and create an environment that fosters cooperation. All agencies with a stake in the hazard risk must be included in the planning conversations, including individuals from appropriate roles. Local problems demand locally developed solutions – support communities to determine their own solutions, with expert advice regarding risks, and support and resources. Cultural beliefs must be taken into account when planning for hazard responses. Exercises are critical to improving planning, education, training and evaluation of effectiveness.

- Public education and training takes time and must be consistent, regular and permanently ongoing. The more channels used the higher the retention of information.

Education and training take time and need to be undertaken within target communities, customised to the audience of individual regions and communities, and in multiple formats and languages. Committed locals are the most efficient education tool an authority can have, as they are trusted within and aware of the needs of, their area.

- Water supply issues are discussed in detail, including: covering treatment plants, flocculation, acidity, testing, supply-line vulnerability, pump filters, community water storage and boiling, sectorisation and redundancy within networks. Rapid street cleanup, and light rain stabilising ash, prevent a large proportion of ash from entering drains. Waste water pumps did not fail but required more regular maintenance of filters and external mechanisms exposed to falling ash, internal mechanisms were unaffected.

- Overload is the largest telecommunication problem reported from ash fall in Quito. There were no reported physical exchange problems, but the study group had no direct contact with communications providers. Electricity transmission flashover has been a problem; ash is cleaned from insulators with water washing or heavy rainfall. Ash damage to hydro-electric generation plants has also been identified in Ecuador as a potential hazard to electricity supply down the line. 'Minor' concentrations of ash in dams have caused no reported turbine blade damage in Ecuador, but lahars overtopping or breaching dams is a significant hazard.

- Cleaning roads is essential for safety from three hazards: (1) obscured road markings, (2) direct loss of traction, and (3) raised-dust causing nuisance and visibility reduction. Vehicles reportedly operate well in Quito in ash fall environments, but air filters require more frequent cleaning and/or replacement. Stockpiling of filters for at least essential service vehicles should be considered. Washing windscreens of ash without wiping will reduce scratch damage.

- Cleanup and ash disposal timing can be difficult to decide: when is an event 'over'? Ash disposal is a huge issue that must be fully pre-planned and pre-costed. Millions of cubic metres of ash must be disposed of from a large city that receives only millimetres of ash.

- Quito's airport and local airlines were considerably affected economically by the eruptions, due to the time needed to clean airport infrastructure (especially runways) and aircraft before normal operations could be resumed. Detailed pre-planning could save millions of dollars for these companies. Although ash on the runways was stabilised through light dampening with water sprayed from trucks, it was not saturated or even 'wet', as this inhibited sweeping. Many airlines carry engine covers, tarpaulins and adhesive tape to cover vulnerable aircraft components in the event of an eruption. Plane cleanup using fire trucks spraying water took 10 to 15 minutes per Boeing 737 (with flaps fully retracted), and full service checks were performed afterwards. No abrasion or chemical corrosion was seen after ash had remained on aircraft from 12 to 48 hours. Aircraft were moved using tow trucks rather than starting jet engines. No problematic ingress of ash or water to the planes was noted.

- Impacts to livestock (mostly dairy cows in the study area) include: tooth abrasion due to mastication of ash; stock death and loss of condition due to ingestion of ash; and loss of grazing potential due to burial by ash. There is a need to plan for stock transport and alternative grazing in the dairying industry. A further effect in New Zealand, maybe not noted in Ecuador, is milking strategy if electricity supplies interrupted.

- The 'burn' of leaves was reported from the heat of ash, but also may occur from ash leachate. Rainfall washes leaves, but may not clean them adequately to make crops saleable. Wind reduces ash collection on leaves, so that ash fall at night (which is less windy) often has a greater impact. It was reported that tens of centimetres of ash may kill all crops. A few centimentres of ash were reported to cause about 50% crop losses in and around Baños. Due to wider economic impacts of an eruption, markets may dwindle even if crops are salvaged. Ash often produces a long-term soil fertility increase, but it reportedly takes about six to eight years to get soil back to its pre-eruption fertility in the study area. Covered flowers were still crushed by the weight of ash on the covers. Younger plants, and those with larger leaves, tend to fare less well in ash fall environments.

The following topics were of interest on this reconnaissance trip, but information was not available or the team were unable to discuss it with an appropriate person or organisation: waste water treatment; sweeper-truck performance; telecommunications performance from the industry itself; and the effect of providing written material only in one language. Analysis of human health impacts was beyond the scope of the trip.

KEYWORDS

Ecuador, volcano, hazards, risk, reconnaissance, Quito, Baños, Latacunga, Cotopaxi, Guagua Pichincha, Reventador, Antisana, Tungurahua, lessons, civil defence, emergency management, lahar, ash, pyroclastic flow, agriculture, horticulture, dairying

1.0 INTRODUCTION

The mitigation of volcanic hazards requires detailed knowledge of the styles of eruption that can occur and the potential hazard impacts that may occur from these. Detailed study of overseas experiences of eruption styles, effects, monitoring and mitigation will help New Zealand manage future volcanic events. Study trips to areas affected by eruptions (both during and after the event), can provide detailed information which is relevant to New Zealand, as such information is not generally published about most overseas eruptions.

This report summarises the observations and interpretations of a reconnaissance trip in November 2004. The purpose of this trip was to investigate infrastructural and agricultural volcanic impacts and volcanic hazard management in Ecuador, with a view to seeing what lessons could be brought back to New Zealand. Outcomes from the trip are presented with a focus on lessons for volcanic hazard and emergency management in New Zealand.

In November 2002 a major ash fall from Reventador volcano caused significant impacts on Quito, the capital of Ecuador. Quito airport and most schools closed for almost a week. This followed ash fall from two eruptions in 1999 and many dozens of earlier historic eruptions. Quito is one of few large urban areas to feel the effects of volcanic ash falls in recent times and the scale of the events experienced provides a unique opportunity to investigate both long and short term impacts of volcanic ash falls on lifelines and urban communities. The town of Baños to the south of Quito has been in danger of proximal (potentially lethal) volcanic hazards from Tungurahua volcano, which has been in eruption since 1999, and on whose flank the town sits. The 25,000 residents of Baños were evacuated for nearly three months in 1999/2000 (Mothes, 2000). Towns and agricultural areas surrounding Quito and Baños also regularly experience ash falls and ongoing lahar hazards.

1.1 Team Participants

The reconnaissance team spent the bulk of its time in the capital city of Quito and the town of Baños to the south, with visits to villages and agricultural regions in between. Team members included:

David Johnston	Natural hazard and social research scientist, Institute of Geological and Nuclear Sciences
Graham Leonard	Volcanic geologist and natural hazard scientist, Institute of Geological and Nuclear Sciences
Sara Williams	Emergency management planner and interpreter (Spanish), Ministry of Civil Defence & Emergency Management
Jim Cole	Volcanic geologist and natural hazard scientist, University of Canterbury
Kirsten Finnis	Volcanic hazard social research Ph.D. student, University of Otago
Scott Barnard	Volcanic hazard impacts Ph.D. student, University of Canterbury

1.2 Itinerary

Below is a brief outline of the places the reconnaissance team visited, and the dates on which they did so:

Based in Quito, Saturday November 6th to Tuesday November 9th, 2004.

November 7th Quito Defensa Civil: Marco Rivera

November 8th Instituto Geofisico, Escuela Politecnica Nacional (IGEPN): Hugo Yepes, Director; various other staff. Web: http://www.igepn.edu.ec/

Escuela Politecnica Nacional: Bernardo Beate, Professor of Volcanology.

November 9th Quito international airport company

Agriculture association 'Associacion de Ganaderos de la Sierra y Oriente'[1] (AGSO)

Quito Defensa Civil (Education and Communications): Eugenio Martenez, Jefe Dept Capacitación, Dirección Nacional de Defensa Civil, eugeniomart@yahoo.com

Quito Civil Security: Ximena Jijón, Adminstrative Zona Valle de los Chillos, Jefe Zonal de Seguridad Ciudadana, Distrito Metropolitano de Quito ; Lorena Vinueza Ruiz, Directora Metropolitana de Seguridad Ciudadana, Quito

Quito Emergency Office : Dr Alberto Maturana Palacios, Director, Oficina Nacional de Emergencia, Ministerio de Emergencia, Quito

Water supply agency (EMAAP)

Based in Baños November 10th to 12th;

November 10th Latacunga Defensa Civil

November 11th Tungurahua observatory (IGEPN)

November 12th Javier Bermeo, Defensa Civil Baños

Local hostel owner and community representative

Local farmer/tourist spa operator: Roberto Castillo

[1] Meaning 'Association of Cattle Raisers of the Mountains and East' in English, although they also support other types of agriculture.

2.0 OVERVIEW OF VOLCANO HAZARDS IN ECUADOR

2.1 Ecuador's volcanoes

Ecuador lies to the east of the tectonic plate boundary where the Pacific plate is being subducted below the South American plate. The down-going Pacific plate gives off a small amount of water below Ecuador, allowing a little of the mantle below the country to melt, rise as magma, and erupt as a chain of volcanoes (Fig. 1). This is part of a patchy chain of subduction volcanoes that stretches from Ecuador through Peru and Bolivia to the south of Chile, parallel to the plate boundary.

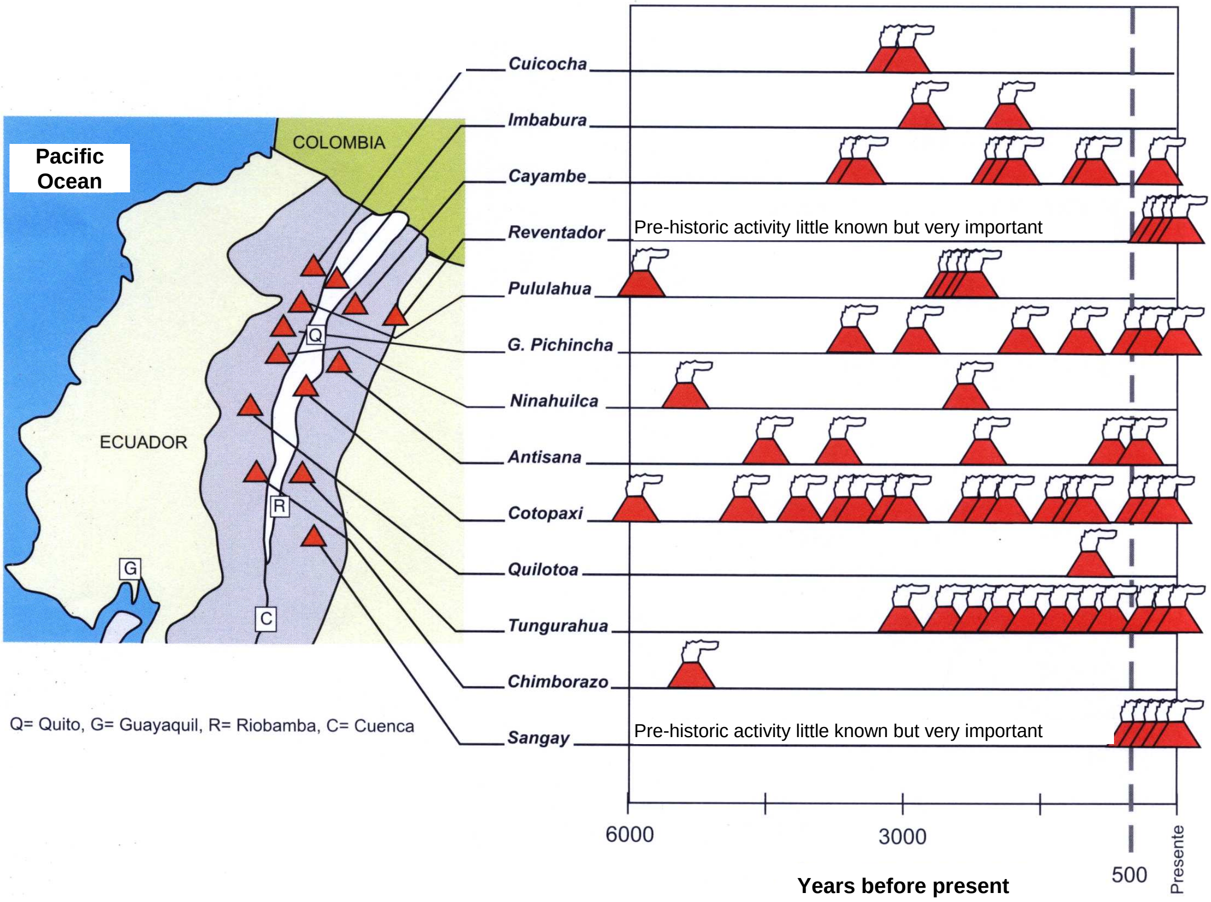

Figure 1 **Map of Ecuador's volcanoes and chart of eruptive history. Modified from IGEPN volcanoes brochure.**

Ecuador's volcanoes lie along a north-elongated zone in the central highlands of the country. Quito lies at about 2850 metres elevation and several of the volcanoes reach over 4000 metres (such as the well known Cotopaxi at 5911 metres). The erupted magmas range from hot fluidal basalts (as seen at Auckland and Northland Volcanic Fields in New Zealand) to cooler more viscous rhyolites (such as those erupted from Taupo and Okataina areas in New Zealand). Rhyolitic eruptions form lava domes and caldera volcanoes. They are relatively infrequent, usually every few thousand years from one active area, but are the most explosive.

