

RESEARCH

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Volcanic ashfall preparedness poster series: a collaborative process for reducing the vulnerability of critical infrastructure

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Abstract

Volcanic ashfall can be damaging and disruptive to critical infrastructure including electricity generation, transmission and distribution networks, drinking-water and wastewater treatment plants, roads, airports and communications networks. There is growing evidence that a range of preparedness and mitigation strategies can reduce ashfall impacts for critical infrastructure organisations. This paper describes a collaborative process used to create a suite of ten posters designed to improve the resilience of critical infrastructure organisations to volcanic ashfall hazards. Key features of this process were: 1) a partnership between critical infrastructure managers and other relevant government agencies with volcanic impact scientists, including extensive consultation and review phases; and 2) translation of volcanic impact research into practical management tools. Whilst these posters have been developed specifically for use in New Zealand, we propose that this development process has more widely applicable value for strengthening volcanic risk resilience in other settings.

Keywords: Hazard; Risk; Tephra; Preparedness; Critical infrastructure; Airport; Electricity; Transmission; Distribution; Generation; Water supply; Wastewater; Buildings; Road; Transport; HVAC; Computer; Electronics; Risk communication

Introduction

Volcanic ashfall can cause a range of societal impacts. Ashfalls of just a few mm can be damaging and disruptive to critical infrastructure services (also known as ‘utilities’ in some countries), such as electricity generation, transmission and distribution networks, drinking-water and wastewater treatment plants, roads, airports and communication networks (Wilson et al. 2012b). Disruption of service delivery can have cascading impacts on wider society. Ashfall can be very widely distributed, potentially affecting communities hundreds of kilometres from the erupting volcano. For example, the recent June 2011 eruption of Puyehue-Cordón Caulle volcanic complex, in southern Chile, deposited ashfall over approximately 75,000 km² of Argentinian Patagonia (Buteler et al. 2011), with a substantial depth of 30–45 mm deposited on

the major regional centre of San Carlos de Bariloche, population approximately 113,000. This led to extensive disruption of the city’s water supply, electricity distribution and generation networks, wastewater networks, ground and air transportation networks, and necessitated a major ash clean-up operation within the town (Wilson et al. 2012c). Specific impacts of ashfall vary considerably, depending on factors such as plant or network design, ashfall characteristics (e.g. loading, grain-size, composition and levels of leachable elements), and environmental conditions before and after the ashfall.

There is also growing evidence that a range of preparedness and mitigation strategies can reduce ashfall impacts (Wardman et al. 2012a, Sword-Daniels et al. 2014). Core components of disaster risk reduction includes (1) providing advice on likely impacts and best-practice mitigation strategies, and (2) encouraging communities or organisations to adopt preparedness measures which increase their ability to manage hazard consequences, and thus increasing their capacity to manage risk (Paton et al. 2008;

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UNISDR 2011). However, this is not as simple as it seems. Firstly, empowering society to utilise scientific and technological advances to reduce the impacts of disasters is a well-established challenge (Tobin and Montz 1997; Miletti 1999; Alexander 2007; ICSU 2003, 2010; UNISDR 2011; Few and Barclay 2011; McBean 2012). Both the UNISDR Hyogo Framework for Action (HFA) and Integrated Research on Disaster Risk (IRDR) program to call for more integration of research with the needs of policy and decision makers (ICSU 2008). Few and Barclay (2011) also stress the need to promote integrated, inter-disciplinary approaches, strengthen two-way links between research providers and end-users, and increase experimentation with research mechanisms (such as 'embedded' approaches) to support more effective research/end-user partnerships.

Secondly, a review of recent risk perception and preparedness studies by Wachinger et al. (2013) suggests that even if an individual perceives a high level of risk from a given hazard, this does not necessarily translate into this individual adopting appropriate risk mitigation behaviour for that given hazard. Ballantyne et al. (2000) found that provision of hazard information by agencies can, paradoxically, decrease a community's perceived need to prepare as they will tend to transfer responsibility to these agencies. In the case of volcanic hazards, knowledge of proximity to volcanic hazards or susceptibility to their consequences does not assure mitigative actions will be taken, and preparedness levels often remain low in proximal regions even in developed countries (Paton et al. 2008). Even experiencing a volcanic eruption may not necessarily act as a catalyst for preparing for a future event (Johnston et al. 1999). These effects may be even more pronounced as eruptions are relatively infrequent and 'exotic' (Paton et al. 1998). For risk communication, simply providing information often fails to change risk perception or motivate volcanic hazard preparedness, implying that more engaged and appropriate strategies are required (Paton et al. 2008). This may be overcome by a more participatory process (Twiggs 2007). When stakeholders (e.g. communities and organisations) actively participate as legitimate partners in the communication (and mitigation) exercise, they are empowered to make change which increases their resilience (Covello and Allen 1988; Paton et al. 2005). The communication exercise should also be transparent and led by a source which is authoritative, credible and trusted (Berlo 1960).

This paper describes an example of this approach, a collaborative process used to develop a suite of posters which summarise the potential impacts of volcanic ash and preparedness and mitigation strategies for different sectors of critical infrastructure. The effort included sustained exchange and development of best practices

through collaboration among researchers, infrastructure managers and emergency managers from within an established practitioner-research volcanic impact advice structure in New Zealand.

Evolution of volcanic emergency management structures in New Zealand

Context: 1995–96 Ruapehu eruption sequence

Over the past two decades there has been growing awareness in New Zealand (as for many other nations) that volcanic hazards can cause substantial and unique impacts on critical infrastructure (known as 'lifelines' in New Zealand). Consequently, a strong culture of natural hazard risk management within the critical infrastructure sector in New Zealand has developed, catalysed through the development of 'regional engineering lifeline groups' which are defined as "an informal, regionally-based process of lifeline utility representatives working with scientists, engineers and emergency managers to identify interdependencies and vulnerabilities to regional scale emergencies. This collaborative process provides a framework to enable integration of asset management, risk management and emergency management across utilities." (NELC, 2007). Typically seismic, storm and flood hazards have been the focus, with well-established, evidence-based design codes and advice for preparedness and response strategies available (e.g. the Civil Defence and Emergency Management Act 2002, the Building Act 2004 and the Resource Management Act 1991 of the New Zealand Parliament). By comparison, volcanic hazards have received less attention. This disparity can be at least partially attributed to few, damaging volcanic events occurring during the past 60 years in New Zealand (OCDESC, 2007). However the 1995–96 eruption of Ruapehu volcano caused widespread and costly impacts to a range of critical infrastructure organisations in New Zealand, despite the relatively modest eruption magnitude (Johnston et al. 2000). The risk of lahars, blasts and surges closed all three ski fields on Ruapehu for many months while volcanic ashfall and lahars impacted critical infrastructure, agriculture and communities many tens to hundreds of kilometres from the volcano. Total losses were an estimated NZ\$130 million (~NZ\$188 million or US\$161 million in 2014) (Johnston et al. 2000). Analysis of the performance of responding organisations (national, regional and local government agencies, utilities, emergency services and private businesses) by Paton et al. (1998) found there was insufficient knowledge of volcanic hazard impact and appropriate mitigation strategies within these organisations. Nor was there sufficient access to information, which further exacerbated uncertainty regarding preparedness, response and mitigation decision-making. Many organisations looked to the government volcano

monitoring agency (formerly the Institute of Geological and Nuclear Sciences, now GNS Science) and the universities for specialist impact and mitigation advice. However, there was limited volcanic impact information easily available, either within New Zealand or internationally (Johnston et al. 2000).

The Ruapehu crisis was exacerbated by relatively rigid, top-down, siloed management structures at local and regional levels which did not cope well with the impacts occurring across a complex multi-jurisdictional setting (Paton et al. 1998). In particular, pre-existing networks between information providers and responders were found to be incomplete and inconsistent with respect to information needs. This detracted from effective communication between organisations hampered decision-making and coordination in an environment characterised by multi-organisational involvement and conflicting demands (Paton et al. 1998).

Most organizations emerged from the Ruapehu disaster relatively unaffected, and many perceived that they had coped effectively with the demands of the disaster. However Paton et al. (1998) argued that this may “stimulate overestimation of future response capability, underestimation of risk, and constrain thinking about future events, making it difficult to conceptualise alternative demands, problems or outcomes...and may ignore the negative outcomes or potential inadequacies of crisis management systems.” These authors argued that it was important to ensure that this experience did not result in complacency about future response effectiveness.

Implementing lessons learned

In the five to ten years after the Ruapehu eruptions, New Zealand’s approach to emergency management has evolved from a ‘civil defence’ approach to a ‘comprehensive emergency management’ approach with the passage of the Civil Defence and Emergency Management (CDEM) Act in 2002. This act recognised the unique challenges of managing disasters and emergencies, and stipulated a more coordinated, integrated approach which focused on developing partnerships and clarifying emergency management responsibilities of critical infrastructure companies.

In this changing environment, the lessons from the 1995–96 Ruapehu eruption acted as a catalyst for 1) developing a volcanic impact evidence base to inform preparedness and mitigation decision-making (particularly for ashfall as the most frequently-produced and widely-distributed volcanic hazard); and 2) enhancing communication and coordination structures between volcano and risk scientists and stakeholders (Paton et al. 1998; Johnston et al. 2000; Leonard et al. 2008).

Volcanic impacts research group

As part of New Zealand’s increased investment in applied volcanology research over the past 15 years, a volcanic impact research group was formed between GNS Science and partner universities (University of Canterbury, Massey University, and University of Auckland). This group has pursued a sustained and systematic approach to assessing the impact of volcanic ash on critical infrastructure, for as wide a range of different eruption types and magnitudes. This group has undertaken reconnaissance trips to areas impacted by volcanic eruptions worldwide at varying intervals after the eruption, to capture both short and longer term impacts, timescales of recovery, successful mitigation strategies and overall management lessons (Table 1). A further goal is to develop quantitative risk tools, such as vulnerability and fragility functions that relate impacts to the amount and characteristics of ashfall received and to develop more quantitative relationships for use in risk modelling. The group has also studied cascading impacts of ashfall within a systems-thinking framework (Wilson et al. 2012b; Sword-Daniels et al. 2014). More recently, empirical laboratory-based testing of critical infrastructure components has been conducted in our Volcanic Ash Testing Lab (VAT Lab) (Wilson et al. 2012a; Wardman et al. 2012b). The strategic focus of the full research group has been on understanding both ashfall impacts on individual system components and overall system functionality. The group has received ongoing funding support from the Natural Hazard Resource Platform (a multi-party research platform funded by the New Zealand Government dedicated to increasing New Zealand’s resilience to Natural Hazards via high quality collaborative research), critical infrastructure organisations (primarily AELG organisations, described in the following section), and the New Zealand Earthquake Commission. In kind funding support from.

Provision and coordination of volcanic impact knowledge

In conjunction with development of the research group, an enhanced partnership with end-users needed to be established for communicating volcanic impact science both during crisis and non-crisis periods. The Auckland Engineering Lifelines Group (AELG) is a group of critical infrastructure organisations within the Auckland region. Its mission is to increase critical infrastructure resilience to all hazards. As such, there was considerable interest within AELG to enhance volcanic impact science capability. Volcanic hazards are one of the most substantial risks to the Auckland region, either from an eruption from the Auckland Volcanic Field upon which the city is built or from distal ashfall hazards from central North Island volcanoes. In 2004, the Volcanic Impact Study Group (VISG) was established as a sub-committee of the AELG. The VISG was designed to be a

Table 1 List of volcanic impact reconnaissance trips undertaken by New Zealand volcanic impact research group

Volcano	Country	Year of eruption	Year of assessment trip
Mt St Helens	USA	1980	1995
Crater Peak (Mt Spurr)	USA	1989	1996
Sakura-jima	Japan	~1980-2000	2001
Ruapehu	New Zealand	1995-96	1995-97
Etna	Italy	2003	2003 (several days after)
Tungurahua & Reventador	Ecuador	1999-2005 & 2002	2005
Merapi	Indonesia	2006	2006 (1 month after)
Pinatubo	Philippines	1991	2007
Eldfell	Iceland	1973	2008
Hudson	Chile	1991	2008
Chaiten	Chile	2008	2009
Redoubt	USA	2009	2009
Pacaya	Guatemala	2010	2010 (4 months after)
Tungurahua	Ecuador	2010	2010 (4 months after)
Shinmoedake	Japan	2011	2011 (9 months after)
Puyehue-Cordón Caulle	Chile	2011	2012 (9 months after)
Tongariro	New Zealand	2012	2012 (2–3 days after)

multidisciplinary and multi-institution consortium of volcanology and natural hazard researchers and practitioners with the following aims (VISG 2012):

- *To collate and advocate existing knowledge about the impacts of volcanic hazards (e.g. ash) on, and mitigation measures for, lifeline infrastructure.*
- *To facilitate and support research on the impacts of volcanic hazards on lifelines and people, and the development of appropriate mitigation measures.*
- *To provide input into the applicability for lifelines of any research being undertaken.*
- *To facilitate reconnaissance investigations, and/or advocate lifeline representation on reconnaissance investigations, to active volcanic areas where this would add to our knowledge about volcanic impacts on infrastructure.*
- *To provide a national focal point for volcanic impacts work on lifelines.*

Initially, the VISG was only focused on the Auckland region and was concerned primarily with impacts from the Auckland volcanic field, an active basaltic scoria cone field upon which Auckland City (pop. 1.5 million) is constructed (Lindsay et al. 2010). This focus has since broadened to support volcanic impacts research with any local, regional or national stakeholder in New Zealand. VISG provides a formalised networked structure between volcanic impact science providers (GNS and the universities) and critical

infrastructure and emergency management organisations. Key activities of the VISG include undertaking focused research on volcanic impacts, contributing to volcano contingency planning and exercising when requested, and running an annual seminar on current research.

