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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 km^2 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 (Twigg 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 subcommittee 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,

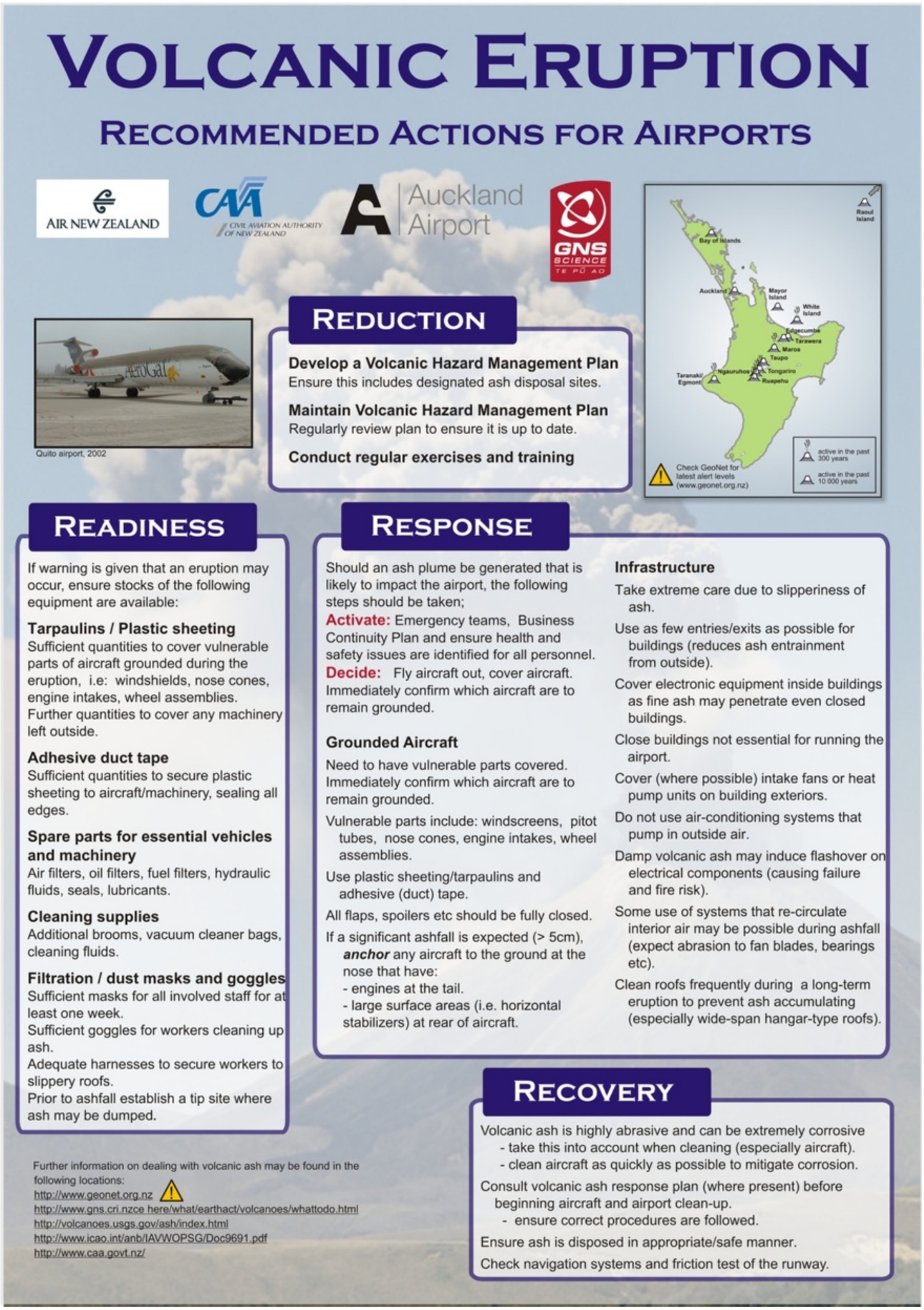


Figure 1 Recommended actions for airports to mitigate ashfall hazard.