The most frequent Ecuadorian eruptions (every few years to tens of years) occur from the andesitic strato-volcanoes (cone volcanoes). Andesites are relatively hot and fluidal, and can produce many relatively gentle lava flows. However, the majority of eruptions are explosive producing ash falls and often pyroclastic flows. Ruapehu, Tongariro (including Mt Ngauruhoe) and White Island are the most active andesitic volcanoes in New Zealand, and display similar characteristics and frequency of eruptions to those in Ecuador.

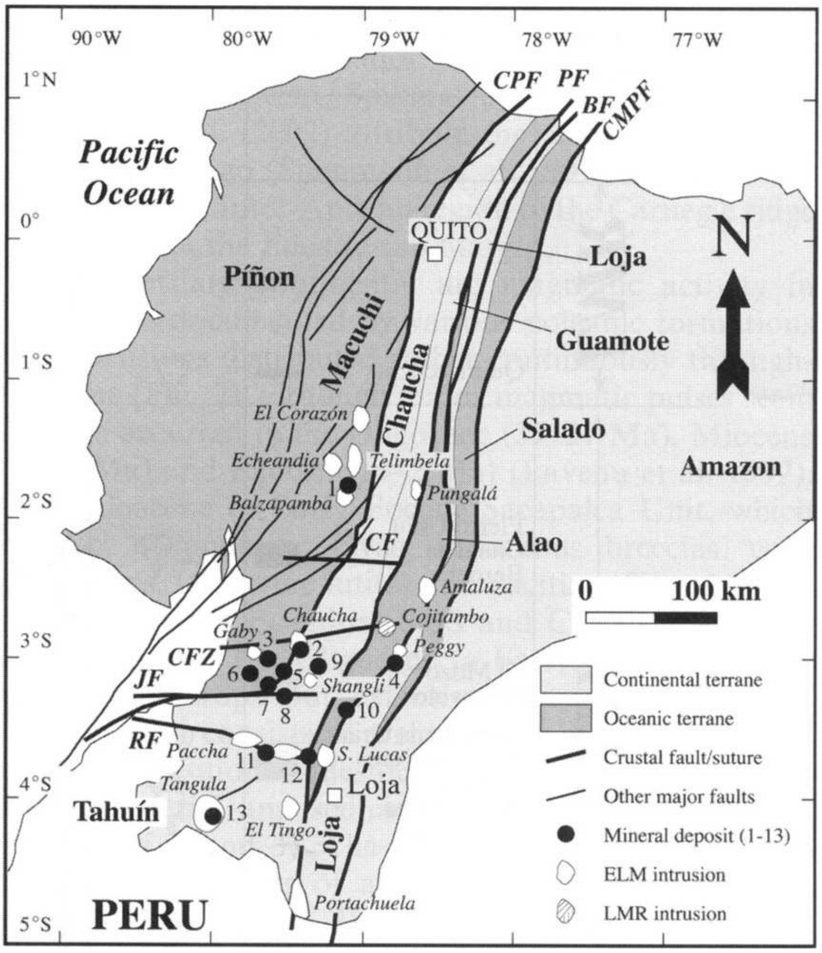

Figure 2 **Geotectonic map of Ecuador (from Chiaradia et al., 2004). Lines represent major faults and fault zones (*CPF* Calacali-Pallatanga-Palenque fault, *PF* Peltetec suture, *BF* Baños fault, *CMPF* Cosanga-Mendez-Palanga fault, *CF* Canar fault zone, *CFZ* Chaucha fault zone, *JF* Jubones fault zone, *RF* Raspas fault zone).**

In addition to volcanic hazards, thrust earthquakes have caused significant damage in the central highlands and are an ongoing hazard of at least equal risk. Ecuador's central highlands area is elevated because it is under compression, driven by the forces of the two tectonic plates pushing against each other. As a result, fault lines cross the entire country (Fig. 2). The compression creates stress on these oblique strike-slip faults that is released in earthquakes, each of which thrusts the central highlands a little higher above sea level. Baños, for example, has had damage from two recent magnitude 6.8 earthquakes nearby, in 1987 and 1998 (Marco Rivera pers comm., 2004). Very large (> magnitude 8) earthquakes are also felt from the plate interface offshore to the west. These offshore earthquakes are broadly analogous to the Alpine Fault setting in New Zealand.

Hot springs and fumaroles are common around Ecuador's andesite volcanoes and geothermal power exploration has been conducted over at least two areas. As yet no geothermal energy is being used to generate power, but commercial hot spring-fed baths have operated in many places for centuries.

2.2 Volcanic history

Figure 1 gives the historic record of eruptions from Ecuador's volcanoes, going back about 6000 years before present. Native and colonial peoples in settlements throughout the country have experienced the effects and products of each of these volcanoes at some time or another.

According to hazard models developed in many countries, generally settlements within tens of kilometres of a volcano may experience pyroclastic flows, lava flows, lahars and thick ash falls, whereas more distant locations may experience thinner ash falls, depending on the wind direction. Internationally, some valleys and flood plains may experience lahars more than 100 km from the volcano. The most recent eruptions to affect Quito and Baños have deposited around 5 mm of ash there.

Ecuadorian volcanoes which have been active since about 1800 AD are described below, together with details of the most recent event from each (Siebert and Simkin, 2002), and additional details from Geophysical Institute Escuela Politécnica Nacional Apartado (IGEPN), Quito, Ecuador (URL: http://www.igepn.edu.ec/):

- **Antisana:** This volcano last erupted in 1801-1802 with lava flows and explosive activity; it lies southwest of Cotopaxi.

- **Cayambe:** A massive isolated compound stratovolcano located northeast of Quito. Its southern flanks lie astride the equator, and it is capped by glaciers, which descend down 4,200 m on the eastern Amazonian side. The modern Nevado Cayambe volcano, constructed to the east of an older volcanic complex, contains two summit lava domes with several other lava domes on the upper flanks. A prominent pyroclastic cone feeding thick lava flows that travelled about 10 km to the east. Nevado Cayambe produced frequent explosive eruptions during the Holocene, with a single historical eruption in 1785-86.

- **Cotopaxi:** Symmetrical, glacier-clad Cotopaxi stratovolcano is capped by nested summit craters and is Ecuador's most well-known volcano, and one of its most active. Deep valleys scoured by lahars radiate from the summit, and large andesitic lava flows extend as far as the base of Cotopaxi. The modern conical volcano has been constructed since a major edifice collapse sometime prior to about 5000 years ago. Post 1800 eruptions include: 32 episodes in the 1800s, then in 1903-1904, 1905, 1906, 1907, 1908-1914, 1922, 1926, 1931, 1939, 1940 and 1942. The most violent historical eruptions took place in 1744, 1768, and 1877. Pyroclastic flows descended all sides of the volcano in 1877, and lahars travelled more than 100 km into the Pacific Ocean and western Amazon basin. Lahars have destroyed Latacunga on the western ring-plain twice in recorded history. Cotopaxi is in an uncharacteristic period of quiet since the 1940s. It poses a loss-of-life hazard in lahars and possibly pyroclastic flows to the suburbs and rural areas around Quito, and these may disrupt lifelines to Quito itself (especially roads and water supply lines). Pyroclastic flows (often confused in historical accounts with lava flows) have accompanied many explosive eruptions of Cotopaxi, and lahars have frequently devastated adjacent valleys.

- **Guagua Pichincha:** Together with the older Pleistocene Rucu Pichincha stratovolcanoes Guagua Pichincha forms a broad volcanic massif that rises immediately to the west of Quito. The central vent lies within a 6 km-wide slope failure of Guagua Pichincha, which occurred 50,000 years ago. It produces explosive activity with pyroclastic flows accompanied by periodic growth and destruction of the central lava dome. Post 1800 eruptions: 1930, 1931, 1968, 1939, 1981, 1982, 1985, 1990, 1993, 1997 and 1998-2001, with a further possible phreatic (steam only) eruption in 2003. In 1999 ash affected Quito and rural areas. Varying winds with different directions at different elevations, and eruption over 2-3 days complicated preparation and response in Quito. This volcanic episode continued until 2001, but did not drop any further significant ash falls on Quito.

- **Reventador:** This is the most frequently active of a chain of Ecuadorian volcanoes well east of the principal volcanic axis. The forested stratovolcano rises to 3562 m above the remote jungles of the western Amazon basin. A 4-km-wide edifice collapse is partially filled by a young, un-vegetated stratovolcano that rises about 1,300 m above the collapse floor to a height above the collapse rim. Post 1800 eruptions include: 1843, 1844, 1856, 1871, 1894, 1898-1906, 1912, 1926, 1929, 1936, 1944, 1955, 1958, 1960, 1972 1973, 1976, and 2002-2003. Reventador lies in the remote jungle about 90 km east of Quito. In November of 2002 ash affected rural areas and Quito; the ash was tan coloured and very fine grained (silty), and deposited 2 to 5 mm-thick in Quito.

- **Tungurahua:** A steep-sided stratovolcano that towers 3 km above its northern base.

Post 1800 eruptions include: 1857, 1885, 1886-1888, 1900, 1916-1925, 1944 and 1999-present from summit crater including strong explosions (sometimes sudden and violent) and sometimes lava flows, lahars and pyroclastic flows reaching popular tourist areas at the base. The eruption from 1999 to present periodically affects Baños and rural areas with ash. There is a potential for lahars and pyroclastic flows in many catchments, including through western Baños township.

2.3 Overview of case study settlements

This section presents a brief overview of the three case study settlements (Quito, Latacunga and Baños) and the rural area surrounding them, all of which were visited as part of this project. Details of the settlements are summarised Wikipedia (2005) and discussion with local civil defence personnel.

2.3.1 Quito

Quito is the capital city of Ecuador in northwestern South America. It is located in northern Ecuador in the Guayllabamba river basin on the eastern slopes of the Guagua Pichincha (about 20 km from the summit) an active stratovolcano in the Andes mountains. At 2850 m above sea level at the Plaza de la Independencia, Quito is the second highest capital city in the world. The population of Quito, according to the most recent census (2001), was 1,399,378. In 2005, however, the estimated population was 1,865,541, an increase of nearly half a million. The area of Quito is approximately 290 km², and is located about 22 miles south of the equator. Due to its altitude and location, the climate in Quito is mild to cool, fairly constant all year round. There are only two seasons in Quito, summer (the dry season) and winter (the rainy season).

All of Quito city can expect ash fall from neighbouring volcanoes from time to time. As mentioned above, the 1999 eruption of Guagua Pichincha and 2002 eruption of Reventador have most recently supplied millimetre-thicknesses of ash to the whole of Quito city (Figure 3). The “valley” suburbs to the south, home to at least 0.2 million people, are also subject to lahar hazards from Cotopaxi volcano.

The reconnaissance team focussed on the infrastructure impacts of ash fall (discussed in Section 3) and urban volcanic hazard civil defence emergency management issues (discussed in Section 5) within Quito.

Figure 3 **Two volcanoes close to Quito have been active in the last 200 years. Above: Cotopaxi viewed southeast over Quito's southern 'valley' district; below left: Guagua Pichincha viewed east over Quito's airport. Quito sits directly at the base of the latter volcano (left-hand photos from wikipedia.org); below right: Guagua Pichincha erupting in 1999, viewed to the west over the suburbs of Quito (Photo courtesy of IGEPN).**

2.3.2 Latacunga

Latacunga is the capital city of the Cotopaxi Province, 89 km south of Quito, near the confluence of the Alaques and Cutuchi rivers to form the Patate. The population of Latacunga is about 50,000, largely mestizo (mixed Spanish origin) and indigenous.

Latacunga is an hour and half south from Quito on the Pan-American Highway. It is 2,760 m above sea level, and its climate is often relatively cold and windy, owing to the neighbouring snow-clad heights, and barren, pumice-covered tableland on which it stands. The active volcano Cotopaxi is only 25 km away, and the town has suffered repeatedly from eruptions. Founded in 1534, it was destroyed four times by earthquakes between 1698 and 1798. The neighbouring ruins of an older native town are said to date from the Incas.

Latacunga’s economy is dependent on agriculture, and floriculture. It has an international airport that is used as an Air Force base and for some special commercial flights. The presence of volcanic activity has led to the accumulation of pumice deposits which are currently mined, as well as the presence of natural sparkling water, which is bottled under the brand name San Felipe.

Latacunga lies within the range of significant (centimetres) ash fall from Cotopaxi and Tungurahua, as well as more distal fall from other central Ecuadorian volcanoes. The city is built across the river Patate, which is a direct lahar path from Cotopaxi (Fig. 4). A large proportion of the city is within the area of historic lahars.

Figure 4 **Civil Defence lahar hazard map of Latacunga, showing the high and moderate lahar danger zones (orange and yellow, respectively) over the street layout; much of the city is at risk.**

2.3.3 Baños

Baños de Agua Santa (Spanish for Baths of Holy Water) is a town in the province of Tungurahua, in central Ecuador. Baños is the second most populous town in Tungurahua, after Ambato, and a major tourist center. It is known as the "Gateway to the Amazon", as it is located on the Pastaza River in the Amazon River Basin.

Baños is sited on the northern foothills of the Tungurahua volcano. It is named after the hydrothermal springs of mineral water located around the city. The city is also a Roman Catholic religious centre, as some Catholics believe that the Virgin Mary appeared nearby at a local waterfall.