Communication of appropriate volcanic impact science with end-users in a timely manner during an eruption crisis can be additionally challenging in the absence of adequate training and communication structures linked to expert knowledge. Pre-existing relationships between end-users and researchers, combined with readily available resources, can greatly reduce information searching and processing time, which aids decision-making timeliness and quality (Paton et al. 1998). The VISG aims to improve non-crisis and crisis communication between providers and recipients by developing relationships and resources which anticipate and provide for likely information needs. It fosters a group of information providers who can access, collate, interpret and disseminate information as needed within a known and regularly used framework. Likewise, the interaction with AELG and other lifeline group members contributes to developing a capacity within their own organisations to interpret, request and use specialist volcanic impact information.

Specific activities have included multi-organisation workshops, targeted 'sector specific' workshops, one-on-one meetings and public lecture tours. Information is also provided to international volcanological initiatives, such as the USGS-GNS Volcanic Ash Impacts Website (<http://volcanoes.usgs.gov/ash/>), the International Volcanic Health

Hazard Network (www.ivhhn.org) and the Cities on Volcanoes Commission of IAVCEI (<http://cav.volcano.info/>).

Poster design

Critical infrastructure organisations that have experienced adverse impacts during ashfall events commonly report low levels of prior awareness of ashfall hazards and impacts (Blong 1984; Paton et al. 1998; Ronan et al. 2000; Wilson et al. 2012b). Whilst many organisations recognise the value of planning and preparedness for volcanic hazards, the necessary investment can be difficult to justify in the context of a variety of other hazards and business pressures. Feedback from AELG members suggested that lengthy reports summarising known impacts, mitigation options/recommendations and interdependency issues were useful, but only during infrequent detailed planning exercises. Authoritative but concise reference materials preferred as a means to inform planning and be readily available during a crisis, supplemented by additional information from science providers as needed. After some experimentation and consultation, posters were judged to be the optimal method for condensing key impact and mitigation information into a concise, palatable and visible form. The first series of posters was commissioned and completed during the period 2007–2010 for five infrastructure sectors: airports, road networks, drinking-water supplies, power-systems (networks), and wastewater collection and treatment systems (Figures 1, 2, 3, 4, 5). These sectors were selected by AELG and VISG members as most likely to be impacted. This edition of the posters were advertised widely in outreach activities, used during emergency management exercises and ultimately became a recognised information source in New Zealand (Bay of Plenty Engineering Lifelines Coordinator pers. comm. 2012).

During subsequent review of VISG resources and risk communication strategy, it became apparent that the content of the first series of posters was becoming outdated; for example, global initiatives in the aviation sector (ICAO, 2007) needed to be incorporated into advice. Thus it was decided in 2012 that a) the current poster suite should be updated with the latest research and accounting for local and global developments, and b) that additional posters should be developed to address knowledge gaps. Subjects of particular interest were advice on ash cleanup operations for city authorities; impacts on building facilities; impacts on heating, ventilation and air-conditioning (HVAC) systems and emergency power generators; and impacts on computers and electronics. A further change was that the content of the original poster on power systems was split between two new posters: one on electricity generation facilities and the other on electricity transmission and distribution networks. This expansion made it possible to incorporate

substantial new research in this area (Wardman et al. 2012a). The new series of posters are shown in Figures 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. We note that despite telecommunications being a key critical infrastructure sector, we did not consider there to be sufficient documentation of impacts or mitigation guidance to create a robust poster.

Poster content

Content was derived from the research team's observations of the consequences of volcanic eruptions around the world (summarised in Wilson et al. 2012b). These insights were supplemented by findings from empirical laboratory experiments, such as the vulnerability of high-voltage transmission insulators to flashover from volcanic ash contamination (e.g. Wardman et al. 2012a; 2012b; Wilson et al. 2012b). Poster content was written to be practical, with action-based knowledge. Expert elicitation from AELG members was used to ensure that content was technically correct, relevant and used accurate with terminology (Figure 16). Consultation broadened beyond AELG as required: power generating companies within Bay of Plenty Engineering Lifelines Group contributed to and reviewed 'Advice for Power Plant Operators', the Ministry of Health reviewed 'Advice for Water Supply Managers' and the Civil Aviation Authority reviewed 'Advice for Airport Managers'. Active involvement with the Ministry of Health has also contributed to improved volcanic health impact coordination between volcanic impact scientists and public health professionals. This approach ensured access to the best possible knowledge, facilitated broad participation of relevant organisations, increased awareness of the posters as a resource, and raised the visibility of VISG.

Posters are tailored for individual sectors and reflect each sector's approach to volcanic risk management. Therefore the 'Advice for Airport Managers' poster simply summarises likely impacts and directs airport managers towards national and global planning and response resources, such as the International Civil Aviation Organisation (ICAO) reference guides. The involvement of Air New Zealand Ltd (the major regional airline in New Zealand) and the New Zealand Civil Aviation Authority in designing and reviewing the poster was essential to create a resource aligned with industry standards and suitable for the New Zealand aviation sector.

The restricted space in a poster format enforced concise summaries of impacts and mitigation measures. It was therefore important to be able to refer to further resources and the posters were designed to link with established, authoritative volcanic ash impact information sources. The USGS/GNS volcanic ash impacts website (<http://volcanoes.usgs.gov/ash/>) and the International Volcanic Health Hazard Network website (www.ivhhn.org) are referred to on nearly all posters,

VOLCANIC ERUPTION

RECOMMENDED ACTIONS FOR AIRPORTS



Quito airport, 2002

REDUCTION

- Develop a Volcanic Hazard Management Plan**
Ensure this includes designated ash disposal sites.
- Maintain Volcanic Hazard Management Plan**
Regularly review plan to ensure it is up to date.
- Conduct regular exercises and training**

READINESS

If warning is given that an eruption may occur, ensure stocks of the following equipment are available:

Tarpaulins / Plastic sheeting

Sufficient quantities to cover vulnerable parts of aircraft grounded during the eruption, i.e.: windshields, nose cones, engine intakes, wheel assemblies.
Further quantities to cover any machinery left outside.

Adhesive duct tape

Sufficient quantities to secure plastic sheeting to aircraft/machinery, sealing all edges.

Spare parts for essential vehicles and machinery

Air filters, oil filters, fuel filters, hydraulic fluids, seals, lubricants.

Cleaning supplies

Additional brooms, vacuum cleaner bags, cleaning fluids.

Filtration / dust masks and goggles

Sufficient masks for all involved staff for at least one week.
Sufficient goggles for workers cleaning up ash.
Adequate harnesses to secure workers to slippery roofs.
Prior to ashfall establish a tip site where ash may be dumped.

RESPONSE

Should an ash plume be generated that is likely to impact the airport, the following steps should be taken:

Activate: Emergency teams, Business Continuity Plan and ensure health and safety issues are identified for all personnel.

Decide: Fly aircraft out, cover aircraft. Immediately confirm which aircraft are to remain grounded.

Grounded Aircraft

Need to have vulnerable parts covered. Immediately confirm which aircraft are to remain grounded.

Vulnerable parts include: windcreens, pitot tubes, nose cones, engine intakes, wheel assemblies.

Use plastic sheeting/tarpaulins and adhesive (duct) tape.

All flaps, spoilers etc should be fully closed.

If a significant ashfall is expected (> 5cm), **anchor** any aircraft to the ground at the nose that have:
 - engines at the tail.
 - large surface areas (i.e. horizontal stabilizers) at rear of aircraft.

Infrastructure

Take extreme care due to slipperiness of ash.

Use as few entries/exits as possible for buildings (reduces ash entrainment from outside).

Cover electronic equipment inside buildings as fine ash may penetrate even closed buildings.

Close buildings not essential for running the airport.

Cover (where possible) intake fans or heat pump units on building exteriors.

Do not use air-conditioning systems that pump in outside air.

Damp volcanic ash may induce flashover on electrical components (causing failure and fire risk).

Some use of systems that re-circulate interior air may be possible during ashfall (expect abrasion to fan blades, bearings etc).

Clean roofs frequently during a long-term eruption to prevent ash accumulating (especially wide-span hangar-type roofs).

RECOVERY

Volcanic ash is highly abrasive and can be extremely corrosive
 - take this into account when cleaning (especially aircraft).
 - clean aircraft as quickly as possible to mitigate corrosion.

Consult volcanic ash response plan (where present) before beginning aircraft and airport clean-up.
 - ensure correct procedures are followed.

Ensure ash is disposed in appropriate/safe manner.

Check navigation systems and friction test of the runway.

Further information on dealing with volcanic ash may be found in the following locations:
<http://www.geonet.org.nz>
<http://www.gns.cri.nz/ce/here/what/earthact/volcanoes/whattodo.html>
<http://volcanoes.usgs.gov/ash/index.html>
<http://www.icao.int/anb/IAWOPSG/Doc9691.pdf>
<http://www.caa.govt.nz/>

Figure 1 Recommended actions for airports to mitigate ashfall hazard.

VOLCANIC ERUPTION

ADVICE FOR ELECTRICITY NETWORK MANAGERS



ASH IMPACTS ON ELECTRICITY DISTRIBUTION

Volcanic ash is: hard, highly abrasive, mildly corrosive and conductive.

Volcanic ashfalls can cause disruption to electricity supplies in the following ways:

- Ashfall buildup on insulators can lead to flashover (the unintended disruptive electric discharge over or around the insulator), causing disruption to distribution networks.
- Line breakages and damage to towers and poles due to ash loading, both directly onto the structures and by causing treefall onto lines, particularly in heavy, fine ashfall events. Snow and ice accumulation on lines and vegetation will exacerbate the risk
- Breakdown of substation and control equipment such as air conditioning/cooling systems due to ash penetration which can block air intakes and cause corrosion.
- Controlled outages during cleaning.

Of these, the main hazard is insulator flashover. Volcanic ashfall may also increase electrocution risks (by increasing touch potentials) to workers in substations.



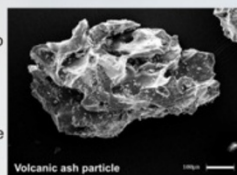
INSULATOR FLASHOVER

Factors contributing to risk of flashover include:

- Light wet weather conditions (dew, fog, drizzle or light rain) wets the ash and leads to a conductive layer forming on the surface which initiates leakage current and leads to arcing and flashover. Heavier rain will wash off contaminants.
- Ash grain size (fine ash adheres to insulators more strongly).
- Presence of other contaminants e.g. sea salt, dust, agricultural sprays, smoke.
- Elapsed time since last maintenance.
- Insulator design and construction (ability to shed ash and resist acidic corrosion).



Ashfall covers a 33kV insulator following the May 2008 Chaiten eruption, Chile



Volcanic ash particle

ELECTROCUTION RISK



Resistivity of ground gravel cover may reduce following ashfall, reducing step potential and possibly increasing touch potentials.

RISK OF LINE AND SUBSTATION INSULATOR FLASHOVER

Risk factors	Ash moisture content	Probability of failure			
		Ash thickness <5 mm		Ash thickness >5 mm	
Line voltage		Fine ash	Coarse ash	Fine ash	Coarse ash
<33 kV (domestic)	Wet	High	Low	High	Medium
	Dry	Low	Low	Low	Low
>33 kV (regional-national)	Wet	Medium	Low	High	Medium
	Dry	Low	Low	Low	Low

RISK OF DAMAGE TO TOWERS, POLES AND LINES

	Weather conditions	Ash thickness <100 mm		Ash thickness >100 mm	
		Fine ash	Coarse ash	Fine ash	Coarse ash
Towers and poles	Wet	Low-medium	Low	Medium-high	Low
	Dry	Low	Low	Medium	Low
Lines	Wet	Low-medium	Low	High	Low-medium
	Dry	Low	Low	Medium	Low

RECOMMENDED ACTIONS

Substations

- Prior to an ashfall, maintain insulators in a clean condition, especially in coastal areas
- During an ashfall, monitor buildup of ash on insulators. If conditions are wet, consider controlled outages to allow cleaning.
- Immediately after an ashfall, dispatch personnel to substations to dust, sweep and blow ash from electrical equipment, and clean roofs and gutters.
- Be aware of increased electrocution hazard if ashfall covers the ground. Isolate substations or electrical equipment before entering site.

Line insulators

- Maintain line insulators in a clean condition, especially in coastal areas.
- During an eruption, monitor buildup of ash on insulators.
- Make controlled cuts if necessary to clean insulators, or replace damaged insulators. Ensure all surfaces are cleaned, including underneath. Cost-benefit analysis will dictate whether cleaning or total replacement is appropriate.