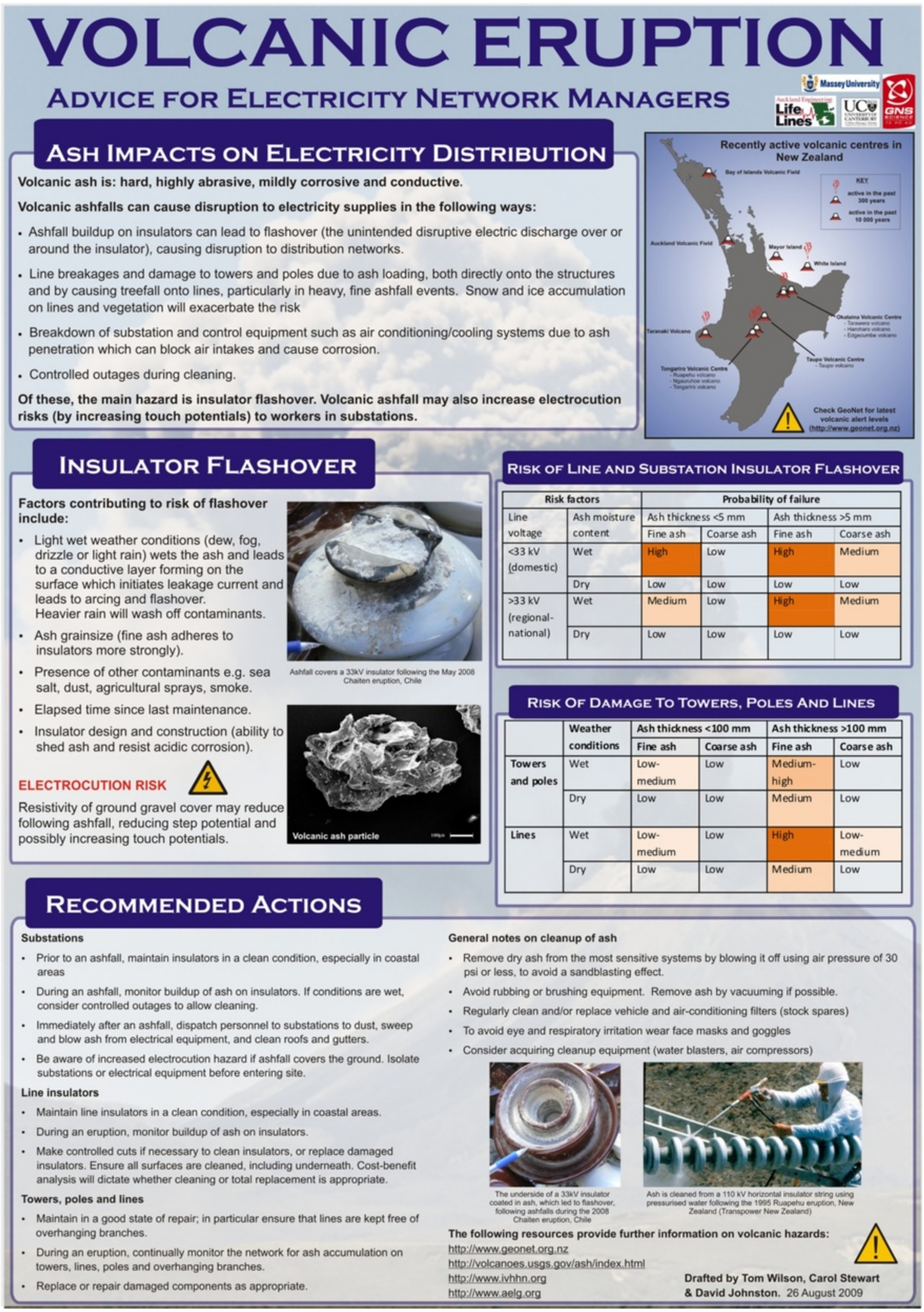