Baños lies on a terrace of pyroclastic flow and lahar deposits formed from Tungurahua eruptions (Fig. 5), with additional lahar material contributed from Cotopaxi volcano. The western part of the town lies within a valley in a steep catchment feeding pyroclastic flows and lahars directly from the summit of Tungurahua. Pyroclastic flows travelling down this valley could easily spread out to engulf most or all of the town. Lahars from this valley may also affect an area of the town more significant than the valley area itself. Baños has in total received centimetres of ash from the 1999 to present eruption of Tungurahua, and continues to get dustings as often as weekly. Local doctors have anecdotally reported greater than normal incidences of some cancer types in the town, up to four times the expected rate, but the cause has not been determined.

Figure 5 Above: the path of lahar and pyroclastic flows from Tungurahua summit (in cloud) that could potentially devastate western Baños (foreground and out of frame to left) at some future time.. Right: Tungurahua erupting in 2003, as seen from the slopes of the volcano. The town of Baños lies at the northern edge of these slopes. (Photo IGEPN)

2.3.4 Rural areas

There are about 500,000 people in lahar-affected areas in the central highlands of Ecuador. Most of these people live in small rural communities or on isolated farms, many of which are in the catchments of Cotopaxi and Tungurahua. Since the onset of the 1999 Tungurahua eruption there have been widespread agricultural effects from ash fall, and some disruption of transportation due to lahars. Many of these communities are at high risk from future larger lahars and pyroclastic flows, as have previously occurred from both volcanoes.

2.4 Volcano monitoring and warnings

The Geophysical Institute Escuela Politécnica Nacional Apartado (IGEPN) is Ecuador's official agency in charge of volcano monitoring. The Institute is government funded with additional support from foreign aid and research agencies. It resides within the Escuela Politecnica Del Ecuador, a university in Quito.

Monitoring involves the use of seismographs, pressure sensors, ground deformation, geochemical, thermal and visual data (Fig. 6). They also have direct international contacts to warn and receive warnings of ash fall from eruptions in neighbouring countries. For example, Peru contacted IGEPN in Quito directly in the last Gallarez eruption (2004).

Figure 6 Computer and smoker-drum monitoring and recording of radio-telemetered seismograph data at Instituto Geofisico in Quito. Earthquake locations are calculated here and Civil Defence is alerted to those indicating eruptions. Staff and students are rostered to provide a constant monitoring presence.

Seismograph data is telemetered in near-real-time via radio to Quito, and in the case of Tungurahua, also to the IGEPN's local observatory, just off the northern flanks of the volcano. Earthquake locations are fixed on computer by staff and graduate students rostered as round-the-clock staff at the Quito office. Seismograph data, as well as being stored on computer, is plotted on smoker drums as it arrives, for easy visual monitoring of earthquake activity.

Regular geochemical measurements are taken by hand from fumaroles, and atmospheric SO_2 is monitored by remote-sensing using COSPEC equipment on a fixed-wing aircraft. The aircraft is also used for visual observations when visibility is good. Staff at the Tungurahua observatory visually monitor its summit, and private oil production and exploration personnel also provide visual information to IGEPN on the remote jungle-situated Reventador volcano.

Satellite thermal imagery is used to monitor broad heat flux, and near-real-time telemetry of this data is being trialled at the Quito IGEPN office.

Information on eruptions, and predictions of possible future eruptions, is transferred directly from IGEPN to Civil Defence, airport, water, electricity and security authorities. Ash fall warnings are given when possible, but changing wind directions, or different wind directions at different heights as experienced during the Guagua Pichincha eruption in 1999, can make such forecasting difficult. Warning sirens are installed in neighbourhoods around Quito, and can be triggered by Civil Defence to alert of ash fall.

In November 2001 Cotopaxi produced three months of elevated seismic activity, but there was no eruption. At the time of this visit in 2004, five staff and sixteen students were involved with monitoring and studying Cotopaxi to understand the implications of such swarms.

2.4.1 Reventador eruption in 2002 – an example of monitoring procedure

Seismic activity began eight hours before the 2002 eruption of Reventador (starting on the 3rd November). There is one seismic station in the caldera, but because of the remote jungle location the next station is many kilometres away. Although there are always two people on duty they may be students rather than expert staff, and thus less experienced at recognising eruption precursors. The seismic activity started at 2am, but three key senior people were unavailable because it was a public holiday in the region. An initial magnitude 4.1 earthquake could not be triangulated because of a lack of stations, and duty scientists did not recognise the tremor until 6am. At that point they were able to detect tremor on the seismic record back to 2am. At 9am a pyroclastic flow travelled 9 km from the vent, and the pyroclastic eruption it formed from was detected in the telemetered seismograph data. (Marco Rivera pers comm., 2004)

Despite a delay in recognising the tremor, once an eruption had been detected warnings were issued at around 10am. Meteorologically based ash-fall forecasts were released by IGEPN and reportedly matched real distribution acceptably well.

3.0 INFRASTRUCTURE IMPACTS AND RESPONSES TO ASH FALLS IN QUITO

One of the principal aims of the visit to Quito was to determine how infrastructure was affected by ash falls of 1999 and 2002, and what adaptations have been made to this infrastructure to minimise future impacts. Infrastructure components include water supply and treatment facilities, electrical, buildings, transport, communications and information technology. In addition information was sought on ash disposal methods and their costs, as well as emergency management structure, procedures and facilities. The findings presented in this section result from many useful discussions with city officials directly involved in management of ash disposal, as well as contact with scientists, water and airport company employees, and our own observations during the week in Quito.

3.1 Wastewater

Much of the ash that fell in urban areas in both eruptions was prevented from entering storm water drainage systems, partly due to rapid clean-up by residents and the military, but also because of light rain that stabilised the ash rather than washing it into drains. Those drains that were blocked were cleaned using high pressure water and brooms (where access permitted). No damage was reported to pumps, but increased maintenance was required. There were a few barrios (street blocks) where enough ash moved into storm water systems to cause localised flooding after the eruption (PAHO, 2003). Local calculations suggest that about 300,000 tonnes of ash was shovelled from drains in Quito after the 2002 Reventador eruption (Fig. 7).

Figure 7 Streets are swept by hand in Quito, and ash enters storm water drains causing some blockage, but no damage to storm water pumps has been recorded. Ash is removed by trucks, so only a small proportion enters drains.

Quito did not treat its sewage as of 2004 (EMAAP, pers comm., 2004). The region of Oyacachi, 45 km from Reventador, was reported by PAHO (2003) to have suffered some damage to its sewage treatment plant. Pipes in the oxidation lagoon were obstructed by ash, and the oxidation process failed, resulting in a strong smell being emitted from the lagoon (PAHO, 2003).

3.2 Water supply

Water supplies in Quito are controlled and maintained by EMAAP, (Empresa Metropolitana de Alcantarillado y Agua Potable). Water is treated using chemical separation, polyelectrolytes, flocculation (Al_2SO_4) and is filtered by sand and anthracite. Many water treatment plants in Quito have had covers built over them specifically to protect them from volcanic ash fall, others were reported to be successfully covered with plastic tarpaulins immediately prior to ash fall. Ash did enter the water supply (pre-treatment facilities) during the 1999 Guagua Pichincha eruption. The ash had a pH of 5.5, lowering the pH of the water and making it less potable; to compensate for this $Ca(OH)_2$ was added. No other treatment was required to maintain potable water standards. Physical (turbidity, colour), chemical (pH/alkalinity) and bacterial analyses were performed frequently (every two hours) to ensure water supplies remained potable (PAHO, 2003).

The increased sediment load caused by the ash entrained in the water supply necessitated more frequent cleaning of treatment plant filters. Rather than 8 to 10 hour intervals, cleaning took place at intervals between 1 and 6 hours. The frequency was determined by the quantity of suspended ash and thus the rate of accumulation. Flocculation takes longer with greater sediment load, but water supply rate limitations can be overcome by increasing the amount of flocculent used. To ensure demand is met extra flocculent should be stockpiled.

Water supply lines from dams to the east of Quito (93-94% of the city's supply) are likely to be broken by future lahars from Cotopaxi volcano. Work on bridging channels with the pipes is currently under way at a local university. Quito water supply had only a 10-hour storage capacity in 1998. Centimetre to decimetre thicknesses of ash would probably create too much turbidity to be flocculated. A delay while this settled in reservoirs would be necessary. These thicknesses might occur in a Cotopaxi eruption affecting the dams in its catchment. These supply about 30% of Quito's water supply, but EMAAP feel this could be replaced by groundwater supply options in the short term.

An EMAAP public information campaign asks the population to sweep ash away, rather than washing it away, in order to conserve water. At times in previous eruptions, water supply has been diverted around the treatment plants to meet demand and protect the plants from suspended ash. Public education was needed to advise that the untreated water was not potable. There had been a cholera epidemic in Quito in 1991-92 so the practice of boiling water was familiar and well executed. EMAAP staff noted that crises build resilience and personal stockpiling; Quito suffered water shortages in 1990s and as a result approximately 50% of households have a backup water supply on their property. The plant and distribution network is sectorised and interconnected, providing redundancy if some areas and/or plants fail.

Some other regions outside Quito reported a range of water supply disruptions, including ash contamination (turbidity and pH), loss of water supply due to electricity supply/transmission failure, and direct physical impacts to treatment plants (PAHO, 2003).

3.3 Communications networks

Physical impacts of ash on telephone networks were not observed. However the increased usage of telephones by the inhabitants of the Quito area during the 2002 Reventador eruption caused the exchange to overload, temporarily cutting communications which rely on telephone lines (Marco Rivera, pers. comm., 2004).

3.4 Electricity supply

Electrical flashover, leading to temporary loss of electricity supply, was caused by damp ash accumulating on insulators and transformers during the 2002 Reventador eruption. The ash was dampened by the high humidity rather than rainfall. Rain on the following day was sufficient to wash the ash off electrical supply equipment. This was the only type of damage to electrical supply systems recorded in Quito (Marco Rivera, pers. comm., 2004), and elsewhere in the central highlands (PAHO, 2003).

There is a substantial hydro-electric generation dam downstream of Baños, which is in the path of lahars from both Tungurahua and Cotopaxi. They have had no known turbine blade damage from ash fall because it is diluted in river water. However, civil defence personnel expect that this dam will fail under future lahar impact, placing at risk roading and communities downstream of the dam (Marco Rivera, pers. comm., 2004).

3.5 Transport networks / roads

Many residents in the Quito area remained indoors during the ash fall from the Reventador eruption (Marco Rivera, pers. comm., 2004). Following the ash fall, vehicle circulation in Quito was reported (on the 4^{th} of November) to have been banned, except for emergencies (PAHO/WHO, 2002). As ash fall is not an uncommon occurrence in Quito, residents are familiar with many of the traffic hazards associated with volcanic ash, which includes reduced visibility due to ash billowing from tyres. While ash created a slippery surface on the roads, most drivers exercised caution. Another reported road hazard from ash fall is obscured road markings (Fig. 8).

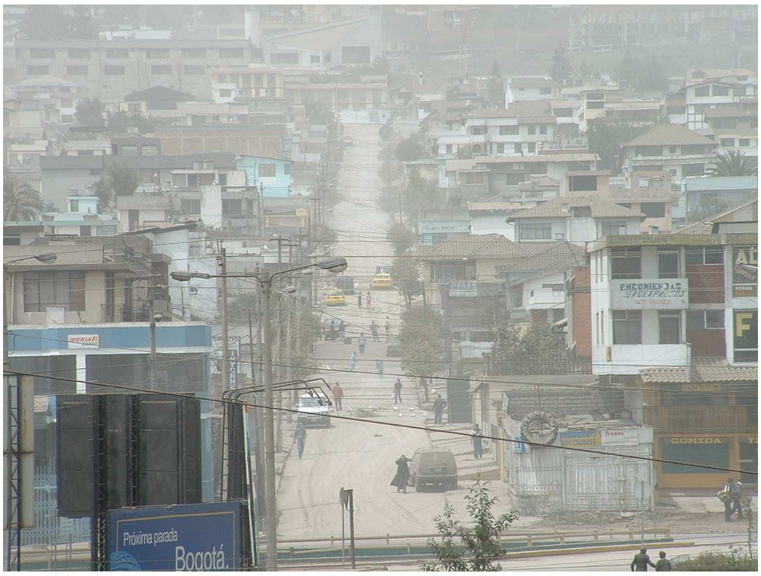

Figure 8 **Road markings were obscured by ash fall from Reventador in 2002 throughout Quito. Buildings and properties were cleaned and ash shovelled into bags placed in the streets for pickup by city trucks (Photo courtesy of Quito airport).**

3.6 Airport / Air Traffic

Quito's international airport (Aeropuerto Internacional Mariscal Sucre) is the main airport for Ecuador. Approximately 25 international and 50 domestic flights operate daily through this airport, in addition to cargo, military and private flights.

The airport was subjected to ash fall from recent eruptions of both Guagua Pichincha (during October to December 1999) and Reventador (in November 2002) (Fig. 9). On three occasions the airport has been forced to close for 7 to 10 days in order to clean ash from the runways, airport infrastructure and aircraft grounded on site during the eruptions.

During the Guagua Pichincha eruption in 1999, 2 to 3mm of ash was twice deposited on Quito airport; the 2002 Reventador eruption resulted in a 4mm covering of ash. In all cases grounded aircraft were covered by ash (Fig. 10). In 2002, the airport was given 5 hours of warning (9am warning from IGEPN), but no mitigation was initiated at that time. The airport was closed one hour before ash began to fall. Rapid response was required to protect vulnerable parts of the aircraft parked on the taxiways and aprons of the airport. Aircraft nose-cones and windshields were covered by tarpaulins. Landing gear, engines and pitot tubes were also covered (all plane baggage compartments contain engine covers). Wings were not covered, but all flaps/spoilers etc. were fully closed/retracted.