Towers, poles and lines

- Maintain in a good state of repair; in particular ensure that lines are kept free of overhanging branches.
- During an eruption, continually monitor the network for ash accumulation on towers, lines, poles and overhanging branches.
- Replace or repair damaged components as appropriate.

General notes on cleanup of ash

- Remove dry ash from the most sensitive systems by blowing it off using air pressure of 30 psi or less, to avoid a sandblasting effect.
- Avoid rubbing or brushing equipment. Remove ash by vacuuming if possible.
- Regularly clean and/or replace vehicle and air-conditioning filters (stock spares)
- To avoid eye and respiratory irritation wear face masks and goggles
- Consider acquiring cleanup equipment (water blasters, air compressors)



The underside of a 33kV insulator coated in ash, which led to flashover, following ashfalls during the 2008 Chaiten eruption, Chile



Ash is cleaned from a 110 kV horizontal insulator string using pressurised water following the 1995 Ruapehu eruption, New Zealand. (Transpower New Zealand)

The following resources provide further information on volcanic hazards:

- <http://www.geonet.org.nz>
- <http://volcanoes.usgs.gov/ash/index.html>
- <http://www.ivhnh.org>
- <http://www.aelg.org>

Drafted by Tom Wilson, Carol Stewart & David Johnston. 26 August 2009



Figure 2 Recommended actions for Electricity Network Managers to mitigate ashfall hazard.

VOLCANIC ERUPTION

RECOMMENDED ACTIONS FOR ROADING MANAGERS

VOLCANIC ASH

Ash dispersal is dependant on prevailing wind direction

Silt to sand size, highly Abrasive, mildly Corrosive, potentially Conductive

May be ingested into engines, blocking filters and abrading the engine and other mechanical parts

Ash may contaminate areas for extended periods of time (doesn't melt like snow), and its fine grain size can make it difficult to handle compared to sand


Thick ashfalls may create extra loadings on bridges (wet ash is very heavy)

Driving Hazards

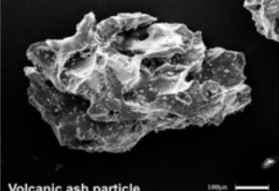
Easily re-mobilised by wind, water, and fast moving vehicles

Driving Hazards: very slippery surfaces, covers road markings, poor visibility during ashfall

Respiratory hazard (easily ingested by humans and animals)



Volcanic centres in New Zealand



Volcanic ash particle

REDUCTION

Volcanic eruptions may have a rapid onset, so emergency planning needs to be done well in advance


Develop a Volcanic Hazard Management Plan
 Identify a hierarchy of roads for priority of clean-up. Ensure this includes designated ash disposal sites and considers road closures.
 Ensure road maintenance equipment is undercover.

Maintain Volcanic Hazard Management Plan
 Regularly review plan to ensure it is up to date.


READINESS

Prior to an eruption (i.e. periods of volcanic unrest), ensure that there are stocks of the following equipment:

- Spare parts for essential road maintenance vehicles (*air filters, oil filters, fuel filters, lubricants hydraulic fluids, seals, wheel bearings, etc.*)
- Safety plan & equipment for personnel (*masks, goggles - sufficient for all staff*)
- Adequate water supply for damping down ash to reduce re-mobilisation (ideally not domestic water supply)
- Facilities for cleaning maintenance vehicles
- Establish ash disposal site (in consultation with Territorial Local Authority)



Clearing roads following ashfall in Catania, Italy during the 2002 Etna eruption (S. Barnard)



Collecting ash from roads in Yakama, Washington, United States following the 1980 Mt St Helens eruption

RESPONSE

ACTIVATE:

- emergency plan
- health and safety plan
- identify priority roads for clearance
- monitor eruption information (www.geonet.org.nz)
- monitor weather conditions (*determines where ash will be deposited*)

Ensure staff are well briefed on ash removal and safety aspects
 Be prepared to distribute information to other road users on best practices

Closely monitor performance of maintenance vehicles and health of staff


RECOVERY

Equipment should be cleaned as often as possible to mitigate damage

Ensure ash is disposed of in an appropriate manner

An on-going eruption & re-mobilised ash may continue to re-contaminate roads long after the eruption

- plan for long term management of ash clearance and disposal from sediment capture devices
- long term supply arrangements of protective and spare parts may be required



Further information on dealing with volcanic ash may be found in the following locations:





- <http://www.geonet.org.nz>
- <http://www.gns.cri.nz/ce/here/what/earthact/volcanoes>
- <http://volcanoes.usgs.gov/ash/index.html>
- <http://www.ivhnh.org>

Drafted by Tom Wilson

Figure 3 Recommended actions for Road Managers to mitigate ashfall hazard.

VOLCANIC ERUPTION

ADVICE FOR WASTEWATER MANAGERS

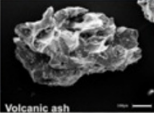





IMPACTS ON WASTE WATER NETWORKS

Volcanic ash is: highly abrasive, mildly corrosive, conductive

Volcanic ashfall can cause damage and disruption to wastewater reticulation networks and treatment plants.

Systems with combined stormwater/sewer lines are most at risk. Ash will enter sewer lines where there is inflow or infiltration of stormwater (through illegal connections, cross connections, via gully traps, around manhole covers or through holes or cracks in sewer pipes).




System component	Impacts of volcanic ashfall
Sewerage reticulation networks	Volcanic ash may form unpumpable masses in catchpits and sewer lines, which may block lines, cause overflows and damage pumping equipment by overloading motors or causing abrasional damage and accelerated wear
Pre-treatment (comminutors, millscreens)	Coarse ash is likely to block screens, cause abrasive damage to moving parts and overload mechanical equipment
Primary treatment (settling tanks)	Coarse ash will increase volume of raw sludge; fine ash may not settle. Low density pumice fragments will float.
Secondary treatment (biological reactors or oxidation ponds)	Ash deposited directly into open biological reactors, ponds and clarifiers may reduce or halt the oxidation process. Ash can also have a highly acidic surface coating that may affect bacterial processes (for example, nitrification). Trickling filter rock media can be stripped by coarse ash (if directly deposited)
Tertiary treatment (disinfection)	Any residual fine ash still present in effluent will reduce transmissivity which will reduce effectiveness of disinfection.
Sludge treatment	Acidic ash could negatively affect digester biological process and sludge dewatering equipment

It is time-consuming and expensive to remove ash from sewer lines and storm drains. In the event of an ashfall, the top priority should be preventing ash from entering stormwater drains and sewers.

In addition to entering treatment plants via sewer lines, ashfall may cause direct impacts on treatment plants:

- Heavy ashfall (>150 mm) may collapse long span roofs
- Airborne ash can clog air filtration systems, cause abrasional damage to moving parts of motors and cause arcing and flashover damage to electrical equipment
- For uncovered waste stabilisation ponds, direct ashfall may interfere with biological treatment processes.

Ashfall can also affect other critical infrastructure (electricity supply, water supply, telecommunications) which may in turn compromise the functioning of treatment plants.



CITY OF YAKIMA, USA

On 18 May 1980, Mount St Helens volcano erupted. The city of Yakima (popn 50,000), 140 km to the east, received about 1 cm of volcanic ashfall.



By the next day, about 15 times the usual amount of solid matter was being removed from the pre-treatment processes at Yakima's wastewater treatment plant. This was despite Yakima having just five percent combined sewage and stormwater lines.

Ash was also observed in the raw sludge in the primary clarifiers.

Two days later, it was evident that the facility was suffering as vibrations were occurring in the grit classifier and the gear box of the mechanically-cleaned bar screen. Raw sewage lines became blocked.

On 21 May the City Manager announced a decision to bypass the treatment plant and discharge sewage directly to the Yakima River.

The total damage to the Yakima plant was estimated to be US\$4 million.

RECOMMENDED ACTIONS


FOR WASTEWATER TREATMENT PLANTS

Prior to an ashfall

- Review stocks of essential items such as treatment chemicals and spare parts
- Ensure access to backup power generation

In event of ashfall

- Cover all external equipment with plastic
- Shut down ventilation equipment where possible
- Maintain a clean site to reduce contamination
- Shut down all equipment not strictly required
- Put all available pre-treatment equipment into operation at maximum removal rates
- Put all primary clarifiers in operation and increase pumping rates
- Shut down biofilters and cover (if open-air)
- Monitor all processes for presence of ash, step up preventative maintenance
- Monitor torque on all motor-driven equipment
- Consider bypassing pumping stations and treatment plant as a protective measure to avoid plant damage/destruction



Prior to an ashfall:


- Minimise stormwater entry to network, such as by enforcing regulations on illegal connections, remediating cross-connections and maintaining pipes in good repair
- Ensure backup power generation for critical pump stations

In event of ashfall

- Instruct public where to deposit ash cleared from property
- Warn citizens against dumping ash into gully traps, stormwater drains, manholes and cesspits
- If hosing ash from streets, place sandbags around or over drains, cesspits and manhole covers to reduce inflow of ash to sewers

The following resources provide further information on volcanic hazards:

- <http://www.geonet.org.nz>
- <http://www.gns.cri.nz>
- <http://volcanoes.usgs.gov/ash/index.html>
- <http://www.lvhn.org>



24 August 2010
 Drafted by Carol Stewart, Tom Wilson, Scott Barnard and David Johnston

Figure 4 Recommended actions for Water Supply Managers to mitigate ashfall hazard.

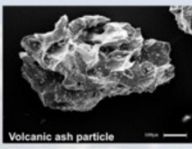
VOLCANIC ERUPTION

ADVICE FOR WATER SUPPLY MANAGERS


IMPACTS ON WATER SUPPLIES

Volcanic ash is: highly abrasive, mildly corrosive, conductive

Freshly-fallen volcanic ash may result in: short-term physical and chemical changes in water quality; increased wear on water delivery and treatment systems; disruption of electrical power supplies; and high demand for water during clean-up.



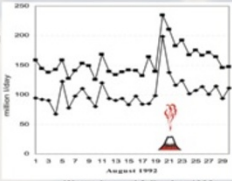
Impact	Comment
Physical impacts of ash	Ash can clog intake structures
	Abrasive nature of ash can cause increased wear on equipment
	Corrosive nature of ash can damage electrical equipment and corrode metallic structures such as pipes
Water shortages	Heavy demands on water for clean-up of ashfall, potentially leading to water shortages
Increased turbidity	Suspension of ash in water increases turbidity; this can make water undrinkable and compromise terminal disinfection
Acidification	Surface coatings on fresh ash are highly acidic; due to adsorbed volcanic aerosols H ₂ SO ₄ , HCl, HF
Fluoride contamination	Fluoride from HF readily leached from fresh ash; can exceed safe limits for people and animals
Other contamination	Freshly-fallen ash releases soluble components (e.g. sulphate, chloride, iron, aluminium, calcium) into receiving waters. This can taint and discolour water.



Check GeoNet for latest volcanic alert levels (<http://www.geonet.org.nz>)

WATER DEMAND

High demand for water typically occurs after an ashfall and can lead to temporary water shortages.



Water demand following 1992 eruption of Mt Spurr Alaska

This may compromise key services, such as fire-fighting capacity.

PUBLIC HEALTH IMPACTS

Public anxiety about contamination of water supplies is common after a volcanic ashfall. Timely and transparent communication of risks to the public is advised.

The main public health issues are:

- 1) Hygiene and sanitation problems can arise if water supplies are disrupted following volcanic activity.
- 2) High levels of suspended ash (turbidity) can inhibit disinfection of drinking water, which may lead to outbreaks of infectious disease if treatment (e.g. chlorination) is not adjusted accordingly.
- 3) Elevated fluoride concentrations may be a problem following some types of volcanic eruptions.

Component	Type of standard	Value	Effects if exceeded
Fluoride	Maximum Acceptable Value (health standard)	1.5 mg/L	Dental and skeletal fluorosis may result from long-term exposure to elevated levels
pH	Guideline value	7.0-8.5	Plumbosolvency is associated with low pH; this can lead to dissolution of toxic metals from metal fittings, and water may be discoloured, bitter and metallic-tasting
Turbidity	Guideline value	2.5 NTU	To protect appearance of drinking water

Authorities will analyse volcanic ash composition and advise on the presence of any toxic elements that may pose a health hazard.

In general ashfall is likely to make water undrinkable (metallic-tasting and discoloured) before it presents health risks.

EFFECTS ON EQUIPMENT

Suspended ash in water can:

- block intake structures
- cause abrasional damage and increased wear of equipment
- block filters and clarifiers and generate increased waste
- decrease pH which can in turn increase plumbosolvency.

Airborne ash particles can:

- clog air filtration systems, causing overheating and engine/motor failure
- abrade and scratch moving parts of equipment and motors
- cause arcing and flash-over damage to electrical equipment.

RECOMMENDED ACTIONS

Anticipate increased water demand for clean-up operations

- conserve water for human consumption
- where possible use alternative, non-potable sources of water for clean-up and fire-fighting, and encourage clean-up with brooms and shovels rather than hoses


Monitor potentially hazardous components of water (pH, turbidity, fluoride)

Review stocks of essential items such as spare filters and treatment chemicals

Ensure access to back-up power generation


Take precautions to keep ash out of water supply equipment/plant:

- close water supply intakes before turbidity levels become excessive
- consider adding coagulation/flocculation agent to reduce turbidity
- cover filter-beds and clarifiers
- protect other exposed equipment such as electrical control panels
- maintain clean site to reduce contamination.