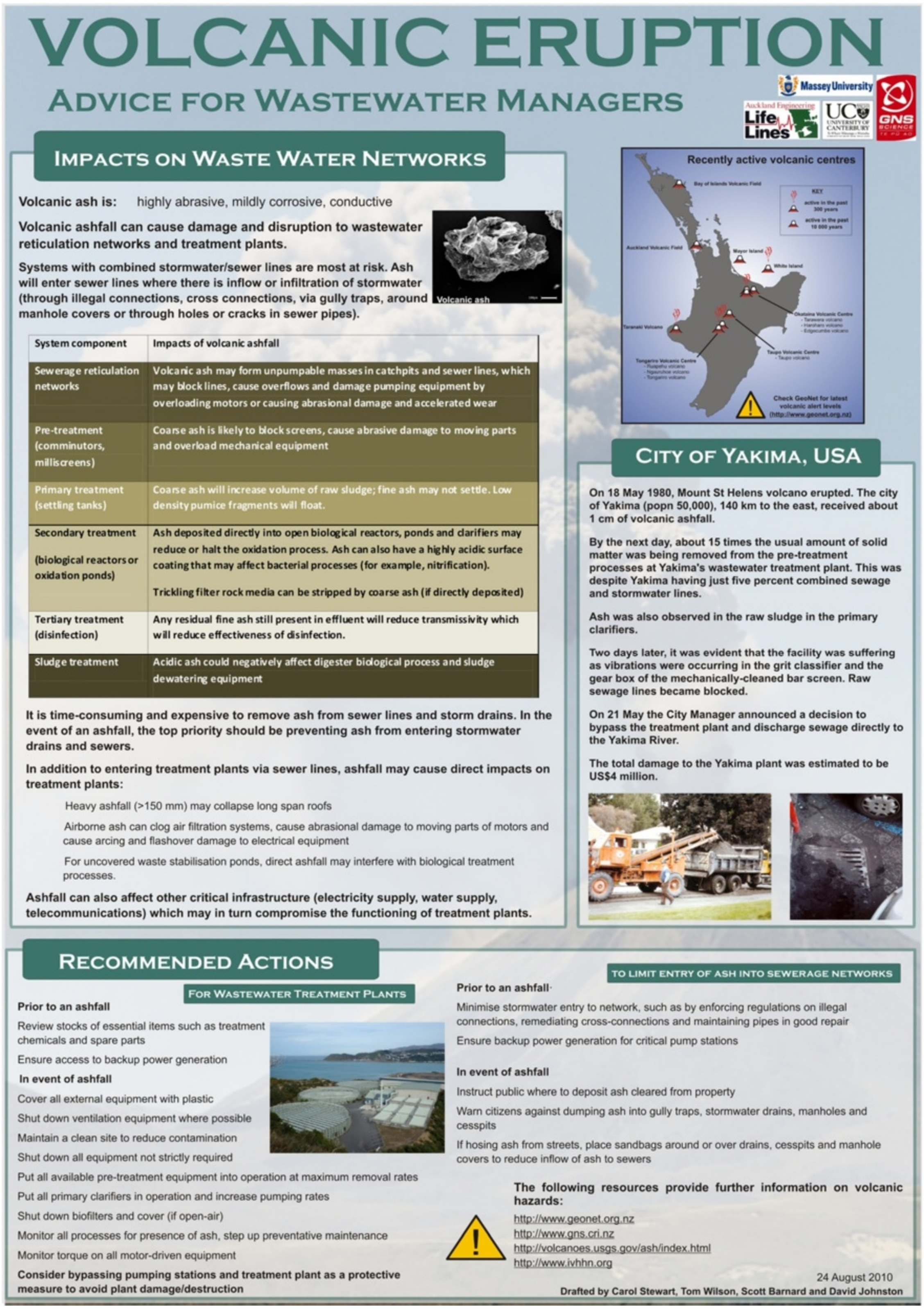