Figure 9 **Two to four millimetres of ash has fallen on Quito airport twice in the last 6 years**

Figure 10 **Average jet airliners were able to be cleaned by high-pressure water blasting from standard fire appliances in 10 to 15 minutes. No water ingress was detected, and no leachate or abrasion damage was noted. Aircraft maintenance experts were on hand to monitor effects. Note the covering of engines and nose cone prior to ash fall.**

Ash adhered to the aircraft, but was dry enough to be removed by a person blowing on it. The ash remained on the aircraft from 12 to 48 hours, depending on when crews cleaned each aeroplane. Aircraft were moved with tow vehicles rather than starting jet engines or auxiliary power units in the presence of ash. Cleaning was performed using high pressure water from an airport fire truck, and flaps were kept fully retracted during this process. This only took around 10 to 15 minutes for a medium sized passenger aircraft (e.g. a Boeing 737). After cleaning, full service checks were preformed on each of the aircraft to ascertain whether any damage had been sustained. No abrasion was seen to have occurred when the ash was washed off with the fire hoses. Similarly, no ingress of ash to the interior of wings etc. was observed. No corrosion was noted, though this was unlikely anyway as the ash remained dry while on the aircraft. The tarpaulins (secured by adhesive tape) were successful in protecting the vulnerable parts of the aircraft. An Airbus representative from Miami flew in to oversee the cleaning and assess any ash damage. Authorities stated that they did not need to open up the engines for inspection, but full 'service inspections' were conducted.

Cleaning of airport buildings and other infrastructure was performed manually with brooms and shovels. The maximum of 4mm of ash that fell on the airport during both the 1999 Guagua Pichincha and 2002 Reventador eruptions was not sufficient to cause structural damage to buildings. Air-conditioning units were not installed at the airport at this time. Airport infrastructure proved to be robust enough to survive the ash fall undamaged. While ash blocked storm-water systems in some parts of the city in 2002, this problem was not significant at the airport – not enough rain fell at the airport in the hours and days after the eruption to cause blockage.

Cleaning the runways and aprons was the most time-consuming task related to the ash fall. The runway at Quito's Mariscal Sucre airport is approximately 3100m long by 46m wide. The taxiway is of similar dimensions. This gives a ground area of over 285,000m^2 to clean. In each eruptive case (once in 1999 and twice in 2002), 500 labourers with brooms performed the runway cleanup, in the absence of available machinery (Figures 11 and 12). In some cases workers were provided with masks, however, most provided their own protection. Ash on the green areas around the runways was sprayed with water from a water tanker to prevent it from being remobilised onto the swept areas. A coagulation chemical supplied by Continental Airlines and sprayed with trucks was reportedly used to stabilise ash in these green areas. The on-tarmac ash being swept was only slightly dampened (with tankers every 30 minutes), as wet ash was found to become sticky and thus more difficult to clean up. The time taken to clean the runway and taxiway was at least 7 days in each eruptive case, for 500 men working 15 hours per day (i.e. the daylight hours). This equates to 52500 hours spent sweeping and bagging ash. On average each worker could thus clean around 5.4m^2 per hour, including the time taken to bag ash and load it onto a truck to be taken away.

After the ash fall in 1999, sweeper trucks were bought by the Ecuadorian equivalent of Civil Aviation (DAC). In 2002 part of the airport was transferred to the city to manage and unfortunately the trucks were unable to be used in the 2002 ash falls for political reasons, so they have not been tested.

Figure 11 Five hundred workers took at least seven days to clear the runways with brooms, working for 15-hour shifts.

Figure 12 Ash was bagged in place then removed by truck.

These interruptions to normal service caused a significant loss of income for both the airport and for carriers, especially local airlines. The clean-up itself was comparatively cheap; in Ecuador labourers were hired cheaply (probably US75 to US100 cents per hour; thus less than about US$50,000 in total).

The national airline in Ecuador (TAME) was particularly affected by the 2002 Reventador eruption. Seven aircraft were trapped on the ground for the duration of the eruption and clean-up. These represented a large proportion of the airline's total fleet of 11. While advanced warning times may have given the airline company more time to move the aircraft, this would also depend on the availability of pilots to fly the planes.

In terms of air traffic control, and the decision to close the airport, Ecuador's Dirección General de Aviación Civil (DAC) is the decision-maker. This body is in communication with IGEPN and the Ecuadorian meteorological service. IGEPN also communicates directly with Volcanic Ash Advisory Centre (VAAC) in Washington (the local centre), which communicates internationally. IGEPN staff noted that the decision-making process was not well established, with some convincing required to get the airport closed. In terms of risk management, it should be noted that while international carriers can cope relatively easily with one airport closure, local carriers are more interested in keeping airports open, to a higher risk threshold, given the larger proportion of their fleets potentially grounded.

3.7 Vehicles

Vehicles were not greatly affected by the eruptions in terms of damage. Quito's water supply company EMAAP, as well as local taxi drivers, reported that some of their vehicles had problems with fuel injectors and carburettors as small amounts of ash managed to get through the air filter. These problems were easily rectified with regular maintenance of vehicles. This included regular filter changes and tuning. Windscreens were often scratched by wiper blades used to remove ash. One of the reconnaissance team's taxi drivers reported abrasion to his windscreen and he had to change his air filter sooner than if there had been no ash fall.

3.8 Domestic cleanup

Domestic cleanup in Quito is reported to have been fast and efficient, with better performance in 2002 given the experience of the 1999 ash fall. Barrio (block) volunteer workers/leaders helped those within their area who had physical difficulty, most commonly due to old age. Roofs (Fig. 13) were swept first, followed by property clean-up. Injuries due to falling from roofs were reported in local media, including one or two deaths which generated concern among authorities, but were reportedly tolerated as understandable among the populace (City Security pers comm., 2004).

Cleanup was made easy in both 1999 and 2002 by the discrete nature of the two ash falls. Ongoing and/or repeated ash fall over days, weeks or even months makes deciding when to clean much harder. For example, in Baños, ash fall has occurred daily or weekly in multiple discrete periods of up to months over the time since eruptive activity resumed in 1999. The initially-evacuated town accumulated ash from multiple events with no, or patchy (clandestine), cleaning. In this case the total ash was not enough to create structural failure, but failure could have occurred if ash was left to build up to thicker depths. Cumulative ash build-up (which is not removed) should be considered in planning for areas likely to experience long-term evacuations.

Figure 13 Ash covered roofs in Quito

3.9 Disposal of ash

During the incidents discussed, ash was swept up and shovelled into plastic bags for collection along with normal rubbish. Experience of this practice in 1999 led residents to take the same action in 2002 without new prompting or public education. Collected ash has been disposed of in the same way as domestic rubbish, in landfills. This was partly advantageous in 2002 as a large landfill was full and ready to be covered, so the ash provided a suitable cover material.

It was unclear how carefully prepared or sealed these landfills are, and given the lack of sewage treatment in Quito, little expense may be taken here. In contrast, carefully located and expensively prepared landfill space is valuable and in finite supply, and would not likely be used for ash disposal (except possibly as cover burden if timing permitted, as in 2002).

4.0 AGRICULTURAL IMPACTS

This section is summarised from discussions with AGSO staff, Civil Defence staff and farmers in Baños. AGSO noted that they have fresh ash samples which can be supplied if needed for analysis or experiments. AGSO has had a farmer near Tungurahua regularly measuring ash depth over the last two years.

Impacts of ash fall on agriculture were comparatively low from the Reventador and Guagua Pichincha eruptions, due to the locations of those volcanoes. More serious are the effects of ongoing activity from Tungurahua Volcano, in southern Ecuador. This volcano is surrounded by agricultural land and constantly remains at a high level of activity (see Section 2.2). Locally grown crops include maize, abas (beans), potatoes, and onions, which constitute about 80% of the crops around Tungurahua, as well as citrus fruit, avocadoes, bananas and sugar cane. Ornamental crops (flowers) such as peregrina are also widely grown. Cattle are the most common livestock animal farmed (90% of stock), mainly for dairying, although there are also a large number of intensive chicken farms.

Due to the equatorial location of Ecuador ('Ecuador' means 'equator' in English), there is no particular growing season for crops. Plants are harvested when mature, which is dictated by the time they are planted. This occurs at any time of the year, therefore, when an eruption occurs there will be crops at various stages of maturity. Ash impacts vary with the age of some crops (see below) and thus agricultural impacts in New Zealand could vary markedly depending on the season(s) over which an eruption takes place. Most farms are small-holdings – an estimate by the AGSO staff puts 80 to 90% of farms at less than 10 hectares.

The small size of the farms makes the communities reliant on them more vulnerable to ash fall. The farms provide little income surplus to basic living requirements even in years when no ash fall affects the farmland. Produce is sold locally, so ash fall affecting the local economy results in everyone having less money – especially during population evacuations. Following disruption to normal community life, business customers have less money to buy any produce that the farmers manage to salvage. Meat buyers have offered to buy large numbers of stock in ash-affected areas, but at greatly reduced prices (1/2 of value or less for chickens in Baños). Banks are also reluctant to lend money to small land-owners in ash-affected areas due to the increased risk, preferring to provide (often in small amounts) food aid. The ash falls reportedly 'broke' some local banks in the Tungurahua area and farmers could not easily get their savings back – some that stayed open could only give 20-30% of clients' savings back per year.

Impacts of ash fall have been severe for some local farmers over the last 3 – 4 years. Actual effects depend not only on the amount, composition and temperature of the ash, but on the type of farming (dairy vs. cropping) and on the type and maturity of the plants. Local effects can also vary significantly due to wind direction and local topography. Farms separated by only a kilometre may experience quite different depths of ash.

Though locally acute, these impacts are not severe for the nation as a whole, constituting a relatively small portion of the national milk and cropping production.

AGSO have set up a call centre to provide advice, but only about 3 % of the affected population use it. During eruptions AGSO uses military and city trucks to disseminate food aid, dropping 15 days worth of food for four people to each farm visited.

4.1 Livestock

There was a severe lack of information on ash impacts and the ongoing eruption upon which to base decision-making within the agricultural sector, particularly impacting dairying. This was also experienced in New Zealand during the initial phases of the 1995/96 Ruapehu eruptions and has led the Ministry of Agriculture and Forestry to provide specific advice to the agricultural sector in New Zealand (Neild et al., 1998).

Ash covering pastures results in livestock (generally cattle) ingesting ash with their feed. Moving stock is not a viable option for most of the local farmers because there is either nowhere to go, no trust in the offered destinations or the distance is too far without any trucks. They will usually remain with their stock, endeavouring to feed them as best they can. Consequently the teeth of livestock are worn down as ash is masticated along with feed. Because less feed is available, cattle lose weight, and may begin to starve. Malnourishment, combined with the ingestion of ash, can lead to death; it has done so for 10 to 15% of cattle during and after recent eruptions (AGSO estimate). Around Tungurahua calves had a particularly high mortality rate and were found to have ash in the stomach and lungs.

People with small subsistence cattle farms have resisted evacuation of themselves and their herds, mostly through fear that they will lose animals or their livelihood. AGSO is therefore helping with the provision of information on protecting and cleaning their stock and pasture. In previous ash falls AGSO have supplied hay from other regions, but stockpiling is needed and it is best if done by farmers in affected areas. ‘Haylage’ bales (round sealed bales) are a useful form of feed to carry on potentially affected farms. AGSO have identified traditional farming methods as something of a barrier to change. Problems and solutions are not shared amongst farmers directly; AGSO have helped by transferring this knowledge amongst farmers themselves. If animals are to be moved, congregation areas with stocks of hay are needed, with animals clearly tagged to individual owners.

Roberto Castillio in Baños reported that pigs were ‘skeletons’ after only 12 days without food due to ash fall, and therefore unsaleable. Cows similarly lost weight, but apparently not as quickly.

4.2 Fish

A local fish farm in Baños has also experienced losses due to ash fall. Fine ash that floated on the surface of the water resembled food, and was ingested by the fish (carp and tilapia) causing digestive problems and the death of approximately 10%. The fish farm formed part of an agricultural farm, but the farmer decided to stop this operation after the deaths of the fish, given the frequency of ash fall in the region (Roberto Castillio pers comm., 2004).

4.3 Crops

Different crops react differently to ash. Plants with larger leaves tend to be affected more, as there is a larger surface area for the ash to accumulate on (Fig. 14). How exposed they are is also a factor, as wind and rain may wash ash off leaves. Leaves closer to the ground will usually be affected more by ash, as these are more sheltered from the wind, and any accumulation of ash therefore remains on the plant for longer. Similarly ash fall at night, when wind is less, tends to adhere to crops of all heights more. With deeper ash fall plants are likely to be killed outright. A local farmer reported that some agricultural areas adjacent to Tungurahua received up to ~20cm of ash (partly remobilised/wind blown ash) during volcanic activity in early 2004. These depths reportedly killed all crops, while a few centimetres or less of ash caused about 50% losses in and around Baños. Crops were quickly burned, reportedly by the 'heat' of the ash (although leachate burns can not be ruled out), with some farms losing 100% of their crops. Even farms with superficial depths of ash lost ~5% of crops due to hot ash burning foliage (Roberto Castillio pers comm., 2004).

Volcán • La turística ciudad se libró de la lluvia de ceniza, a diferencia de otras poblaciones de la zona

Baños, intacta al pie del Tungurahua

El plan de contingencia, a criterio del Alcalde está a punto. Sin embargo, desde hace 14 meses la efectividad del mismo no ha sido comprobada.