The following resources provide further information on volcanic hazards:

<http://www.geonet.org.nz>
<http://www.gns.cri.nz>
<http://volcanoes.usgs.gov/ash/index.html>
<http://www.lvhn.org>



Drafted by Carol Stewart, Tom Wilson, & David Johnston. 27 February 2009

Figure 5 Recommended actions for Waste Water Managers to mitigate ashfall hazard.

VOLCANIC ASH

ASH IMPACTS ON DRINKING WATER TREATMENT

EFFECTS ON RAW WATER SOURCES

WATER DEMAND

EFFECTS ON TREATMENT PLANTS

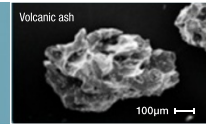
RECOMMENDED ACTIONS

ADVICE FOR WATER SUPPLY MANAGERS

VOLCANIC ASH IS: HARD, HIGHLY ABRASIVE, MILDLY CORROSIVE AND CONDUCTIVE WHEN WET.

A VOLCANIC ASHFALL CAN:

- Increase turbidity in raw water sources
- Create high water demand during the cleanup phase.
- Cause operational problems for water treatment plants

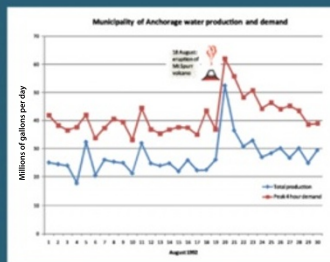


IN GENERAL, THE MAJOR EFFECT OF ASHFALL ON RAW WATER SOURCES IS LIKELY TO BE INCREASED TURBIDITY RATHER THAN CHANGES IN CHEMICAL COMPOSITION.

EFFECTS OF ASHFALL ON RAW WATER QUALITY

Turbidity	Ash suspended in water will increase turbidity in raw water sources. Very fine ash may settle slowly and residual turbidity may remain in standing water bodies. In streams, ash may continue to be remobilised by rainfall events, and lahars may be a hazard in some regions.
Acidity	Fresh ashfall commonly has a strongly acidic surface coating. This may cause a slight depression of pH (not usually beyond pH 6.5) in low-alkalinity surface waters.
Potentially toxic elements	Fresh ash has a surface coating of soluble salts that are rapidly released on contact with water. The most abundant soluble elements are typically Ca, Na, S and Cl, followed by Mg, K, Al, Si, Fe and F. Compositional changes depend on the ash surface chemistry, the amount of ashfall and the dilution volume. <ul style="list-style-type: none"> • In streams, there will be a short-lived pulse of dissolved constituents. • In lakes and reservoirs, the volume of dilution is usually large enough that compositional changes are not discernible. The constituents most likely to be elevated above background levels are Fe, Mn and Al. Thus water is likely to become unpalatable due to discolouration or a metallic taste before it becomes a health hazard.

HIGH DEMAND FOR WATER TYPICALLY OCCURS AFTER AN ASHFALL DURING THE CLEANUP PHASE. Demand may remain high for months afterwards if water is needed to dampen down wind-remobilised ash.



The 18 August 1992 eruption of Mt Spurr volcano, Alaska, deposited around 3 mm of sand-sized volcanic ash on the city of Anchorage. The population used mostly wet methods to clean up the ash, creating a peak water demand which resulted in water shortages and loss of pressure in some parts of the city due to bottlenecks in the distribution system. This incident prompted a major upgrade of the city's distribution network.



VOLCANIC ASH CAN CAUSE A RANGE OF OPERATIONAL PROBLEMS FOR WATER TREATMENT PLANTS.

- Turbidity may be satisfactorily removed by normal coag/floc treatment
- If turbidity exceeds normal operating range of plant for flood flows, suspended ash may penetrate further into plant and block filtration equipment.
- Ash is highly abrasive and likely to cause accelerated wear on pump impellers
- Ash can penetrate bearings and seals and overload motors

An ashfall is unlikely to cause service interruptions for water treatment plants, but a great deal of increased maintenance can be expected. Ash-induced electricity outages are the most common cause of disruptions to water production after an eruption.



Ash can enter sand filter beds both from direct fallout, and through the intake. Cleaning of filter beds creates heavy additional labour demands, such as at Bariloche WTP following the June 2011 Puyehue Cordón-Caulle eruption (below)

WHERE TO FIND WARNING INFORMATION

See www.geonet.org.nz for ashfall forecasts in the event of an explosive eruption.

HOW TO PREPARE

PLANNING

At-risk water treatment plant should ensure that their PHRMPs include provision for ashfall events, including site cleanup. The plan should have procedures for incorporating up-to-date information from GeoNet into operational decisions.

Anticipate increased water demand following an ashfall. Where possible, use alternative, non-potable sources of water for cleanup and firefighting. Do not use recycled wastewater (e.g. treated effluent) for these purposes. Encourage cleanup using brooms and shovels rather than hoses.

Anticipate increased maintenance schedule: review stocks of essential items.

Ensure access to back-up power generation.

HOW TO RESPOND

Take precautions to exclude ash:

- Close intake before turbidity levels become excessive
- If necessary adjust coagulation/flocculation dosage to remove excess turbidity
- Consider covering open filter beds and clarifiers
- Protect other exposed equipment such as electrical control panels
- Maintain a clean site to reduce contamination.

Ensure regular monitoring of turbidity, pH, chlorine residuals and indicator bacteria in distribution network.

Be aware of the possibility of pH depression in low-alkalinity water sources and adjust any pH-sensitive treatment steps as required. For treatment processes that do not include pH adjustment, remind consumers of the need to flush their taps briefly before drawing water.

Public anxiety about contamination of water supplies is common after a volcanic eruption. Refer concerns to the Drinking-Water Assessor at the Public Health Unit of your local DHB.

THE FOLLOWING RESOURCES PROVIDE FURTHER INFORMATION ON VOLCANIC HAZARDS:

- <http://www.geonet.org.nz>
- <http://www.gns.cri.nz>
- <http://volcanoes.usgs.gov/ash/index.html>
- <http://www.ivhnn.org>

DRAFTED BY CAROL STEWART & TOM WILSON.
 30 January 2013



Figure 6 Volcanic Ash: Advice for Water Supply Managers.

VOLCANIC ASH

IMPACTS ON WASTEWATER COLLECTION AND TREATMENT SYSTEMS

RECOMMENDED ACTIONS

ADVICE FOR WASTEWATER MANAGERS

VOLCANIC ASH IS: HARD, HIGHLY ABRASIVE, MILDLY CORROSIVE AND CONDUCTIVE WHEN WET.

VOLCANIC ASH CAN CAUSE SERIOUS DAMAGE TO WASTEWATER TREATMENT PLANTS.

- Cities with combined stormwater and sewer lines are particularly at risk
- Ash will enter sewer lines where there is inflow or infiltration (through illegal connections, cross connections, gully traps, manhole covers, cracks in sewer pipework etc).



SYSTEM COMPONENT	IMPACTS OF VOLCANIC ASHFALL
Sewerage pumping network	<ul style="list-style-type: none"> • Ash may form unpumpable masses in sewer lines and catchpits which may cause blockages and overflows. • Ash in sewer lines will cause accelerated damage to pump impellers (pitting and thinning of metal). • Ashfalls can cause power outages which will affect pumping stations without backup generation. Lack of pumping can lead to overflows if storage capacity is exceeded.
General effects on plant	<ul style="list-style-type: none"> • Expect accelerated wear and tear on pump components (pistons, impellers, seals, etc).
Pre-treatment equipment	<ul style="list-style-type: none"> • Ash may damage comminutors and grit classifiers. • Coarse (>1 mm) ash is likely to block mechanical screening equipment, overloading motors and gear boxes. <p>Mechanical pre-treatment equipment is highly vulnerable to damage from ash-laden raw sewage. To avoid serious damage, consider bypassing treatment plant.</p>
Primary settling tanks	<ul style="list-style-type: none"> • Coarse ash will increase volume of sludge for disposal. • Ash will change the proportion of organic to inorganic matter entering the plant.
Secondary treatment	<ul style="list-style-type: none"> • Ash will enter open reactors and tanks from direct fallout but the main ingress is likely to be through the sewer lines. • The main effect is likely to be reduced capacity (due to ash accumulation on tank floors) rather than interference with bacterial processes. • Cleaning reactors while operational is difficult.
Tertiary treatment	<ul style="list-style-type: none"> • Any residual very fine ash may increase suspended solid load of effluent, which may interfere with disinfection.
Sludge treatment	<ul style="list-style-type: none"> • Expect an increased mineral content of sludge.

CASE STUDY: CITY OF YAKIMA, WASHINGTON STATE, USA

Volcanic ash can cause serious damage to wastewater treatment plants. The City of Yakima, Washington State, USA, sustained US\$4 million (1990 value) damage to its plant following the 1990 eruption of Mt St Helens volcano which deposited approximately 10 mm of sand-sized ash on the city. This was primarily due to damage to the mechanically-cleaned bar screen and grit classifier.



Ashfall will cause accelerated wear and tear on sewage pump impellers (metal pitting and thinning)

WHERE TO FIND WARNING INFORMATION

See www.geonet.org.nz for ashfall forecasts in the event of an explosive eruption.

HOW TO PREPARE

PLANNING

At-risk wastewater treatment plant should develop operational plans for ashfall events, including site cleanup. Plans should include provision for:

- incorporating up-to-date information from GeoNet into operational decisions;
- monitoring the presence of ash in raw sewage;
- monitoring torque on motor-driven equipment;
- shutting down non-essential equipment;
- covering exposed equipment such as HVAC systems, switchboards and electric motors to protect them from airborne ash;
- limiting the ingress of ash into buildings;
- equipment and labour requirements for site cleanup; and
- coordination with local and regional emergency plans.

Review stocks of essential items, as an ashfall may affect road and air transport.

Ensure access to back-up power generation, particularly for pumping stations

HOW TO RESPOND

Work with local authorities to limit ingress of ash into stormwater drains and sewer lines.

Step up preventive maintenance.

Be aware that increased maintenance and site cleanup will create significant additional labour demands.

Consider bypassing pumping stations and treatment plant as a protective measure to avoid severe and costly damage to pumping and pre-treatment equipment.



THE FOLLOWING RESOURCES PROVIDE FURTHER INFORMATION ON VOLCANIC HAZARDS:

- <http://www.geonet.org.nz>
- <http://volcanoes.usgs.gov/ash/index.html>

- <http://www.ivhnh.org>
- <http://vattlab.org>

DRAFTED BY TOM WILSON, CAROL STEWART & JOHNNY WARDMAN.

20 January 2013



Figure 7 Volcanic Ash: Advice for Wastewater Managers.



IMPACTS ON POWER GENERATION FACILITIES

ADVICE FOR POWER PLANT OPERATORS

VOLCANIC ASH IS: HARD, HIGHLY ABRASIVE, MILDLY CORROSIVE AND CONDUCTIVE WHEN WET.

GENERAL IMPACTS:

- **Flashover:** Ash contamination of station and line insulators leading to flashover is the most common impact at power plants
 - » See companion poster "Advice for Power Transmission and Distribution System Operators"
- **Step/Touch Potential:** ash may reduce the resistivity of ground gravel cover, reducing tolerable step and touch voltages
- **Disruption to Control Systems:** ash ingress into heating, ventilation and air-conditioning (HVAC) systems can block intakes leading to reduced performance, and affecting dependent systems
- **Structural damage:** Very thick ash deposits (>100 mm) may create excessive loads on structures
 - » Long span, low pitched roofs are typically the most vulnerable
 - » When ash is wet, static loads may increase by up to 100%
- **Internal gutters:** may block with ash, potentially leading to water ingress to indoor electrical equipment.

HYDROELECTRIC POWER STATIONS

- Ash suspended in intake water can cause accelerated wear of hydroelectric turbines (e.g. runner blades, labyrinth seals, cheek plates and wicket gates)
 - » Hazard depends on volume of ash deposited in catchment, reservoir size, settling rate of ash, abrasiveness of ash
- Ash may also fill rain gauges in climate stations throughout river and reservoir catchments.

THERMAL POWER STATIONS

There are few case studies to guide possible impacts or advice.

- Ash may block air intakes for gas turbines and boilers, or sub-aerial condenser systems causing blockages, abrasion and creating cleaning difficulties
 - » Ash falls have created airborne particle concentrations of up to 9 g m^{-3} , several times higher than dust- or sand-storms
- Mechanical seals may be vulnerable to abrasion and corrosion by ash
- Fine ash ingested into gas turbines may cause accelerated wear or melt on turbine surfaces (similar to an aircraft turbine)
- Ash may contaminate exposed surface water cooling reservoirs, potentially blocking heat-exchange systems.



Accelerated abrasion damage to wicket gates from Agyan HEP, Ecuador. Normal design life of turbines at this plant is 6-7 years, but this has been reduced to 5 years due to ashfalls from nearby Tungurahua volcano contaminating reservoir water.



The October 1995 eruptions of Ruapehu volcano deposited 7.6 million m^3 of coarse ash into the Tongariro river catchment, leading to high levels of suspended ash. This catchment feeds the Rangipo power station (120 MW). While generation remained continuous throughout the eruption, two Francis turbines and all auxiliary components that had been in contact with ash-laden intake water were found to have suffered greatly accelerated abrasion damage, with 16 years' damage sustained in 6-7 months. A refurbishment program installed hardened components. Turbidity instrumentation was also installed at the intake point which is closed when thresholds are exceeded.

RECOMMENDED ACTIONS

WHERE TO FIND WARNING INFORMATION

See www.geonet.org.nz for ashfall forecasts in the event of an explosive eruption.

HOW TO PREPARE

At-risk power generation facilities should develop operational plans for ash fall events, including:

- Install turbidity monitoring instrumentation at intake and identify threshold for intake closure
- Priority schedule for inspecting/cleaning essential sites and components
- Site cleanup may be required following an ash fall. Cleanup plans should include:
 - » Standardised ash fall clean-up procedures, suitable to your local conditions and site
 - » Stock or have access to sufficient supplies and equipment for cleaning;
 - » Clean up and additional maintenance can create significant additional labour and resource demands
 - » Insulators usually require cleaning. See the companion "Transmission and Distribution" poster and IEEE Std 957 "Guide for Cleaning Insulators". Ensure that roofs and similar elevated areas where ash accumulation will need to be removed, have pre-installed fall arrest anchor points and that a safe means of access is identified

- Field crews should use safe operating procedures when operating in an 'ashy' environment. See www.IVHHN.org for guidelines for protecting people from ash hazards
- Transmission/distribution lines feeding the generation site may be disrupted and require additional planning – see "Transmission and Distribution" poster
- Hydroelectric plant (HEP) facilities may consider hardening turbines during design and refurbishment programmes.

HOW TO RESPOND

- Consider increased inspection and preventative maintenance
- Seal key facilities to limit ash ingress. See companion "Facilities Managers: Buildings" poster
- Clean up site to reduce remobilisation of ash and thus recontamination of energised components. Use dry methods where possible
 - » Remove ash from gutters to avoid localised flooding
 - » Internal gutters may require suction cleaning
- Be aware of increased electrocution hazard if ash covers the ground. Isolate and earth energised apparatus before entering site
- **Hydroelectric Power Plants:** Monitor the suspended solid load in water intakes. Be mindful of volcanic debris flows (lahars). Consider by-passing turbines, if necessary
- **Geothermal/thermal:** assess ash hazard and consider shut-down if necessary.

DRAFTED BY TOM WILSON, JOHNNY WARDMAN AND CAROL STEWART.

20 September 2013

MORE INFORMATION

THE FOLLOWING RESOURCES PROVIDE FURTHER INFORMATION ON VOLCANIC HAZARDS:

- <http://www.geonet.org.nz>
- <http://www.gns.cri.nz>
- <http://volcanoes.usgs.gov/ash/index.html>
- <http://www.ivhhn.org>



Figure 8 Volcanic Ash: Advice for Power Plant Operators.

VOLCANIC ASH

IMPACTS ON TRANSMISSION AND DISTRIBUTION NETWORKS

INSULATOR FLASHOVER

SUBSTATIONS

RECOMMENDED ACTIONS

ADVICE FOR POWER TRANSMISSION AND DISTRIBUTION SYSTEM OPERATORS

VOLCANIC ASH IS: HARD, HIGHLY ABRASIVE, MILDLY CORROSIVE AND CONDUCTIVE WHEN WET.

- **Insulator Flashover** : Ash contamination of station and line insulators can lead to flashover.
 - » Flashover may occur with <3 mm of ash fall provided a significant portion of the insulator creepage distance (>50%) is covered in wet ash;
 - » This is the most common and widespread impact;
- **Loading Damage** : ash accumulation may overload lines, weak poles and light structures, and cause additional tree-fall onto lines. Precipitation will exacerbate the risk;
 - » Typically occurs with >100 mm ash accumulation;
 - » Induced tree fall from ash load may occur with thicknesses >10 mm;
- **Disruption to Control Systems** : ash ingress into heating, ventilation and air-conditioning (HVAC) systems can block intakes leading to reduced performance, and affecting dependent systems;
 - » Possible during any thickness of ash fall;
- **Earth Potential Rise** : Ash may reduce the resistivity of substation ground gravel cover, reducing tolerable step and touch voltages;
 - » Not observed, but theoretically possible.



ASH RESISTIVITY AND ASH COVERAGE OF THE PROTECTED LEAKAGE (CREEPAGE) DISTANCE OF INSULATORS ARE THE PRIMARY CONTROLS ON FLASHOVER LIKELIHOOD

- Dry ash is highly resistive. Wet ash can be highly conductive
 - » Light precipitation (dew, fog, drizzle or light rain) wets ash which initiates a leakage current, leading to flashover.
 - » Heavy rain will wash off contaminants, and high winds will clean non-cemented dry ash from insulators.
- Flashover may occur with <3 mm of ash fall provided a significant portion of the insulator creepage distance (e.g. >50%) is covered in wet ash
- Ash adherence is often variable, ranging from non-binding to cementing. Fine grained ash (<0.5mm) typically adheres and cements to insulators more readily.
- Insulator profile, orientation and material will influence its ability to shed or retain ash.
 - » **Material:** Non-ceramic (e.g. polymer) insulators generally outperform ceramic designs and have smaller shed diameters which appear to shed ash more effectively
 - » **Design:** Anti-pollution insulator designs can increase performance
 - » **Orientation:** evidence suggests suspension (vertical) insulator strings are generally more vulnerable, but this depends on the direction of falling ash and weather conditions
- Overseas experience suggests over-insulation (increasing creepage distance) and clean insulators are the most effective mitigation. See IEC TS 60815 'Selection and dimensioning of high-voltage insulators for use in polluted conditions'.



3 mm of ash fall cover on a glass insulator string inducing a flashover. Note how the current is tracking through the volcanic ash covered insulator surface

- Specialist inspection and cleaning procedures may be required for substation insulators, power transformer HVAC systems and control systems;
- Ash may reduce the resistivity of substation ground gravel cover, reducing tolerable step and touch voltages

WHERE TO FIND WARNING INFORMATION

See www.geonet.org.nz for ashfall forecasts in the event of an explosive eruption. www.geonet.org.nz

HOW TO PREPARE

- Cleaning ash contaminated sites and components, especially insulators, is commonly required after an ash fall. Ensure availability of both live-line and de-energised cleanup plans which include:
 - » Priority schedule for inspecting/cleaning essential sites and lines
 - » Standardised ash fall clean-up procedures
 - » Ready access to cleaning supplies and equipment (air compressors, water-blasters, PPT gear, vehicle air filters,)
- Cleaning Guidance: see IEEE Std 957 'Guide for Cleaning Insulators'. Experience suggests:
 - » Ensure all insulator surfaces are cleaned, including undersides of weathersheds
 - » Insulator cleaning method will be determined by strength of ash adherence:
- Field crews should use safe operating procedures when operating in an 'ashy' environment. See www.ivhhn.org for guidelines for protecting people from ash hazards
- Coordinate with local, regional and national emergency planning, as appropriate

HOW TO RESPOND

- Initiate priority schedule for inspection and cleaning. Increased inspection and preventive maintenance may be prudent.
- A proactive communication campaign for customers/public covering your response, expected outages/restoration times and recommended actions aids awareness and good will
 - » Advise customers not to clean electrical equipment and to be careful when using hoses near electrical equipment.



Ash is cleaned from a 220 KV strain insulator string using pressurised water following the 1995 Ruapehu eruption, New Zealand (Transpower New Zealand)

MORE INFORMATION

THE FOLLOWING RESOURCES PROVIDE FURTHER INFORMATION ON VOLCANIC HAZARDS:

- <http://www.geonet.org.nz>
- <http://www.gns.cri.nz>
- <http://volcanoes.usgs.gov/ash/index.html>
- <http://www.ivhhn.org>

DRAFTED BY TOM WILSON, CAROL STEWART AND JOHNNY WARDMAN.
28 May 2013



Figure 9 Volcanic Ash: Advice for Power Transmission and Distribution System Operators.

VOLCANIC ASH FAL

ADVICE FOR ROADING MANAGERS

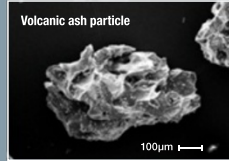
VOLCANIC ASH IS: HARD, HIGHLY ABRASIVE, MILDLY CORROSIVE AND CONDUCTIVE WHEN WET.

IMPACTS ON ROAD NETWORKS

ROAD NETWORKS ARE VULNERABLE TO ASH IMPACTS, BUT CAN BE KEPT OPERATIONAL:

- Visibility can be severely reduced during an ashfall;
- Visibility can be severely reduced after an ashfall if there is remobilisation of ash by wind or traffic;
- Ashfalls >1 mm depth may cover road markings;
- Ash reduces traction, in both dry and wet conditions. Ashfalls >50 mm may make roads impassible when wet;
- Very thick ashfalls may create extra loading on bridges, especially when wet. Ash remobilised in rivers may also create a risk of mud-flows (lahars).

The road closure threshold is dependent on the ash fall depth and characteristics, road gradient and local weather conditions.



DAMAGE TO VEHICLES

ASH MAY CAUSE A RANGE OF DAMAGE TO VEHICLES:

- abrasion to windscreens
- clogging of air and oil filters
- abrasion of moving engine parts
- corrosion of exposed metal surfaces.
- abrasion damage to paintwork

CASE STUDY FUTALEUFU, CHILE

The May 2008 eruption of Chaiten volcano, Chile, deposited 30-40 mm of fine-grained rhyolitic ashfall on the town of Futaleufu, Chile.



Clearing main road in the town of Futaleufu, Chile



Driving in approximately 10 mm ashfall, near Futaleufu.

RECOMMENDED ACTIONS

WHERE TO FIND WARNING INFORMATION

See www.geonet.org.nz for ashfall forecasts in the event of an explosive eruption.

HOW TO PREPARE

PLANNING

At-risk regions should develop operational plans for volcanic ashfall. These should include:

- Identification of a hierarchy of roads for priority of cleanup;
- Road closure protocols;
- Equipment and labour requirements for cleanup operations;
- Identification of ash disposal sites;
- Coordination of plans with local and regional emergency plans.

HOW TO RESPOND

IF OPERATING MACHINERY OR VEHICLES:

Check, clean and replace air and oil filters regularly.

Wash windscreens, painted and metals surfaces rather than wiping, to avoid abrasion damage. Avoid using windscreen wipers.

Apply lubricant/grease more frequently and check for wear.

MANAGEMENT OF ROADING NETWORK

Advise public to reduce non-essential travel.

If ashfalls are causing traction or visibility problems, implement safety measures such as reduced speed advisories, one-way rules, headlights on and ensuring a safe following distance.

CLEANUP

Ash cleanup can be expensive and time-consuming. It can be complicated by ongoing volcanic activity producing further ashfalls, or by wind remobilisation of deposited ash. See 'Advice for ash cleanup' poster in this series for more specific guidance. General principles are to:

- Clean roads as soon as possible, to reduce remobilisation problems and to make safe;
- In urban areas, take steps to prevent ash from entering storm drains or sewers, as it can block underground pipework and be extremely difficult to remove, and can cause severe damage to wastewater treatment plants;
- Ensure that field crews wear appropriate protective clothing (long-sleeved clothing, approved face masks and goggles) when operating in ash environments;
- Dispose of ash in appropriate sites;
- Communicate work schedule with other stakeholders and the public.

THE FOLLOWING RESOURCES PROVIDE FURTHER INFORMATION ON VOLCANIC HAZARDS:

- <http://www.geonet.org.nz>
- <http://www.gns.cri.nz>
- <http://volcanoes.usgs.gov/ash/index.html>
- <http://www.ivhnh.org>

DRAFTED BY TOM WILSON, CAROL STEWART, GRANT WILSON AND MARLENE VILLEMURE.

7 February 2013



Figure 10 Volcanic Ash: Advice for Roading Managers.



ADVICE FOR URBAN CLEAN-UP OPERATIONS

VOLCANIC ASH IS: HARD, HIGHLY ABRASIVE, MILDLY CORROSIVE AND CONDUCTIVE WHEN WET.