Redacciones Ambato y Manta

Desde que empezó el proceso eruptivo del volcán Tungurahua, en 1999, Baños encabezó l referente de este fenómeno naral. Es que sus atributos naturas y desarrollo logístico en el tuismo lo calificaban como tal.

Por ello, cuando fueron evacuaos sus 17 000 habitantes el sábao 16 de octubre del mismo año; l 90 por ciento de su población erdió su sustento: el turismo. Y os dos meses y medio que pasaron fuera, en calidad de evacuados, fueron considerados como la peor humillación. En la ciudad la dolarización se había puesto en marcha, antes que en otra urbe y ese estado influyó en toda su economía. Un baneño tenía un sueldo mayor que el promedio en la provincia y la región. El retorno por la fuerza era inevitable y entre finales de diciembre del 99 y el 5 de enero del 2000, los baneños lo hicieron, pese a la oposición mi-

Fotos: Carlos Campaña / EL COMERCIO

UNA LABOR DE HORMIGAS • El despacho de las raciones alimenticias sufre atrasos en los centros comunitarios. Pero además muchos damnificados nunca las reciben.

Figure 14 Crop damage in 1999 in Baños from Tungurahua volcano

Corn stands in rural areas east of Quito were crushed and ruined by centimetres of ash that fell in 2002 from the Reventador eruption. Flowers are a major crop in tropical Ecuador, and despite being covered and not directly contacted by ash, they were crushed by centimetres of ash on the covers.

Cooler ash may not always kill plants as quickly as hot ash, but the end results have been equally disastrous for farmers. Acid burns on leaves and fruit have commonly killed or sickened plants in the region, and near Baños many citrus trees are still growing very small fruit following the 1999 ash falls. Burial of plants and/or stripping or weighing down of leaves is common. Younger plants (e.g. maize) are often killed before more mature plants, however even more robust mature plants have been commercially ruined by the covering of ash, as it is uneconomic to clean the produce (Roberto Castillo pers comm., 2004).

Irregular ongoing eruptions have a greater cumulative effect than a single isolated fall. Light dustings of ash in 2004 were still damaging leaves (Fig. 15). Farmers sometimes face several cycles of ash fall – plant loss – new plantings – ash fall – plant loss and so on. This may lead to eventual economic failure of a farm which might have coped with a single ash fall and crop loss.

Figure 15 Crop damage in Baños in 2004 from occasional dustings of ash only

4.4 Soil fertility

Tungurahua is a very active volcano: degassing is almost constant and ash emissions occur several times each year. The local farming community are very aware of its destructive capability, but they are also aware of the long term benefits it can provide. While farms are still producing less than they were before the 1999 eruption (in some cases about 50%), based on previous experience, local expectations are that it will take 6 to 8 years for the land to return to fertility values equal to, and then likely exceeding, those prior to significant ash fall.

AGSO note that it is about three months after the ash fall that fields are usable and productive again. They have provided a programme of machinery ploughing aid, to turn ash-covered fields and restore productivity following ash falls.

5.0 VOLCANIC HAZARD EMERGENCY MANAGEMENT IN ECUADOR

5.1 Direccion Nacional de Defensa Civil (National Direction of Civil Defence)

Civil Defence (CD) in Ecuador (Defensa Civil in Spanish) is "…a permanent State Service to protect the community. It has to develop and coordinate all the measures destined to predict and to prevent disasters with any origin; to limit and to reduce the damage that such disasters could cause to people and goods; as well as to undertake in affected zones, the actions to allow the continuity of the administrative and functional regime in all orders of activity" (excerpt from http://www.defensacivil.gov.ec/). Civil Defence in Ecuador is organised on several levels (Fig. 16).

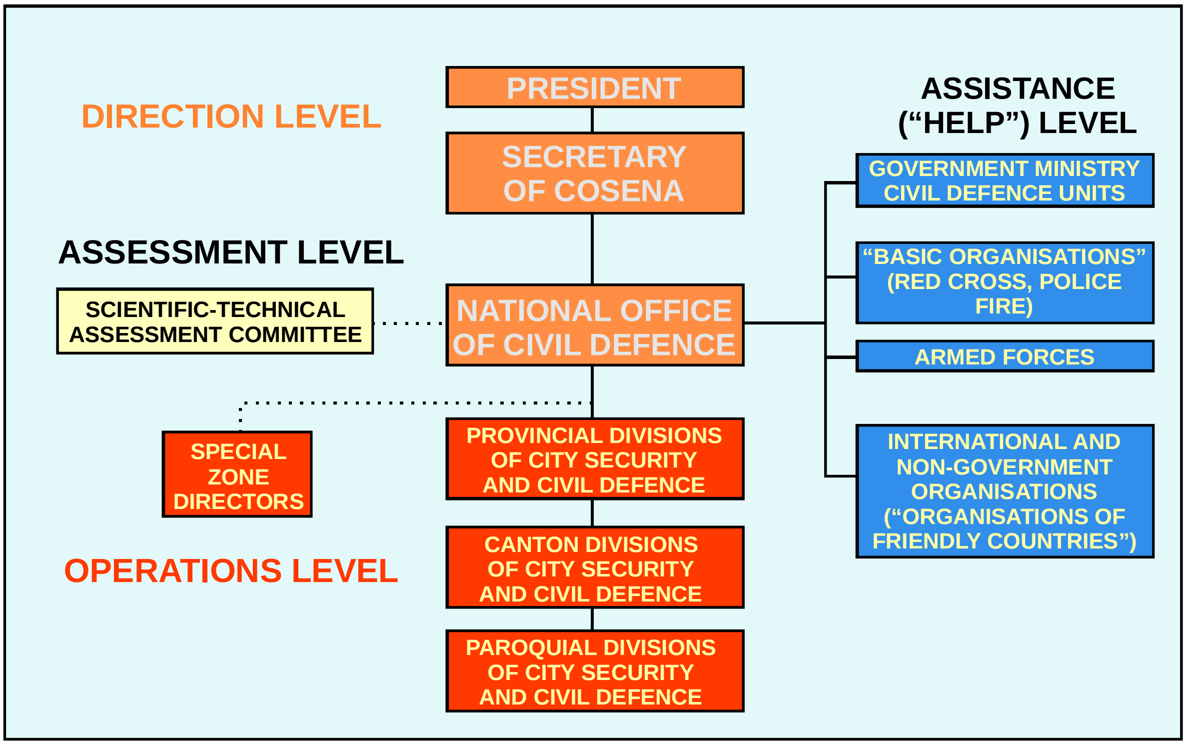

Figure 16 Civil Defence organisation in Ecuador (translated from original document)

The Mission of Civil Defence is to
"Develop and coordinate those actions that prevent and take care of disasters, originated from any event or cause, and assist in the rehabilitation of the affected community to re-establish normal conditions. These activities are developed through the National System of Civil Defence."

The National System of Civil Defence involves the joining of agencies and organisations of the public and private sectors, national, provincial and municipal, who oversee the integrated coordination, and execute permanent actions to protect the population and assets, before, during and after a disaster of natural or human origin.

The Direction Level is headed by the President of the Republic of Ecuador. The secretary of COSENA (a high-level officials' committee that is similar to the New Zealand Officials Committee for Domestic and External Security Co-ordination, ODESC, arrangement) is the next in charge, and the Director of Civil Defence sits below them (with the agency). Civil Defence is supported at the Assessment Level with a technical and scientific assessment committee; and at the Operations Level, which comprises the CD capacity at provincial, canton (national territorial subdivision), city and Special Zone level. The overall structure is also supported at the Assistance Level, comprising the Police, Red Cross, Fire Service, Armed Forces and international organisations.

The stated objectives of Civil Defence are to:

- Prevent and mitigate risks by reducing effects of adverse events.
- Provide adequate and sufficient help in a timely manner to the affected or threatened community.
- Work towards emergency rehabilitation of the community.
- Consult and instruct the people to contribute to individual and collective security.

Each level of CD outside the National Office has certain responsibilities and representatives. These are similar to those seen in the New Zealand Civil Defence and Emergency Management Group or Territorial Authority context, with the notable exception that representation from the Church (Roman Catholic) is always included in the city planning committees.

Civil Defence is organised in 22 provinces with representation in each one. Provinces work with City Security bodies (the part of local government responsible for all aspects of security, sanitation and safety in a city area).

5.1.1 National Plan

Civil Defence in Ecuador is described in the Ecuadorian National Civil Defence Plan. Areas of work are assigned to be undertaken by the authorities representing the different ministries of the province, canton, city, and all relevant institutions in the three phases of an emergency.

In each work area planning is undertaken in three phases: before (prevention, preparation, mitigation and alerts); during (response); after (rehabilitation and reconstruction).

Areas of work are as follows:

- *Evacuation and Emergency Shelters:* Lead agency - Ministry of Social Welfare, with relevant supporting agencies.
- *Health:* Lead agency - Ministry of Health with related agencies.
- *Food and Water:* Lead agency - Ministry of Agriculture and supporting agencies.

- *Engineering and Communications:* Lead agency - Ministry of Public Works with supporting agencies.
- *Public Information:* Lead agency - Press Secretary of the President of the Republic.
- *Economics and Finance:* Lead agency - Ministry of Finances.
- *Public Security:* Lead agency - Ministry of the Government.

Although various agencies are detailed in the plan as having a role in CD at a national level, it appears that in practice this is not how the operations are distributed. For example, although the Social Ministry does have a responsibility, as per the national plan, to plan for and conduct evacuations, it is actually CD who do all the work. From discussion with CD officials it appears that the issue is with the national government agencies who have been assigned roles in the plan: money allocated to this work (and provided from CD) is assigned to general funding programmes and is 'lost'. Civil Defence also indicates that it is very difficult to work with the other agencies in obtaining appropriate representation levels for meetings and planning committees (e.g. lower ranked 'representatives' who cannot make funding and resource commitments, are sent to meetings).

5.2 Public education, communications and development

In reality national CD is responsible for public education, communications and development. The CD organisations oversee various programmes for public education such as volcanic hazard, earthquake, flooding and landslide hazard and the risks associated with El Niño/storm. One of the key tasks of CD is to develop a census in risk zones so that the government can know how many people and assets are at risk.

Civil Defence programmes start with educating the government and responsible agencies (such as capacity building by working with police, fire, Red Cross, etc., which are all considered primary partners in response) and work down to the family level. Civil Defence is also involved with education facilities, helping them develop emergency plans.

At a family level CD works with risk maps and informs people regarding the 'where, what and how' of natural hazards. Where possible (there are marked resource constraints), CD conducts exercises and simulations with at-risk populations. The best-practice approach involves working with the community to help them build their own conclusions regarding their risks and required actions. Volunteers undertake most activities outside the main municipal areas.

Civil Defence also has a national responsibility for public communications. They have two major functions –

1. Production and diffusion of information and campaigns – radio, TV, etc. They also produce some educational documentaries.

2. Release of information during and after disasters – CD coordinates all national information and releases the official information.

5.2.1 Examples of Civil Defence public education

The public education material produced by CD Ecuador conforms to international best practice. CD produces an extensive range of material in a format most likely to be preferred, used and understood by the public. The printed material is all in colour and uses simple instructive and constructive images. The text is informative and varies in content and length depending on audience and size of publication. CD videos are also an excellent educational tool. The material, however, is only produced in Spanish. Although Spanish is the national language of the 14 million inhabitants, only 9.5 million are thought to speak Spanish, with many Ecuadorians speaking Quechua, the native language.

a. Manual de Autoproteccion

For the first time in 2004 CD produced a "Manual de Autoproteccion", a 'self protection manual' (Fig. 17). The manual is a small (15 x 10 cm), 180 page, colour-illustrated book, designed for ready reference. The manual is divided into two parts, disaster preparedness and first-aid. Disaster preparedness has four sections covering natural hazards, other hazards, preparedness on holiday and family/house plans. The natural hazards section describes protection measures for El Niño, earthquakes, volcanic eruptions, tsunami, floods, landslides and droughts, as well as describing alert levels and pre-disaster psychological reactions. Self protection for other hazards covers prevention and action measures for forest fires, pesticides, cholera, in the home (chemicals, gas, hot water, etc.), general fires and terrorism. The third section, holiday-specific safety, covers travel to remote areas, at the beach (sunburn, drowning etc.), camping, preparing your vehicle and securing your house.

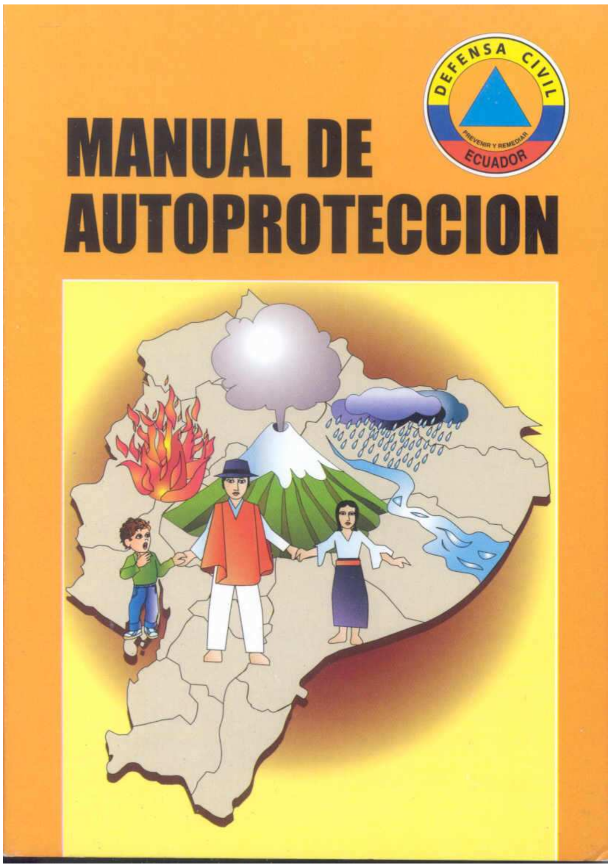

Figure 17 Cover of the Ecuador 'self protection' manual, produced for the first time in 2004.

The final section gives recommendations on family activities for emergency preparedness. At the end of this section is a quiz crossword on preparedness measures.

The second part of the manual provides first aid advice. This section covers: what is first aid, how to get help, preventative measures in the home and on the road, what should be in a medical kit, and what to do in case of accidents, burns, cuts, heart attacks, animal bites, etc.

b. Education Videos

Civil Defence has produced a number of short (10-15 minute) films to be shown at group meetings. There is a series of four films covering volcanic eruptions, earthquakes, landslides and floods. They each start by explaining to the audience why each phenomenon occurs and the areas of risk in Ecuador. The volcanic eruption film also covers the alert level system by describing the signs from the volcano and actions that should be taken at that alert level. The films then go on to illustrate what to do before, during and after an event. Community participation in CD activities is stressed for the preparation period. Preparing an emergency kit, storing water and planning and practicing family evacuations are also key themes. Keeping calm during an event, as well as other phenomena-specific information, like wearing breathing/eye protection in volcanic eruptions, is recommended. After an event, the main themes are to turn off electricity and gas, listen to the radio for more information and to go and help others.

Importantly, the videos show mostly images of local events and people. This is critical for people to be able to personalise the risk (Paton and Johnston, 2001). Where local examples of hazard phenomena are not available, international images are used so the audience can still get an idea of what the phenomena are like. Images of destruction and devastation are shown, but not dwelled upon. Rather, preventative and preparative measures are demonstrated being undertaken in a calm, everyday manner.

c. Brochures

There are five brochures produced by CD covering volcanic eruptions (Fig. 18), floods, forest fires and earthquakes (two brochures). Three are entitled “Let us learn to live with the threat of… an earthquake / a flood / an eruption” and the other two are “How to cope with a terremoto (destructive earthquake) / forest fire”. The brochures are colour A4 size, folded into three. Illustrations in the brochures are cartoons and depict emergency actions, equipment and scientific diagrams.

The three “Let us learn to live with…” brochures have a similar format and cover the same themes. Inside on the first third of the page, a simple definition of the phenomena and description of how/why these events occur is given. For earthquakes, the Richter and Modified Mercalli scales are also explained and for volcanic eruptions, the alert level system is described. The rest of the page explains ways to reduce the risk; firstly explaining the risk in Ecuador, what to do when the phenomenon occurs and other CD recommendations. The back page covers what to do when the danger has passed, emergency kit items to have at hand and other relevant instructions.

The “How to cope with…” pamphlets are much simpler, describing three things to do to be prepared for an earthquake, or for a forest fire, and three actions during and after an earthquake or fire, with cartoons illustrating each point. The back of the pamphlet gives a brief description of the phenomena, self-organisation and preparedness recommendations.

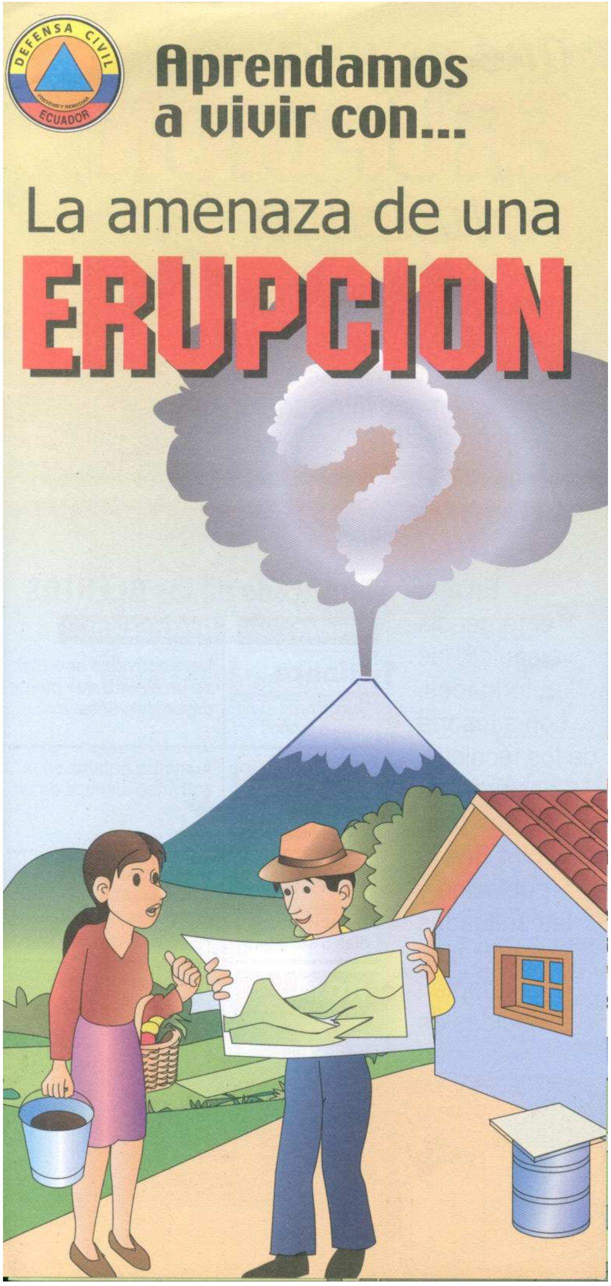

Figure 18 The ‘let us learn to live with the threat of an eruption’ brochure produced by Civil Defence

d. Booklets

Civil Defence also produces information booklets for dissemination to the public. Examples of these are “First Aid Advice”, “Let us face the effects of El Niño” and “My neighbour Cotopaxi” (Fig. 19). The brochures are colour, A5-size and 10-20 pages in length. The illustrations are simple cartoons showing people in action, maps and/or diagrams. The first aid booklet describes what to do for a number of conditions and accidents including electrocution, drowning, fever, sunburn, animal bites etc. The “El Niño” booklet is similar to the “How to cope with” brochures, in that it mainly gives advice on what to do before, during and after floods, landslides and storm surges. It also gives a brief explanation of what El Niño is, where its effects are most likely to be felt in Ecuador and what emergency items to have in case of these events.

The “My Neighbour Cotopaxi” booklet is much more detailed than the other booklets and volcanic eruption brochures, containing more text (~100 words per page) and fewer illustrations. Whole pages are devoted to what volcanoes are, the history of Cotopaxi, what will occur when Cotopaxi erupts, a detailed list of all the risk zones and districts within these zones, how to identify zones of risk and safety, how to reduce the risk, what to do when an eruption occurs, alert levels and knowing when to evacuate. Emergency kit items and CD contact details are also given.

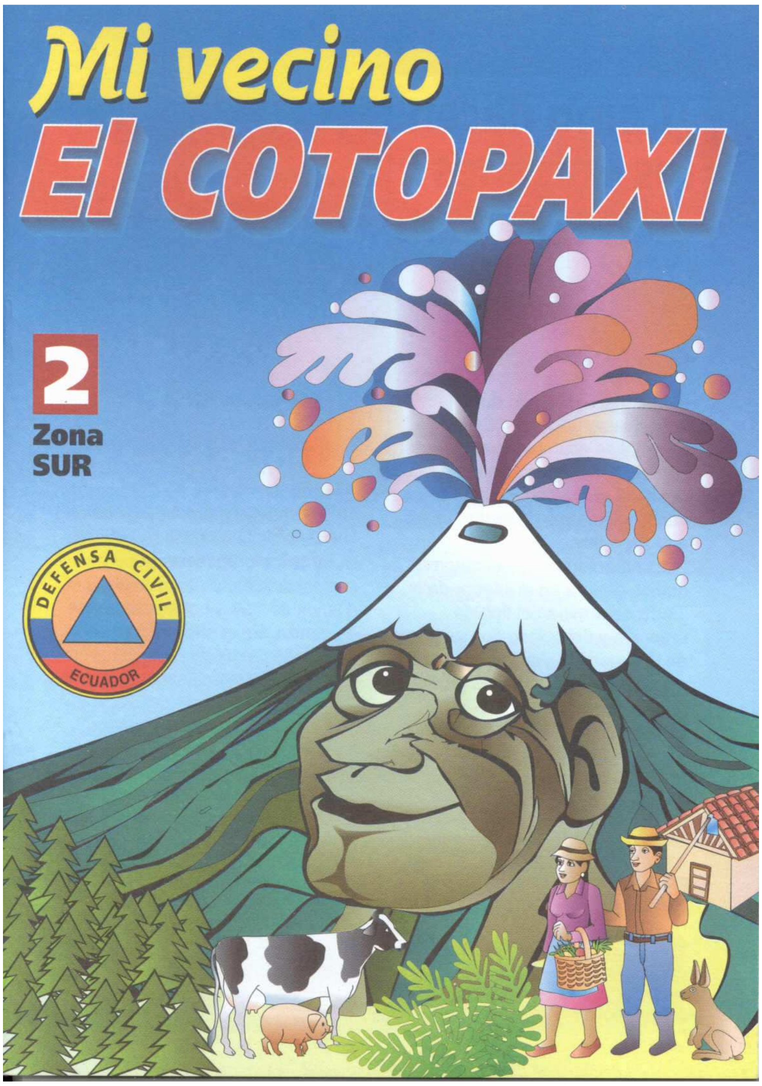

Figure 19 The information booklet ‘My neighbour Cotopaxi’ produced and disseminated to the public by Civil Defence.

e. Release of information

Civil Defence works with all districts to ensure all information is standardised and assists publishers to prepare newspaper articles/releases/bulletins. In emergencies CD is responsible for providing all the information needed (such as situation updates and sensible actions to take). However, there are a number of problems with this process, including a general lack of resources (insufficient quantities for wide distribution); a lack of preparation to distribute and coordinate information; a need for more work on who the target audience is, how information should be delivered and with what content; a need to increase competencies of people in the region; and problems with integrating actions of all agencies.

5.3 Local Capacity Examples

5.3.1 Projects around Cotopaxi Volcano: Northern Flank Zone

Over the past year, CD in the Valle de los Chillos administrative zone has been working closely with communities in San Rafael, educating them about the dangers of lahars from Cotopaxi and how to be prepared. San Rafael, a satellite city of Quito, is situated 45km north of Cotopaxi on the junction of the Rio San Pedro and Rio Pita. Lahars travelling down these rivers will take approximately 40-60 minutes to reach San Rafael from Cotopaxi's summit.

In September 2002 the Administrative Zone for Valle de los Chillos (AZVCH) initiated the development of a contingency plan for the region. Information for the plan was sourced from state documents, field investigations and maps. Documents used included the Political Constitution of Ecuador, Law of National Security and the National Plan to confront the potential eruptive process of Cotopaxi volcano. Field studies carried out by the Instituto Geofisico and Escuela Politecnica Del Ecuador located zones of risk on the margins of the rivers, establishing eight high-risk sectors in the AZVCH. They identified the at-risk and safe residential, educational, commercial, emergency services and utility areas. Plans of at-risk areas, safe areas, and evacuation routes have been produced, as well as a revised version of the hazard map by using city plans, census and topographic maps and the EPN 1988 Cotopaxi Volcano hazard map, along with the data from the field studies.

To get an idea of the number of people potentially needing to be evacuated and the type of people CD had to educate about lahar hazards, a census of the area was conducted in June 2003. Over 4000 people reside in the eight high-risk sectors, and of these 465 will require emergency shelter. More than half the population is female and 22% are either under 12 or over 60 years old. San Rafael is a growing middle to upper class area of Quito and therefore has a relatively high population in 'white collar' jobs such as lawyers, architects and especially engineers. Most of the population have always lived in the Pinchincha province and are likely to be aware of Cotopaxi and its hazards; but 29% are originally from other provinces and 5% come from outside of Ecuador.

Knowing the size of the population and having detailed maps of the area, it was then possible for CD to designate 26 evacuation shelters across the 8 sectors. Each shelter has to meet with international shelter standards which include solid construction, basic services, sanitary conditions, food and adequate room for population in need of shelter. Civil Defence keeps a database storing information on all the necessary parameters for each of the 26 shelters; these include location of the shelter and shelter representative contact details, structural observations (composition of floors, walls, doors, ceiling, windows), sanitary conditions, etc.

From October 2003 to March 2004, CD went to work in the community. Family meetings were held in every barrio, where a CD member would present information about the lahar hazard through slides or videos and maps and then explain evacuation procedures, working with the new evacuation plans. Households were also visited, where CD members would help them devise family plans. These plans consist of household evacuation procedures for every day of the week, morning, day and night, division of tasks (set jobs, such as turning off gas, getting pets etc., for each family member) and instruction on evacuation routes, shelters and what items to take.