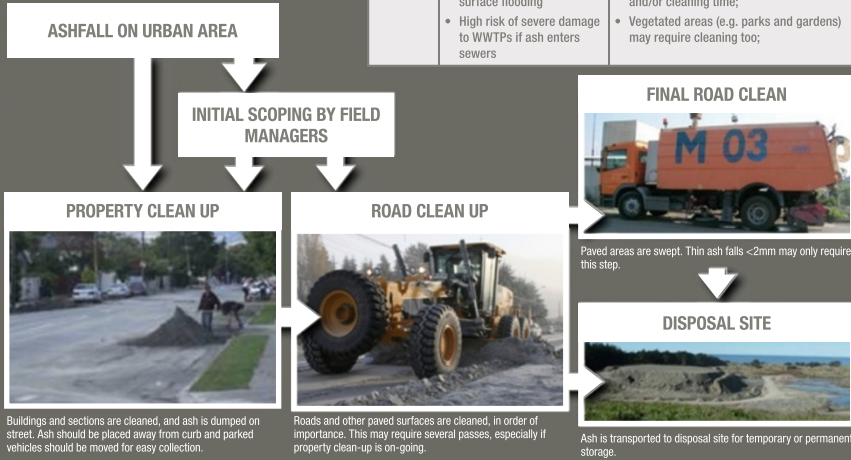
- Prompt clean-up of urban areas is essential to minimise damage and disruption
- Ashfalls of only a few mm depth will generate large volumes of ash for collection and disposal

EFFECT OF ASH CHARACTERISTICS

- Some ashes may 'cement' over time, especially if saturated and then dried
- Fine grained ash (<0.5 mm particle size) readily remobilises, so may require a binding agent
 - » For more information: <http://volcanoes.usgs.gov/ash/remove.html>
- Coarse ash (>1 mm) is less easily-remobilised, but may be crushed when driven on or moved
- Some ashes are extremely abrasive and can cause greatly accelerated wear on equipment. Refer to 'Advice for Roading Managers' poster

ASHFALL DEPTH	TYPICAL IMPACTS IF NOT CLEANED UP	SCALE OF CLEAN-UP
<0.5 mm	Minimal	• Usually no action required
0.5-2 mm	• Minor traffic hazards due to covering of road markings and loss of traction.	Minor clean-up • Sweeping of roads, paved areas, and roofs/gutters usually sufficient.
2-30mm	• Significant traffic hazards • Gutter collapse/blockage • Ash may block storm drains • Risk of severe damage to wastewater treatment plants (WWTPs) if ash enters sewer lines	Moderate clean-up • All roads and paved areas on public and private properties require cleaning; • Private properties require assistance with clean-up • Need for coordination of clean-up • Ash dump(s) established.
>30 mm	• Severe traffic hazards • Blockage of storm drains and/or sewers, leading to surface flooding • High risk of severe damage to WWTPs if ash enters sewers	Major clean-up • As above, but with significantly larger volumes which will require greater resources and/or cleaning time; • Vegetated areas (e.g. parks and gardens) may require cleaning too;

ASH CLEAN-UP GUIDE



RECOMMENDED ACTIONS

WHERE TO FIND WARNING INFORMATION

See www.geonet.org.nz for ashfall forecasts in the event of an explosive eruption.

HOW TO PREPARE

- Further guidance on ash clean up and disposal is available from:
 - » http://www.aelg.org.nz/volcanic-impacts/visg_home.cfm
 - » <http://volcanoes.usgs.gov/ash/remove.html>

Areas exposed to ash hazards should have plans in place beforehand covering the following aspects:

- **Personnel and equipment requirements.** Include mutual support agreements for ash clean-up as part of regional contingency planning
- **An incident management system/database** to manage the clean-up operation
- **Identification of potential disposal sites** on a regional basis as part of contingency-planning
- **Strategies for stabilisation of deposits**

Spontaneous volunteerism: Volunteer labour can significantly speed clean-up operations, but requires effective management and integration with professional crews

- The following may help: regular briefings, liaison officers, provision of appropriate equipment and health and safety support

MORE INFORMATION

THE FOLLOWING RESOURCES PROVIDE FURTHER INFORMATION ON VOLCANIC HAZARDS:

- <http://www.geonet.org.nz>
- <http://www.gns.cri.nz>
- <http://volcanoes.usgs.gov/ash/index.html>
- <http://www.ivhnh.org>

HOW TO RESPOND

Avoid cleanup until ash has stopped falling where possible.

- Clear and ongoing communication with the public during clean-up operations aids efficiency, public trust and goodwill

Coordination

- Prioritize clean-up (i.e. arterial routes, key facilities, etc.)
- Avoiding or limiting ash ingress into storm-water networks is a key consideration
 - » Wet clean up methods should only be used where storm-water drains have been isolated.
- A coordinated clean-up of neighbourhoods will optimise use resources and reduce recontamination of cleaned sections

Machinery may need additional maintenance in the ashy conditions. See companion poster "Advice for Roading Managers" for recommended advice (http://www.aelg.org.nz/volcanic-impacts/visg_home.cfm)

Health and Safety

- Workers and volunteers involved in clean-up operations can be exposed to high concentrations of airborne ash particles
 - » See www.ivhnh.org for more information on Personal Protective Equipment guidance
- Advise extreme caution as many injuries and some fatalities have occurred during ash clean-up operations, particularly due to falls from roofs or ladders.

DRAFTED BY TOM WILSON, CAROL STEWART AND MARLENE VILLEMURE.

20 September 2013



Figure 11 Volcanic Ash: Advice for Urban Clean-up Operations.

VOLCANIC ASHFALL

ASH IMPACTS TO AIRPORTS

ADVICE FOR AIRPORT OPERATORS

VOLCANIC ASH IS: HARD, HIGHLY ABRASIVE, MILDLY CORROSIVE AND CONDUCTIVE WHEN WET.

ASH IS HAZARDOUS TO AIRCRAFT.

- It can cause engine failure and severe abrasion to exposed surfaces
- **ASHFALL MAY REQUIRE AIRPORTS TO CLOSE. TYPICAL IMPACTS INCLUDE:**
- Difficult landing conditions due to reduced runway friction, especially when ash is wet.
- Loss of local visibility when ash on the ground is disturbed by engine exhausts during takeoff and landing.
- Ingestion of remobilised ash into jet engines during taxi-ing, takeoff and landing.
- Deposition of ash on hangars and parked aircraft, with structural loading considerably worsened if ash becomes wet.
- Contaminated ground-support systems.

ASH ACCUMULATIONS OF LESS THAN 1 MILLIMETRE MAY BE SUFFICIENT TO TEMPORARILY CLOSE SOME AIRPORTS.

Cleaning up airports after an ashfall is a time-consuming, costly and resource intensive operation. The complexity and immensity of this task should not be underestimated.

ASH IN AIRSPACE IN THE VICINITY OF AIRPORTS MAY ALSO CAUSE DISRUPTIONS TO AIRPORTS EVEN IF IT DOES NOT ACCUMULATE ON THE GROUND.



3-5 mm of ash fall at Mariscal Sucre International Airport in Quito, Ecuador, following the 3 November 2002 eruption of Reventador volcano. The airport closed for 8 days due to the ash deposition on aircraft and runways.

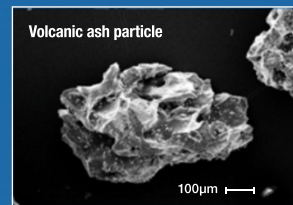


5-10 mm of ash fall at San Carlos de Bariloche International Airport in Bariloche, Argentina, following the June 2011 eruption of Peñufoe Cordón-Caulle volcano in Chile. The airport closed for 31 days due to the on-going ash falls, remobilisation of ash and cleanup.

WARNING INFORMATION

WHERE TO FIND WARNING INFORMATION

- **ASH CLOUD FORECAST** (ash suspended in atmosphere): The Wellington Volcanic Ash Advisory Centre (VAAC) will issue Volcanic Ash Advisories (VAA) and Graphics (VAG) forecasts on suspended ash in the atmosphere affecting aviation. See: <http://vaac.metservice.com/>
- **ASHFALL FORECAST** (ash falling to ground): GeoNet (GNS Science) will provide ashfall forecasts in the event of an explosive eruption (see: geonet.org.nz).
- **AVIATION COLOUR & VOLCANO ALERT LEVEL** (ash falling to ground): GeoNet (GNS Science) sets the Aviation Colour Codes and Volcano Alert Level for New Zealand's volcanoes (see: geonet.org.nz).



RECOMMENDED ACTIONS

HOW TO PREPARE

At-risk airports should develop comprehensive operational plans for ashfall events (including cleanup – see companion "Advice for Urban Clean-Up Operations" poster). These plans should, where possible, be integrated with airline plans.

A more comprehensive summary of ashfall consequences to airports and detailed planning guidelines are available from:

- ICAO: www.paris.icao.int/news/pdf/9691.pdf

The ICAO resource provides guidance on:

- standing arrangements prior to volcanic eruptions;
- responses during an eruption
- post-eruption cleanup and re-opening of the airport.

FURTHER INFORMATION ON DEALING WITH VOLCANIC ASH MAY BE FOUND IN THE FOLLOWING LOCATIONS:

- <http://www.geonet.org.nz>
- <http://www.ivhnh.org>
- <http://volcanoes.usgs.gov/ash/trans/index.php#airports>
- <http://www.caa.govt.nz/>

Field crews should use safe operating procedures when operating in an 'ashy' environment.

- Protective clothing (full-length clothing, face masks and goggles) should be worn and care must be taken on ash-covered surfaces, particularly roofs.
- See www.IVHNN.org for further advice on protecting people from ash hazards.

ROLES AND RESPONSIBILITIES

The NZ Civil Aviation Authority (CAA) has a comprehensive document outlining roles and responsibility in managing volcanic ash in New Zealand for the aviation sector.

- www.caa.govt.nz/meteorology/living_with_volcanic_ash.pdf

DRAFTED BY TOM WILSON AND CAROL STEWART.

7 February 2013



Figure 12 Volcanic Ash: Advice for Airport Operators.

VOLCANIC ASH FAL

IMPACTS ON GENERATOR SETS AND HVAC SYSTEMS

RECOMMENDED ACTIONS

ADVICE FOR FACILITIES MANAGERS: GENSETS AND HVAC

VOLCANIC ASH IS: HARD, HIGHLY ABRASIVE, MILDLY CORROSIVE AND CONDUCTIVE WHEN WET.
 AIRBORNE ASH CONCENTRATIONS CAN BE AS HIGH AS 9 g m^{-3} , SEVERAL TIMES GREATER THAN SAND AND DUST STORMS

A volcanic ashfall can cause electricity outages (see companion poster on Advice for Power Transmission and Distribution System Operators). Therefore use of emergency power generation equipment on electrical transmission (Generator Sets or GenSets) may be necessary. Air intakes on GenSets are vulnerable to airborne ash and need to be protected. Air intakes on heating, ventilation and air-conditioning (HVAC) systems are similarly vulnerable.

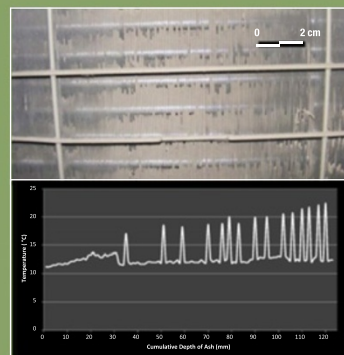
COMMON IMPACTS:

- Ash Ingress through air intake and condenser units: ash ingress may cause ash accumulation in the radiator and air filters, reducing air flow and and HVAC condenser system performance. Reduced airflow may cause stalling and overheating:
 - » High humidity significantly increases ash adhesion and thus blockage
 - » Filters are generally not designed to cope with the suspended particle volumes seen in volcanic ash falls
 - » HVAC systems with low fan speeds block more readily
 - » Horizontal air-intakes and condensers ingest significantly less ash than vertical systems
- Ash may cause accelerated corrosion and wear, usually over timescales of weeks to months:
 - » Exposed, sensitive components outside the GenSet or HVAC casing, such as fuel valves or electrical switches, can be vulnerable to wear, contamination and corrosion
 - » Ingestion of ash into the engine is rarer, but can wear moving parts and block fuel filters, lines and valves

See companion posters on "Advice for Power Transmission and Distribution System Operators" and "Advice for Power Station Managers" for additional information on effects of ash on power supply systems.



Adaptations to protect GenSet equipment in Bariloche, Argentina, from repeated airborne ash exposure following 2011-2012 eruption of Cordón Caulle volcano, Chile. Top: sealed fuel valve. Bottom: hood to protect air intake.



Top: Ash accumulation on a HVAC condenser after 11 hours of simulated high-humidity ashfall (1.5 mm/hr ; max. 2 g m^{-3}). Ash with a mean grain size of $\sim 100 \mu\text{m}$ was deposited in the fins (1.5 mm separation). Bottom: Increasing accumulation of moist ash on air conditioner condenser fins leads to increased frequency of shutdowns as compressor overheats.

WHERE TO FIND WARNING INFORMATION

See www.geonet.org.nz for ashfall forecasts in the event of an explosive eruption.

HOW TO PREPARE

At-risk facilities should develop operational plans for managing ash fall events, including a priority schedule and standardised procedures for inspecting/maintaining/cleaning:

Physical mitigation options:

- Install hoods over air intake to reduce direct ash ingestion (see bottom left figure)
- Add temporary filtration to external air intakes, monitor and replace as needed
- Seal or cover sensitive equipment, such as external fuel valves and switches

Cleaning Guidance:

- Vacuum or gently (30 psi or less) blow away excess ash from air intakes or condensers, then wipe down with a cloth. Air filters should be removed before cleaning
- Wet methods for ash cleanup are not recommended, as they may promote clogging of radiator fins, or cause short-circuits

MORE INFORMATION

THE FOLLOWING RESOURCES PROVIDE FURTHER INFORMATION ON VOLCANIC HAZARDS:

- <http://www.geonet.org.nz>
- <http://www.gns.cri.nz>
- <http://volcanoes.usgs.gov/ash/index.html>
- <http://www.ivhthn.org>

HOW TO RESPOND

- Initiate priority schedule for inspection, cleaning and preventative maintenance
- Regularly check and service air and fuel intakes and filters (stock spares)
 - » Frequency of air filter replacement could be as high as every 30 minutes during high rates of ash fall. In this case, step up preventative maintenance
- Maintain a clean site, especially in front of air intakes, to reduce remobilisation of ash
 - » Use dry methods where possible. See companion "Advice for Urban Clean-Up Operations" poster
 - » Store collected ash in bags to prevent remobilisation
 - » Ensure stockpiled ash is well clear of equipment and air intakes
- Beware wet ash maybe conductive. Isolate and earth energised apparatus as appropriate
- Advise customers/users not to clean electrical equipment and to limit the use of water in clean up, and to be careful when cleaning near electrical equipment.

DRAFTED BY DANIEL HILL, TOM WILSON, CAROL STEWART, SAM HAMPTON AND JOHNNY WARDMAN.

20 September 2013



Figure 13 Volcanic Ash: Advice for Facilities Managers: GenSets and HVAC.

VOLCANIC ASH FALL

IMPACTS ON COMPUTERS AND ELECTRONICS

ADVICE FOR FACILITIES MANAGERS: COMPUTERS AND ELECTRONICS

VOLCANIC ASH IS: HARD, HIGHLY ABRASIVE, MILDLY CORROSIVE AND CONDUCTIVE WHEN WET.

Modern electronics are well-protected from airborne contaminants, so short-term exposure to ash is unlikely to cause damage. However, functionality may be reduced.

Short term impacts:

- Ash particles may block ventilation grills and jam cooling fans, increasing operating temperatures which may in turn trigger overheating shutdowns
- Ash (if wet) may cause short circuits across exposed electrical contacts:
 - » Fine wet ash is less mobile than dry ash however, so is less likely to be drawn into electronic compartments
- Ash may affect the functionality and operation of keyboards, mice, compact disk drives and USB ports, requiring frequent cleaning
- Hard Disk Drives are unlikely to be damaged by ash due to their robust filtering systems
- Laptop computers are less vulnerable than desktop computers because of their smaller number of openings and lower cooling requirements

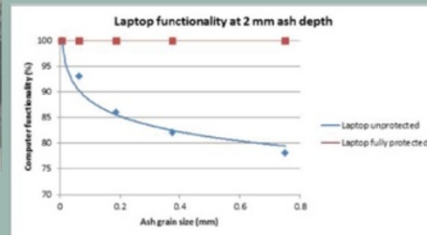
Longer-term exposure (months to years) may cause more significant damage, such as corrosion due to the reactive surface chemistry of volcanic ash.



Reducing the exposure of computer equipment to ashfall is the most effective mitigation action. Experiments suggest that laptops may shut down due to overheating when covered in ash, but relatively little enters the internal compartment. After cleaning, the laptop shown in this experiment restarted successfully.



Vacuum cleaning ash from computer keyboard.



For a 2 mm ashfall, very fine-grained ash (<0.2 mm) has less impact on computer functions than coarser-grained ash. This is because ash between 0.2-1 mm is the optimal size to block key mechanisms on keyboards, cooling fans and vents, USB ports and infrared sensors on mice.

RECOMMENDED ACTIONS

WHERE TO FIND WARNING INFORMATION

See www.geonet.org.nz for ashfall forecasts in the event of an explosive eruption.

HOW TO PREPARE

The most effective mitigation is to avoid exposure of electronic equipment to ash. This can be achieved by sealing the equipment, or the building in which it is housed.

Ensure stocks of protective equipment such as plastic sheeting and duct tape.

Limiting ash ingestion into buildings which house electronic equipment is also effective. See companion poster: *Advice for Facilities Managers: Buildings & Advice for Facilities Managers: GenSets and HVAC*

- » Identify single entry/exit point into building
- » Close and seal all other doors and windows
- » Identify areas to be sealed off within building
- » Monitor cooling systems (i.e. HVAC units)



MORE INFORMATION

THE FOLLOWING RESOURCES PROVIDE FURTHER INFORMATION ON VOLCANIC HAZARDS:

- <http://www.geonet.org.nz>
- <http://www.gns.cri.nz>
- <http://volcanoes.usgs.gov/ash/index.html>
- <http://www.ivhnh.org>

HOW TO RESPOND

- If possible, move any outdoor electronic equipment indoors prior to an ashfall
- Set up 'ash lock' on single entry/exit point into building (see companion poster for further details)
- Seal off areas housing sensitive and/or critical electronics
- Cover non-essential equipment with plastic sheeting and shut down if necessary

Clean-up:

- Avoid cleanup until ash has stopped falling. However in some cases immediate action may be required to prevent loss of function of critical equipment
- If possible, shut down electronic equipment before cleaning to avoid possible short circuits
- Electronic equipment can be carefully cleaned using low pressure compressed air or a soft brush
- Avoid excessive rubbing as this may scratch delicate surfaces
- Use a vacuum cleaner to clean rooms to avoid recontamination of cleaned areas
- Monitor HVAC systems (see companion poster). Minimise use if necessary.

DRAFTED BY GRANT WILSON, TOM WILSON, AND CAROL STEWART.

20 September 2013



Figure 14 Volcanic Ash: Advice for Facilities Managers: Computers And Electronics.

VOLCANIC ASH FAL

ASH IMPACTS ON BUILDINGS AND STRUCTURES

RECOMMENDED ACTIONS

ADVICE FOR FACILITIES MANAGERS: BUILDINGS

VOLCANIC ASH IS: HARD, HIGHLY ABRASIVE, MILDLY CORROSIVE AND CONDUCTIVE WHEN WET.

- Disruption of HVAC units due to obstructed filters, condensers & air intakes
- Contamination of building interiors, leading to:
 - » Risk of adverse health impacts for building occupants (see www.ivhhn.org)
 - » Damage to sensitive equipment
 - » Abrasion damage to flooring
- Ash may block gutters and downpipes, leading to localised flooding and damage, especially on roofs, drainage networks, and in ceiling spaces. Internal gutters are particularly at risk and are not easily accessible for cleaning
- Abrasive damage to roofing materials during ash removal.
- Loss of essential services, due to disruption by ashfall
 - » For more information please see companion posters (www.aelg.org.nz)
- Structural damage due to excessive ash loading. Very thick ash deposits (>100 mm) may cause roof collapse, although this ash thickness is rare.
 - » Long span, low pitched roofs are typically the most vulnerable
 - » When ash is wet, static loads may increase by up to 100%
 - » Non-structural elements, such as gutters, are more vulnerable to failure. Gutters will accumulate ash from the roof, reducing the drainage capacity and further increasing loading

See companion poster for advice on operating Generator Sets and Heating, Ventilation and Air-Conditioning (HVAC) systems and Advice for Facilities Managers: GenSets and HVAC.



WHERE TO FIND WARNING INFORMATION

See www.geonet.org.nz for ashfall forecasts in the event of an explosive eruption.

HOW TO PREPARE

At-risk facilities should develop operational plans for managing ash fall events, including:

- Identify entry/exit points required for building operation, areas which need sealing and restricted access to limit spreading ash
- Ensuring adequate supplies of necessary equipment
- Ensure that roofs and similar elevated areas where ash accumulation will need to be removed, have pre-installed fall arrest anchor points and that a safe means of access is identified
- Cover outlets / downpipes to reduce ash ingress into drainage networks, and if possible disconnect down pipes and/or gutters
- Shutdown and cover exposed non-essential equipment, where possible
- Consider dependency on critical services and take steps to increase resilience:
 - » Ensure backup power generation
 - » Cover water tanks

Ash cleanup operations create significant additional labour and resource demands.



An eruption of Pacaya volcano in 2010 deposited ~20 mm of coarse basaltic ash on Guatemala City. This photo shows cleanup of ash from the roof of a major public hospital. Ash entered gutters and drains, causing flooding. Some abrasion damage to the paint coating on the roof occurred.

MORE INFORMATION

THE FOLLOWING RESOURCES PROVIDE FURTHER INFORMATION ON VOLCANIC HAZARDS:

- <http://www.geonet.org.nz>
- <http://www.gns.cri.nz>
- <http://volcanoes.usgs.gov/ash/index.html>
- <http://www.ivhhn.org>

HOW TO RESPOND

Avoid cleanup until ash has stopped falling. However, in some situations, immediate action may be required to prevent damage or loss of function to the building

Use extreme caution as falls from roofs/structures are a major cause of casualties during ashfalls

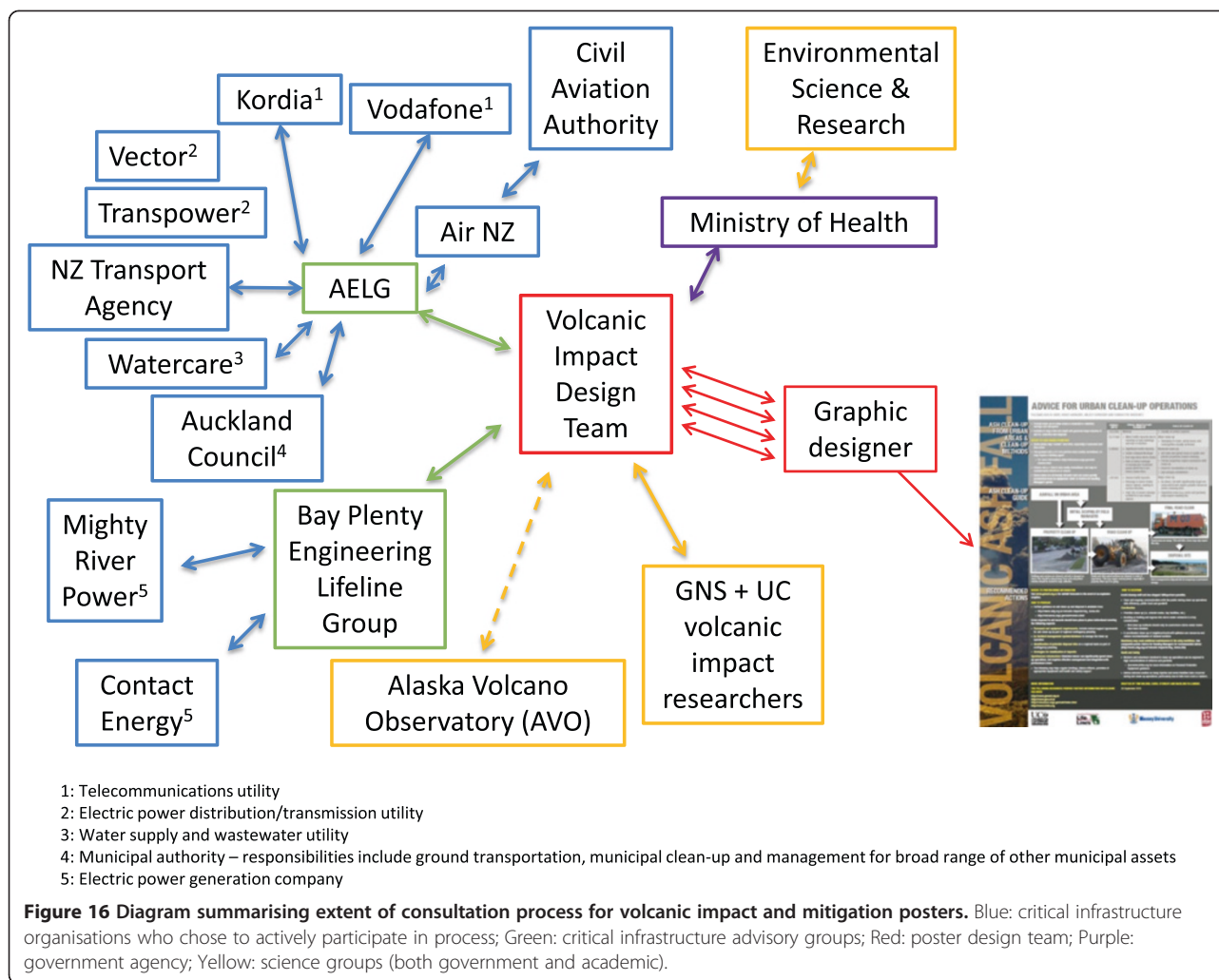
- **During ashfall:**
 - » Seal building to limit ash ingress:
 - Select an entry point which can be used as an 'ash lock'. Two sets of doors separated by a few meters are ideal
 - Ash-covered clothing and footwear should be left in this area
 - Use ash foot baths
 - Place damp towels at the bottom of external doors
 - Close and seal (e.g. with duct tape) non-essential doors, windows, vents and other gaps
- Monitor HVAC systems (see companion poster). Minimise use if operation is necessary;
- Limit movement of staff and contractors to reduce their exposure
- **After ashfall**
 - » **Exterior Clean up**
 - Prioritize areas to be cleaned. Use a 'top down' and 'up-wind' method to prevent recontamination of cleaned areas
 - Use dry methods where possible. Use shovels to remove bulk of ash, then brooms. Ash may be dampened slightly to reduce dust
 - Start with a small test area, as sweeping some ash types may cause damage to roof surfaces. Innovation may be required
 - Clean gutters after adjoining roof surfaces have been cleaned, with a gutter scoop or small trowel
 - Store removed ash in bags to reduce remobilisation
 - » **Interior Clean up**
 - Use a vacuum to clean ash where possible
 - Difficult surfaces can be cleaned with a damp cloth
 - Avoid excessive rubbing as this can scratch delicate surfaces
 - » **Computers and Electronics**
 - Cover sensitive equipment with plastic sheeting
 - Equipment can be cleaned carefully using low pressure compressed air and a damp cloth
 - See companion poster: "Advice for Facility Managers: Computers and Electronics"

DRAFTED BY TOM WILSON, CAROL STEWART, DANIEL HILL AND GRANT WILSON.