Evacuation simulations are the next step in CD's community education plan. Not only are the simulations intended to get people to practice evacuating (i.e. learning routes and where they are going to stay), but to verify CD coordination abilities, routes and capacity of evacuation centres. Simulations will also build a civil defence culture between families, neighbours and CD. Each simulation will consist of three phases: preparation, execution and evaluation. The preparation phase consists of simulation co-ordination, dissemination of notices about the simulation, and investigation into people's 'pre-simulation' evacuation knowledge. The execution phase is simply the simulation itself. The evaluation phase investigates community and authority attitudes towards the simulation and 'post-simulation' knowledge. The first of these simulations was held in June 2004 within Sector 3. Comparison of pre- and post-simulation awareness showed that before the simulation less than a quarter of the evacuees knew when to evacuate, their evacuation route, shelter site and what to take. After the simulation all evacuees knew their evacuation route, shelter site and items to take, however, there was still some uncertainty as to when people felt they should evacuate. Instituto Geofisico concluded that the first evacuation simulation was carried out with relative success and that the majority of the population and organisations involved participated with enthusiasm. The simulation proved that the population would have sufficient time to reach the shelter and that the proposed refuge was adequate for the population in need. Evacuation simulations are planned for the remaining 7 sectors over the next few years.

The AZVCH Civil Defence effort in community education about the lahar hazard from Cotopaxi is impressive, considering the limited personnel and funding for CD. The fact that they are using best-practice methods in a developing nation sets a precedent for New Zealand.

Latin American culture does make it easy for organisations to work with communities, by working through extended family groups who often comprise their own communities. However, there are many community networks that can be targeted in developed nations, and the AZVCH example shows us that community education at this level is possible on a very restricted budget.

Unfortunately, evacuations may not go as well as AZVCH Civil Defence plan. A proportion of the population in the AZVCH live in the area between the two rivers, with only one bridge crossing the Rio Pita to safe ground. There is also a significant population not living in the AZVCH who also live in the high risk areas between the rivers and will need to evacuate through the AZVCH. The administrative zone that borders on the AZVCH has not yet put any evacuation plans into place and as the population is not part of the AZVCH, they have not been considered in AZVCH plans. Until CD in Ecuador moves away from its very militaristic (hierarchical/command-and-control) nature, this problem is unlikely to be resolved.

5.3.2 Projects around Cotopaxi Volcano: Southern Flank Zone

Civil Defence in the Latacunga area (Cotopaxi Province), have also been heavily involved with educating the southern flank at-risk communities. Figure 20 presents a table-top model used in their face-to-face education. In Latacunga, CD has jurisdiction over a much larger area than just the city itself, incorporating the majority of the populations at high risk from lahars along the Rio Cutuchi. Approximately 130,000 people are believed to live in high-risk zones in the Latacunga Valley, and as historical evidence shows that over 60% of Cotopaxi's lahars travel down this valley it is important that preparedness and evacuation education reaches these people. Civil Defence estimates that over 80% of residents in the high risk zone have received preparedness/evacuation education; however, around a quarter are thought not to believe, or take notice of the information until Cotopaxi erupts. Demographics of this area have a significant influence, with indigenous peoples comprising a higher proportion of the population, especially in the sierra region (leading to belief and language barriers in hazard education), as well as a generally lower level of education than in urban areas.

Recently, when seismic activity recommenced in 2001, the hazard map for the south side of the volcano was revised with help from IGEPN. Following this, CD determined which populations would need to be evacuated in the event of an eruption, and it subsequently determined which communities needed to be educated about the risk and evacuation plans. Before going to the communities CD first educated authorities in these areas for them to understand and also be able to pass the information onto the communities themselves. As in San Rafael, CD spent time in barrios and communities showing video and slide presentations (aimed at different education levels) and helping families with evacuation plans. World Vision also plays a part by funding education of the sierra communities; this area is more resource intensive due to the time needed to build relationships and find people who can teach in the Quechua language.

Figure 20 Table-top relief model of Latacunga Valley used as an education tool by Cotopaxi Civil Defence.

At present there is no lahar warning system for the entire southern flank of the volcano. As the cost of such a system is estimated at US$2.5 million, it is unlikely there will be one in the near future. Therefore, CD is encouraging each barrio, where they can afford it, to buy and install their own alert system, comprising a series of warning sirens.

Latacunga CD recognise that this preparedness/evacuation education needs to be ongoing, but faces major difficulties in providing this education, as there is no support from the Ecuadorian government, either monetarily or morally. Despite this, they have again shown that public education at a community level can be undertaken with very limited funding.

5.3.3 Quito city – learning from experience

Planning for Quito City's response to volcano activity is undertaken by the Direccion Metropolitana de Seguiridad Ciudadana (City Security). City Security is the directorate within local government responsible for planning for all aspects of city security from street safety to emergency planning.

During the eruption event of 2002 (Reventador), the official response within Quito City was generally efficient. Both the municipality and the population responded quickly, owing to general recall of the recommended actions and actual experience of the eruption of Guagua Pinchincha in 1999. This previous experience ensured that the general public took measures to safeguard their health and homes, by avoiding going outside, not driving, cleaning ash from roofs and walls, and bagging cleared ash (as opposed to sweeping it into the streets). In many areas of the city community leaders organised groups to sweep and bag ash in the streets; combined with the municipality efforts in clearing the larger roads and motorways, this ensured the city was largely free of ash only 8 days after the eruption.

In spite of the efficiency of the clean-up, the municipality recognised that lessons remained to be learned. City Security in Quito took advantage of the event to review practices and experiences of an eruption from the city's point of view. To this end they commissioned work to document what had occurred in the city during the eruptions, and the learning that could be gained from this for future planning.

The report identified the areas of Quito city that are in most need of urgent attention, to ensure a more coordinated and efficient response to another emergency event. Establishing the officials' emergency committee to coordinate response to the event needs to be pre-planned, with stronger links between officials and responding agencies established prior to an emergency. City Security is seeking to support this with planning meetings and scenario-based exercises. In addition, strengthening and protection of both the potable water system and the electricity system are needed – especially as the water system relies in many places on electricity generation. Planning for mitigation and recovery from loss of agriculture, urban transport (such as taxis and private buses) and other industry affected by ash-fall (e.g. loss of tourism revenue was estimated at US$270,000 a day) has been identified as equally critical in ensuring that the labour and social situation of the city can recover as quickly as possible. City Security in conjunction with other municipal agencies are working to address these issues by collating information, identifying issues and setting up task groups.

5.3.4 Baños – a community response to threat

In 1999 the town of Baños was forcibly evacuated by authorities following advice from the scientific community that the town and its surrounds were in imminent danger of a life-threatening eruption, which would lead to pyroclastic flows. The townspeople were re-located to surrounding towns and cities to family and friends (if available), while the poor and isolated elderly were housed in a camp on a nearby hillside from which they could see their homes. Although there were widespread eruptions over the next months, there was no serious damage to the town or surrounding valleys. Meanwhile the social and economic impacts were debilitating for many in the community, with loss of income and livelihood. After some months of being isolated from their homes and livelihoods the people of Baños revolted against the instruction and attempted to break through military blocks around the town (Fig. 21). After a period of conflict with authorities, during which there was some loss of life, the citizens were allowed to reoccupy their town just before Christmas 1999. Baños was socially and economically affected by the eruptions and evacuations, and has suffered decreased farming productivity (discussed above). However, locals report increased tourism related to the volcano, reportedly up to twice as much as before the eruptions started.


2000 - 01 - 09

Baños, un retorno con drama y violencia

ESPECIAL DOMINGO

Eduardo Terán / EL COMERCIO

El 30 de diciembre, 800 habitantes decidieron retornar. Días más tarde, los militares tuvieron que dejar la ciudad y la marea umana se hizo incontenible.

El costo más grave fue el del 5 de enero, cuando los enfrentamientos cobraron una víctima. Una crónica íntima sobre hechos inéditos y sobre las motivaciones del retorno.

Págs. A6 y A7

Figure 21 The ‘violent and dramatic return’ of the population to their town after the military-enforced evacuation of Baños in 1999 was widely reported in Ecuadorian media.

A local civil defence organisation was established in Baños in 2001 with four people and now has 45 members (Fig. 22). All are volunteers with the exception of a paid secretary. The CD organisation was developed in response to the issues that arose around the 1999 evacuation and the community’s increased desire for self-control in matters relating to the volcano, warning systems and evacuation processes.

Although the volunteers in Baños CD know their town was not directly physically affected by the last eruptions, they do recognise that they could be affected next time. The major barrier to their working with the wider community is that people are not always open to education because of the bad experience with the 1999 evacuation and the advice of scientific community[2]. In particular this has led to a reluctance from the community to ‘open their doors’ to information as they fear they will once again be told to leave their homes. The people’s Catholic faith also contributes to unwillingness to accept scientific advice (Figs. 23 and 24).

[2] Although reviews of the decision to evacuate the town have confirmed the scientific advice and authorities decisions taken in 1999, the resultant outcome (no damage to the town) has led to a deep distrust of scientists in the area (Fig. 24).

Baños CD struggles not only with community attitudes, but resourcing. The organisation has no funding and it struggles to get materials – all those used (sirens, printing, signs, paint) are donated by local business. In spite of these barriers the organisation is working on educating barrios to accomplish an internal evacuation first, to get people together, then practising leaving the town by one of the access ways (Fig. 25). Baños CD has carried out one unexpected town-wide drill with fair success (more are planned) and conducts regular drills with various groups in the community. Increasing interest and involvement from the community is attributed in part to CD's involvement in schools (50% now involved), which has led to a 100% awareness rate of issues and evacuation routes among attending students. CD provides some locally developed education material for students, while all posters used come from an international aid organisation. Local students are also taught to form buddy systems in their barrio and to plan with their families and neighbours to assign responsibility for the elderly and young in their areas. Two years ago students made evacuation route signs for the town using donated paint.

Figure 22 Sara Williams (centre foreground) meets with Baños Civil Defence in 2004 as part of the reconnaissance trip.

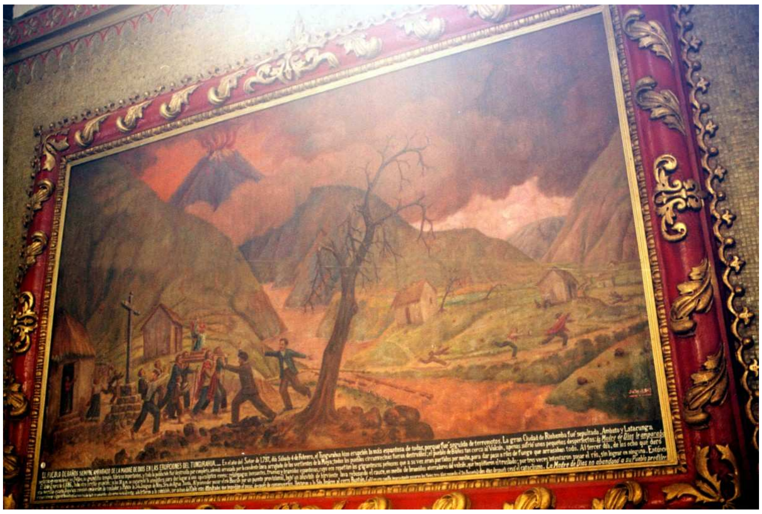

Figure 23 **The Catholic church in Baños has several frescos depicting the population's interaction with Tungurahua's eruptions, and the sainted Virgin of Baños's protection of those worthy. Regular religious processions are held to please the Saint and protect the town.**

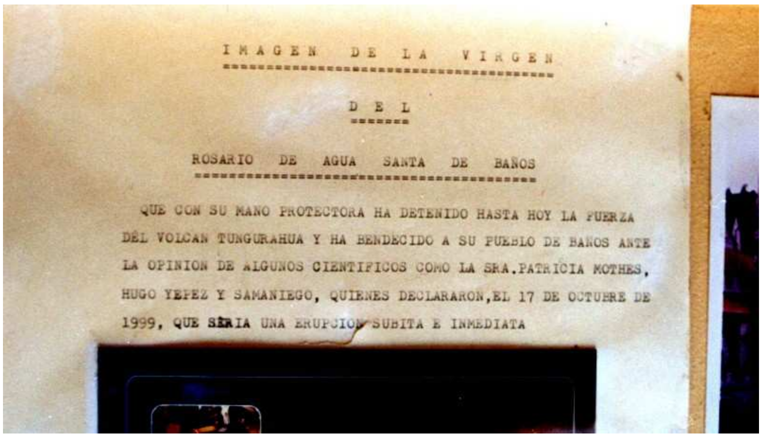

Figure 24 **An example of the attitude of the devout Catholics in Baños, on display in the church museum. Rough translation: " Image of the virgin of the holy water of Baños. Who with her protective hand has detained until today the force of Tungurahua volcano and has blessed her town of Baños, against the opinion of certain scientists … who declared, on the 17th of October 1999, that there was going to be a large and immediate eruption"**

Figure 25 Bridge to safety: Installed since the 1999 reawakening of Tungurahua, this bridge provides an evacuation route from Baños (at left) but there is concern that it crosses the major lahar and pyroclastic flow valley, and connects to a part of Baños also likely to be in the path of a pyroclastic flow.

Another barrier to effective local CD planning is a lack of real support from the municipality. While CD receives a yearly $6000 grant from the municipality, they have to pay all wages with the money. No other support is provided and there is a lack of willingness from the authorities to look at the overall issues – for example, during recent upgrading of the streets some of the evacuation route signs were removed and thrown away. The head of CD noted that there is no culture of prevention in Ecuador, and they regret that the government does not see that prevention and education is cheaper than clean up afterwards. This lack of support has extended to a refusal to look at recovery planning. CD has done a lot of development work looking at projects to make the community safer, but the only one to be funded to date is a project identifying tourism facilities that are in the high-risk areas. There appears to be a lack of willingness to use scarce resources wisely – for example, the municipality 'boss' has gone to a number of international meetings on volcano issues, but the community has never seen the results of his visit or any outcome to assist at a community level. At the same time CD is struggling to maintain its premises.

The siren system is well-established in Baños, although the organisation observes that locals are getting used to the alarms and tend to ignore them. CD is responsible for monitoring the sirens and their upkeep. Sirens are located at all schools, police, fire and Red Cross. In addition CD maintains a system of 75 people with radios and cell phones to communicate information – these people are notified of activity and also of heavy rains (which frequently cause flash-floods in the hilly terrain).

6.0 LESSONS FOR NEW ZEALAND

As in New Zealand, urban centres in Ecuador are exposed to volcanic risk from multiple volcanic sources. Recent ash fall events in Ecuador provide useful insight into impacts from and response to such events. Although falls on Quito have been relatively minor (a few millimetres) they have nevertheless caused significant social and economic disruption and some physical impacts. The notable physical impacts were to agriculture and airport operations. Other vulnerable sectors were water supplies, sewerage, storm water and electricity supply. The recent ash falls have highlighted the range of complex management decisions that need to be made before, during and after an ash fall with respect to warning messages, mitigation actions and ash removal/disposal. The following sections outline the key lessons learned that could be applied in New Zealand.

6.1 Volcano monitoring

- Monitoring staff need to be prepared for high levels of stress when they are required to provide feedback and information to end users over long periods. Discussion of what can and cannot realistically be expected of them, rostering of staff time-off (strictly enforced), and stress-management training are all likely to be beneficial.
- It is difficult to maintain all monitoring equipment and communications in an eruption due to equipment failure/damage and weather conditions; the provision of information under such an environment should be planned for, as well as providing the resources (people and materials) to restore/maintain monitoring as much as possible.
- Beware of the lack of trust of monitoring agencies and staff amongst the community in Baños following the false warning and evacuation in 1999. Note that any false alarms may reduce monitoring credibility and place scrutiny and criticism on those agencies (exacerbated by strong widely-held religious beliefs in Baños).
- Direct personal relationships between monitoring agency staff and all responding agencies prior to events is essential. The best response occurs where those who need to exchange information in an event have talked to each other ahead of time, and trust each other.
- IGEPN find a combination of seismograph, pressure sensors, ground deformation, geochemical, thermal and visual data are essential to effective eruption forecasting and in-eruption monitoring.

6.2 Emergency management

While some of the particular challenges and constraints that are present in Ecuador are not similar to those in New Zealand, investigation of community-based response to the volcanic hazards has identified several key areas of learning:

- Clear planning at national and local, strategic and operational levels is necessary to

pre-determine the division of responsibility, and create an environment that fosters cooperation.
- All agencies with a stake in the hazard risk must be included in the planning conversations – this includes the business, infrastructure and community groups.
- Local problems demand locally developed solutions – the best way to do this is support communities to determine their own solutions, with expert advice regarding risks.
- Local groups with responsibilities (e.g. CD and community) must be adequately resourced and supported from government.
- At all levels it is critical that representatives at an appropriate level (ie. with the ability to make financial and resource decisions) are included in the planning process.
- Cultural beliefs must be taken into account when planning for hazard responses. Failure to do so will result in misunderstandings and can create hostility between officials and at risk communities.
- Exercises are critical to improving planning, education, training and evaluation of effectiveness. As an example of best practice, each simulation in the Northern Flank Zone of Cotopaxi consists of three phases: preparation, execution and evaluation. Preparation involves simulation co-ordination, dissemination of notices about the simulation, and investigation into people's 'pre-simulation' evacuation knowledge. Execution is the simulation itself, with full exercising of actions. Evaluation of community and authority attitudes towards the simulation and 'post-simulation' knowledge is then fed back into improved planning.

6.3 Public education and training

- Simulations are effective for public education and training.
- Multiple formats and languages are needed for different audiences to ensure a wide uptake of messages (including, for example, printed material, maps, models, videos and discussion groups). The more channels used the higher the retention of information.
- Effective public education and training take time and must be consistent, regular and permanently ongoing.
- Effective public education and training need to be done 'on the ground', customised to the audience of individual regions and communities.
- Committed locals are the most efficient education tool an authority can have.

6.4 Water supply

- Covering smaller water treatment plants with tarpaulins (materials must be on hand) effectively managed a few millimetres of ash; however many Quito plants have special covers built to protect from ash. This should be evaluated for all plants in New Zealand.

- Flocculation with Al_2SO_4 effectively rendered water drinkable, and avoided any internal equipment damage. Flocculation takes longer with greater sediment load, but supply rates can be increased by using more flocculent. It was reported that centimetre to decimetre ash falls on water supply lakes would probably overload flocculation; a delay while this settles in reservoirs would be necessary.
- Low pH ash lowers the pH of water, requiring $Ca(OH)_2$ to be added to raise the pH back to acceptable levels.
- Treatment plant filters needed to be checked and cleaned more regularly, from two to ten times as frequently as in non-ash fall times.
- No testing of ash leachates in drinking water has been reportedly conducted in and around Quito, but should be considered in New Zealand.
- Water supply lines themselves may be vulnerable to physical breakage by proximal volcanic hazards such as lahars, pyroclastic flows and lava flows. This may be mitigated against in some cases by, for example, allowing for lahar passage under or over pipes as is being evaluated for Quito.
- Conservation of water by avoiding use for ash clean up is important and is part of public education and communication planning.
- If water supply has to be stopped, communities will cope better if they have their own stockpiles of water, and know to boil water of uncertain quality. This is the case in Quito, and was originally prompted by past disease outbreaks not related to volcanic hazards.
- Sectorisation and redundancy in the water network allows damaged sections to be isolated and bypassed.

6.5 Wastewater

- Rapid street cleanup, and light rain stabilising ash, prevents a large proportion of ash from entering drains. Cleanup and disposal must be pre-planned.
- No treatment of wastewater is normally conducted in Ecuador so impacts to these systems was not gauged.
- Pumps did not fail but required more regular maintenance of filters and external mechanisms exposed to falling ash. Internal contacts with ash-laden sewage were not damaged.
- As well as physical damage to equipment at sewage treatment plants (seen in New Zealand in Rotorua in 1995/96), ash in ponds was seen in Oyacachi to disrupt the oxidation process, resulting in a strong smell and ineffective treatment. Shutting down plants and diverting sewage before damage occurs will likely lead to orders of magnitude shorter down-time, and thus reduce social and environmental impact (and cost) than that required to allow for repairs if operated and damaged with ash-laden water.

6.6 Telecommunications

- Overload was seen to be the largest problem in the Ecuador examples; planning is required to manage and maintain critical communications.
- There were no reported exchange problems, but the study group had no direct contact with communications providers. Filter blocking (especially important in air-conditioning for telecommunications), and power loss, were reported as problems for other utilities in Quito; these also likely apply as telecommunications vulnerabilities in New Zealand.

6.7 Electricity transmission

- Flashover has been a problem in Quito. Ash is cleaned, and insulation restored, with water washing or heavy rainfall. Planning for adequate resourcing for cleaning is needed in New Zealand.
- Ash damage to hydro-electric generation plants has been identified in Ecuador as a potential hazard to electricity supply down the line. 'Minor' concentrations in dams has caused no reported turbine blade damage in Ecuador, but lahars overtopping or breaching dams is a significant hazard to consider in New Zealand.

6.8 Land transport

- Cleaning is essential for safety from three hazards: (1) road markings temporarily obscured, (2) direct loss of traction and (3) raised-dust causing nuisance and visibility reduction. The best advice is to avoid non-essential travel. Advising extra caution, slower speeds and reduction in use are a public education responsibility that should be pre-planned and in place; enforcement should be pre-considered.
- Vehicles reportedly operate well in Quito in ash fall environments, but air filters require more frequent cleaning and/or replacement. Stockpiling of filters for at least essential service vehicles should be considered.
- Washing windscreens of ash without wiping will reduce scratch damage.

6.9 Ash cleanup and disposal

- Cleanup and ash disposal timing can be difficult to decide: when is an event 'over'?
- Ash disposal is a huge issue that must be fully pre-planned and pre-costed, millions of cubic metres of ash must be disposed of from a large city that receives only millimetres of ash.

6.10 Airports

- Quito's airport and local airlines were considerably economically affected by the eruptions, due to the time needed to clean airport infrastructure (especially runways) and aircraft before normal operations could be resumed. Detailed pre-planning could save millions of dollars for these companies.

- The lack of available equipment to facilitate rapid clean-up of the ash led to the employment of manual labour to clean the airport runways. Due to its prohibitive cost this may not be a realistic option in New Zealand.
- While ash on the runways was stabilised through light dampening with water sprayed from trucks, it was not saturated or even ‘wet’, as this inhibited sweeping.
- The point above illustrates the need for the availability of equipment in NZ to be able to respond to ash fall events. Where manual labour is used for ash clearance, protective equipment would be needed in NZ. There is currently a research project underway for Auckland Engineering Lifelines Group looking at health and safety working in an ash environment.
- Previous eruptions in South America had prompted many airlines to carry engine covers, tarpaulins and adhesive tape to cover vulnerable aircraft components in the event of an eruption. This low-tech, low-cost mitigation method proved to be extremely effective in protecting grounded aircraft from abrasion damage, and is thus worth noting in airports potentially affected by ash fall in NZ.
- Plane cleanup using fire trucks spraying water took 10 to 15 minutes per Boeing 737 (with flaps fully retracted), and full service checks were performed afterwards. No abrasion or chemical corrosion was seen after ash had remained on aircraft from 12 to 48 hours. Aircraft were moved using tow trucks rather than starting jet engines. No problematic ingress of ash or water to the planes was noted.
- Clear pre-planned decision making hierarchies, protocols and criteria at airports are needed.

6.11 Animals

- The impacts observed in Ecuador provide useful insights into the range of potential animal health and stock management issues which New Zealand will face in future ash eruptions (the dominant livestock are dairy cows in the study area):
    - Tooth abrasion due to mastication of ash
    - Stock death and loss of condition due to ingestion of ash
    - Loss of grazing potential due to burial by ash
    - Pre-planning of stock evacuation method and destination
- Agricultural impacts around Tungurahua volcano have demonstrated the need for planning for stock transport and alternative grazing in the dairying industry.
- A further effect in New Zealand, maybe not noted in Ecuador, is the need for a milking strategy if electricity supplies are interrupted (this is already a major problem in NZ where any event cuts power)
- A fish farm noted a loss of 10 % through deaths of carp and tilapia, suggesting that hatcheries and farms in New Zealand should prepared covers for their water surfaces.

6.12 Horticulture

- ‘Burn’ of leaves was reported from the heat of ash, but also may occur from leachate.
- Rainfall washes leaves, but may not clean then adequately to make crops saleable.
- Wind reduces ash collection on leaves, so that ash fall at night (which is less windy) often has a greater impact.
- Tens of centimetres of ash may kill all crops. A few centimentres of ash were reported to cause about 50 % crop losses in and around Baños.
- Due to wider economic impacts of a eruption, markets may dwindle even if crops are salvaged.
- Ash often produces a long-term soil fertility increase, but it reportedly takes about six to eight years to get soil back to it’s pre-eruption fertility in the study area.
- Covered flowers were still crushed by the weight of ash on the covers, this may affect greenhouses in New Zealand.
- Younger plants, and those with larger leaves, tend to fare less well in ash fall environments.

6.13 Gaps in knowledge from this trip

The following topics were of interest for this reconnaissance trip, but information was not available, or the group were unable to discuss it with an appropriate person or organisation:

- Waste water treatment (not conducted in Quito).
- Sweeper-truck performance; not tested in Quito, because manual ash sweeping has been employed for both the city and airport.
- Telecommunications performance from the industry itself. Comments reported here are second hand from several other agencies.
- Effect of providing written material only in one language (In Ecuador in Spanish to non-Spanish speakers, in New Zealand more an issue with foreign visitors).

Analysis of human health impacts was beyond the scope of the tripEmergency managers reported no long-term effects, but this information not confirmed with health officials. Grainsize, chemical leachates and gas all have potential health impacts. In this respect COSPEC and TIMs satellites showed SO_2 and likely HCl in remobilised ash clouds for about 15 days after the most-recent eruption; and the light-toned ash was a very fine silt.

6.14 Further work

Future reconnaissance trips will allow comparison of the findings from Ecuador across multiple settings, and to glean impact details that cover the gaps in knowledge from this trip noted above. There is a need for further work in New Zealand to devise clear methods for addressing the lessons summarised here.

Areas of further work in regard to emergency management and public education have been suggested as a result of the study trip. These include:

- Development of models for effective event pre-planning in regard to agency and organisation engagement (eg. Welfare agencies, social agencies, councils, etc.).
- Development of models to assist at-risk communities to seek management solutions at a local level.
- Investigation of the particular barriers to education and hazard responses in New Zealand – such as Maori land ownership processes, or recent immigrants language barriers.
- Development of effective forms of communication for education in regard to volcanic threat, that is appropriate for all audiences.
- Development of best practice guides for implementing, carrying out and supporting grass-roots public education regarding volcanic risk

There is specific further research underway in New Zealand around airports and grounded airplanes; ash impacts to the dairying industry; human health in an ash environment; ash disposal; drinking water chemical modelling; ash testing requirements and standards; and waste water/water supply engineering effects lab testing.

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