20 September 2013



Figure 15 Volcanic Ash: Advice for Facilities Managers: Buildings.



depending on topic and intended audience. Sector-specific resources are provided where available, such as the ICAO Manual on Volcanic Ash, Radioactive Material and Toxic Chemical Clouds (ICAO 2007) referenced on the poster on 'Advice for Airport Managers'.

Design

The posters are designed as fact sheets which refer the specialist audience to specific information, such as further web-based resources or industry standards where appropriate. Language, terminology and graphics used on the posters are designed primarily for the target audience of New Zealand critical infrastructure managers. Design elements of the posters are described in Figure 17.

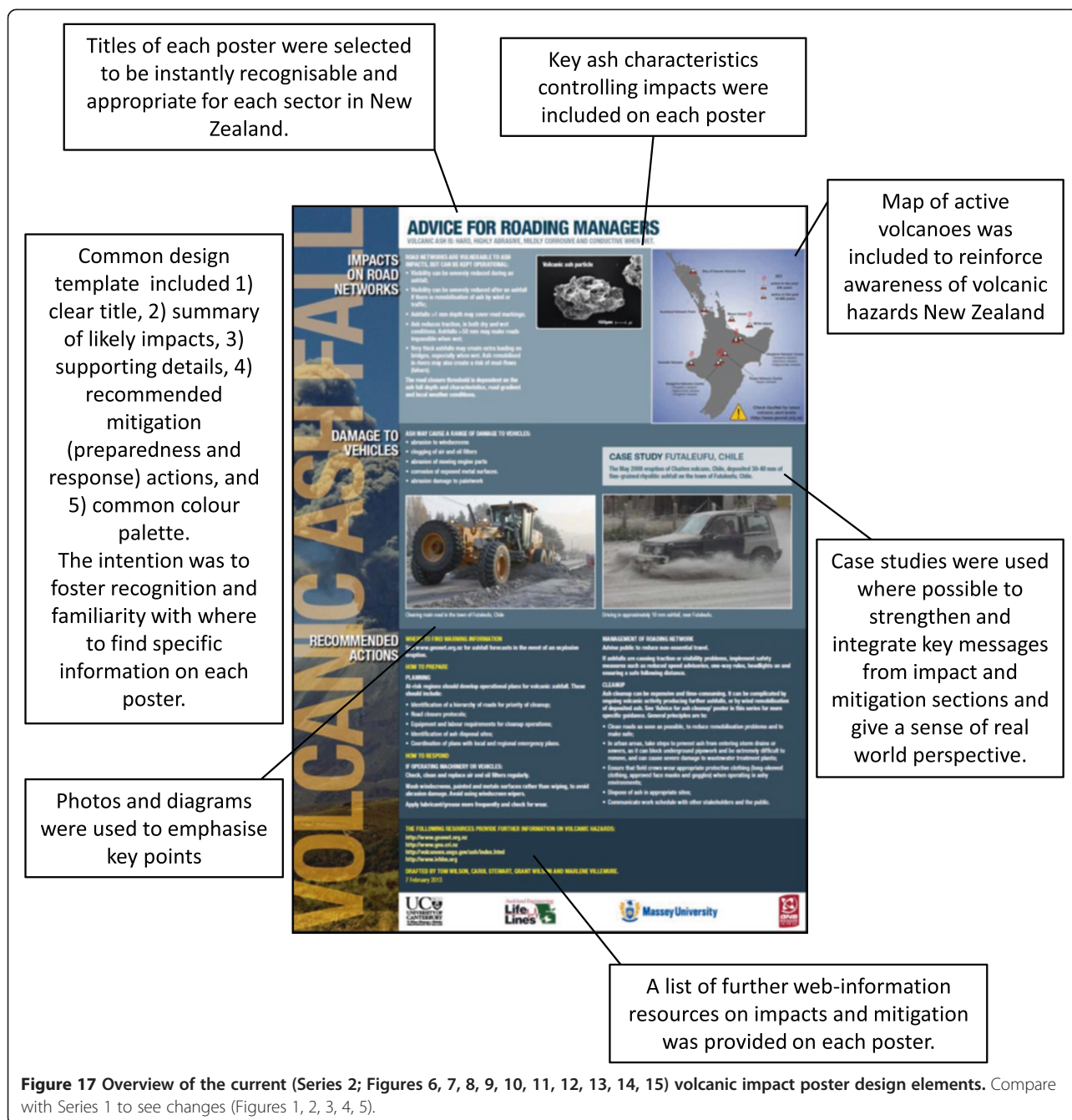
Review process

The posters underwent a two-stage review process. Initially they were reviewed by a team of eight scientists within the VISG project team, then submitted to a

technical sub-group of the AELG or other appropriate organisations (Figure 16), typically including engineers, risk managers and business continuity advisors. Their feedback was used to revise the posters. This process was repeated as required, with up to five iterations in some cases. Posters were also reviewed by colleagues from the Alaska Volcano Observatory, who have extensive operational experience in responding to ash-producing eruptions and interacting with affected sectors before, during and after ashfall events. This provided a valuable external perspective.

Dissemination

Once finalised, the updated Series 2 posters were distributed to all AELG members, to the New Zealand National Engineering Lifelines Committee for national distribution, and also hosted on the AELG and GNS Science websites as an open access resource (<http://www.aelg.org.nz/volcanic-impacts/visg-projects/>;



Titles of each poster were selected to be instantly recognisable and appropriate for each sector in New Zealand.

Key ash characteristics controlling impacts were included on each poster

Map of active volcanoes was included to reinforce awareness of volcanic hazards New Zealand

Common design template included 1) clear title, 2) summary of likely impacts, 3) supporting details, 4) recommended mitigation (preparedness and response) actions, and 5) common colour palette. The intention was to foster recognition and familiarity with where to find specific information on each poster.

Photos and diagrams were used to emphasise key points

Case studies were used where possible to strengthen and integrate key messages from impact and mitigation sections and give a sense of real world perspective.

A list of further web-information resources on impacts and mitigation was provided on each poster.

Figure 17 Overview of the current (Series 2; Figures 6, 7, 8, 9, 10, 11, 12, 13, 14, 15) volcanic impact poster design elements. Compare with Series 1 to see changes (Figures 1, 2, 3, 4, 5).

What-to-do/Ash-Impact-Posters). Public outreach talks and briefings by GNS Science staff in New Zealand, which regularly include briefings to regional engineering lifeline groups, routinely promote awareness of the posters, along with other preparedness and mitigation resources. An annual volcanic hazard short-course for infrastructure and emergency managers also uses the posters during exercises. They are also used in university teaching for scenario-based role-play simulations. Series 1 posters were also widely disseminated and utilised during the 2012 Te Maari eruption from Tongariro volcano.

The suite of posters has also been shared internationally, via distribution by the IAVCEI Cities and Volcanoes Commission's Volcanic Ash Impacts Working Group and will be hosted on the USGS Volcanic Ash Impacts Website (<http://volcanoes.usgs.gov/ash/index.html>) as a resource for the global community.

Posters in action – Esquel case study

A practical test of the posters' utility occurred during the May 2008 eruption of Volcan Chaitén, Chile (Stewart et al. 2009). In early May 2008 widespread ashfall from the

explosive rhyolitic eruption was distributed by the prevailing westerly winds over Argentina. The city of Esquel (pop. 35,000), located 110 km east of the volcano in Chubut province, Northern Patagonia, received approximately 5 mm of fine ash on the morning of 5 May (Figure 18A). Public authorities were immediately concerned about contamination of the city's water supply as residents reported a 'strong metallic taste' in the drinking water.

The water sources for the city are primarily groundwater and thus are relatively resilient to ashfall contamination. However, there is a point of vulnerability where the water is delivered to the treatment plant along the open, concrete-lined 2.3 km-long Canal de Faldeo (Figure 18B).

The water supply authority did not have any knowledge of potential impacts of an ashfall on the water supply. In their search for information they contacted a member of our research team (CS) who had authored a review of the subject (Stewart et al. 2006). She provided advice, in collaboration with a local university, on an appropriate water sampling and monitoring regime and interpretation of ashfall leachate data. Using the poster "Advice for water supply managers" (Figures 1, 2, 3, 4, 5), she also provided guidance on impacts and mitigation strategies. Water sampling showed that levels of sulphate and dissolved iron and aluminium were higher in the Canal de Faldeo than the raw water source, and to a lesser extent, in treated drinking water (Stewart et al. 2009). These elevated levels were sufficient to produce a noticeable taste in the final drinking water but remained well below Argentinian drinking water standards (see Stewart et al. 2009). The water authority was thus able to reassure the public that ashfall contamination of the water source did not pose a public health risk.

Two-way exchange of information between the poster design team and the water authority was critical for ground-truthing and refining the management advice on

the posters. Our predictions were that the primary impacts of the ashfall would be an increase in raw water turbidity and that water demand would increase as residents cleared ash from their properties. These both proved to be the case. Local authorities also noted the value of the poster's advice to communicate information to the public in a timely and transparent manner as the metallic taste in the water had caused some anxiety about contamination of the water supply.

Internationalising posters?

The case study above illustrates that these posters may be useful tools during an eruption crisis beyond the New Zealand context for which they were designed. The technical and engineering content of the posters was based on findings of ashfall impact assessment trips, to an extensive range of volcanically-active countries (Table 1, Volcanic impacts research group). Thus, the advice given is applicable to infrastructure not just in New Zealand (which has highly-modernised infrastructure) but in other, less-developed, settings. For example, the 'Advice for Wastewater Managers' poster (Figure 7) describes ashfall impacts on individual system components, so that individual treatment facilities can select relevant components. Similarly, many components of infrastructure systems such as pumping equipment, HVAC units and engine components are universal thus the mitigation advice given is applicable.

However, we note that the emergency management content of the posters is specific to New Zealand. This includes aspects such as where to find warning information in the event of an eruption, and (for the 'Advice for Airport Managers' poster) contact details for the local Volcanic Ash Advisory Centre (VAAC).

Summary

This paper describes a collaborative process used to create a suite of ten informational posters intended to improve



Figure 18 Chaiten ashfall in Esquel, Argentina. **A)** Approximately 5 mm of fine-grained rhyolitic ash fell in the town on 5 May 2008; **B)** The Canal de Faldeo open water supply line for Esquel, Argentina.

the resilience of critical infrastructure organisations to volcanic ashfall hazards. Key features of this process were:

- a collaborative partnership between critical infrastructure managers and relevant government agencies with volcanic impact scientists;
- consultation and review phases; and
- translation of volcanic impact research into practical management tools.

In addition to producing the posters, which are a unique global resource, the process has further enhanced and grown networks between volcanic impact scientists/agencies and critical infrastructure organisations. We note that our work has been developed in a New Zealand context and thus has relied heavily on the highly networked VISG and AELG structures, and existing risk management culture. Whilst the posters have utility beyond New Zealand, as demonstrated by the Chaitén case study, we propose that this development process may be a useful model for strengthening volcanic risk resilience in other settings.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

TW and CS planned and conducted the research, and wrote the manuscript. JW, GW, DJ, DH, SH, MV and LR contributed to poster content and design. SM, GL, MD, ND and LR contributed to poster design and review and to manuscript preparation. All authors have read, reviewed and approved the final manuscript.

Acknowledgements

We kindly thank all poster reviewers from the AELG, BoP ELG, NZ Ministry of Health and ESR. Special thanks to Brian Park (WaterCare), Scott Muspratt (Vector Ltd), Bob Fletcher (Air NZ) and Peter Lechner (NZ CAA). Our sincere thanks to Tina Neal and Kristi Wallace from the Alaska Volcano Observatory for their review of posters and continuing support. Thanks also to Jim Cole for supporting the project. We acknowledge funding support from AELG, the DEVORA project (funded by the Earthquake Commission, Auckland Council and Ministry of Business, Innovation and Employment), and MBIE Research Contract C05X0907 (TW, CS, DJ).

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Received: 19 February 2014 Accepted: 18 July 2014

Published: 5 August 2014

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doi:10.1186/s13617-014-0010-x

Cite this article as: Wilson et al.: Volcanic ashfall preparedness poster series: a collaborative process for reducing the vulnerability of critical infrastructure. *Journal of Applied Volcanology* 2014 3:10.

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