Figure 2 Recommended actions for Electricity Network Managers to mitigate ashfall hazard.

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



VOLCANIC ERUPTION

Advice for Wastewater Managers

Massey University
Auckland Engineering Life Lines
UC University of Canterbury
GNS Science

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).

Volcanic ash

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, milliscreens)	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.

Recently active volcanic centres
Bay of Islands Volcanic Field
KEY
active in the past 300 years
active in the past 10 000 years
Auckland Volcanic Field
Mayor Island
White Island
Okataina Volcanic Centre
- Tarawera volcano
- Haroharo volcano
- Edgecumbe volcano
Taranaki Volcano
Taupo Volcanic Centre
- Taupo volcano
Tongariro Volcanic Centre
- Ruapehu volcano
- Ngauruhoe volcano
- Tongariro volcano
Check GeoNet for latest volcanic alert levels (http://www.geonet.org.nz)

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**

To limit entry of ash into sewerage networks

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.ivhhn.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.

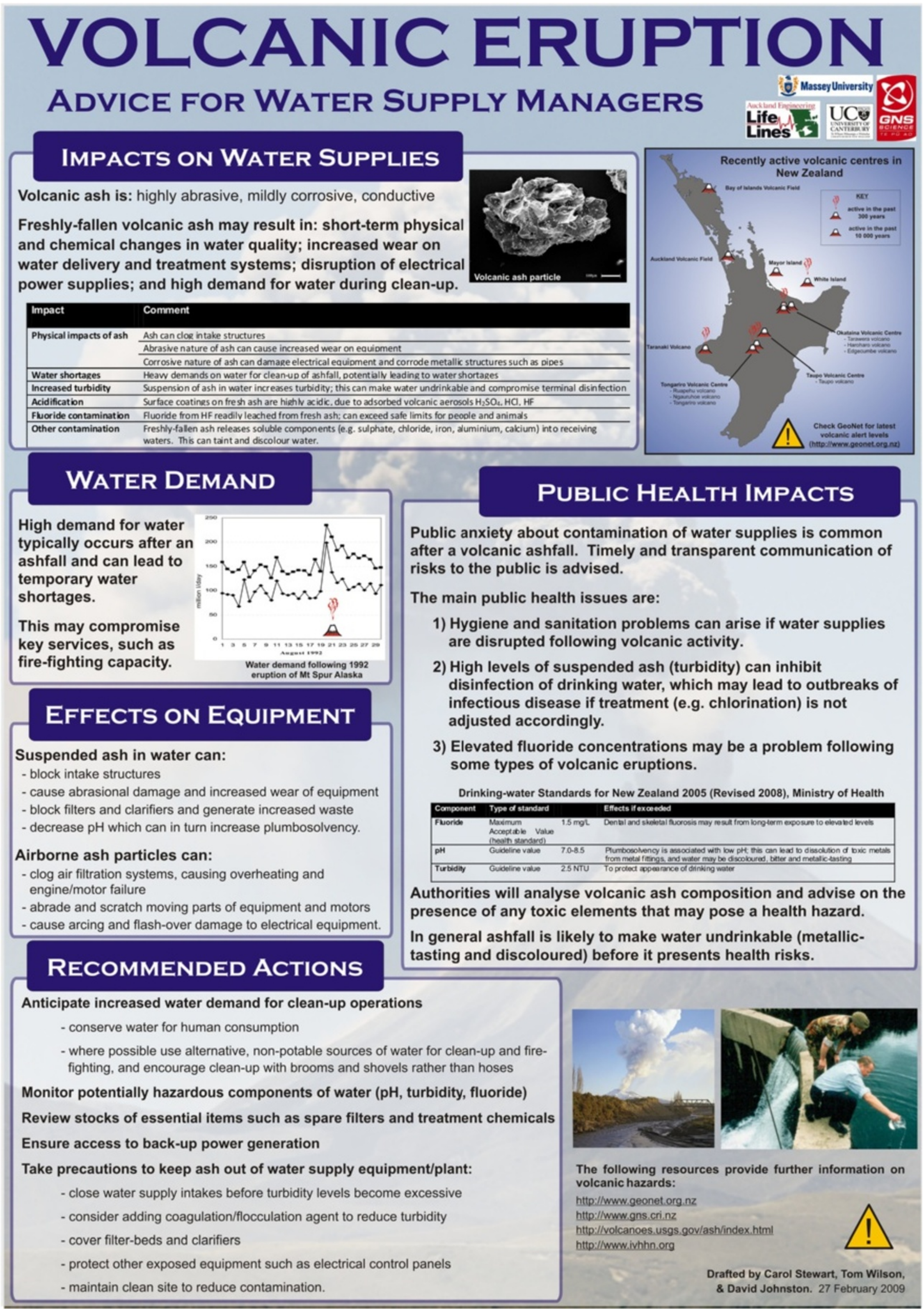


Figure 5 Recommended actions for Waste Water Managers to mitigate ashfall hazard.

VOLCANIC ASHFALL

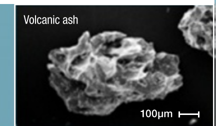
ADVICE FOR WATER SUPPLY MANAGERS

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

ASH IMPACTS ON DRINKING WATER TREATMENT

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



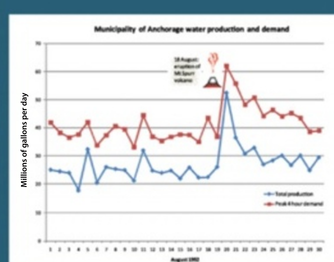
EFFECTS ON RAW WATER SOURCES

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. • 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.

WATER DEMAND

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.



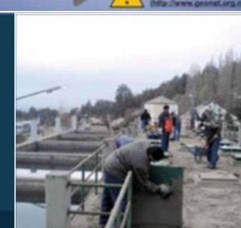
The 18 August 1992 eruption of Mt Spurr volcano, Alaska, deposited around 3 mm of sand-sized volcanic ash on the city of Anchorage. The population used mostly wet methods to clean up the ash, creating a peak water demand which resulted in water shortages and loss of pressure in some parts of the city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

EFFECTS ON TREATMENT PLANTS

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 Cordon- Caulle eruption (below)

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 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.ivhhn.org

DRAFTED BY CAROL STEWART & TOM WILSON.
30 January 2013

UC University of Canterbury — Auckland Engineering Lifelines — Massey University — GNS Science

Figure 6 Volcanic Ash: Advice for Water Supply Managers.

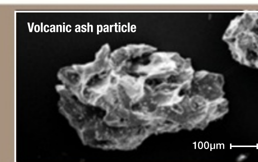
ADVICE FOR WASTEWATER MANAGERS

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

IMPACTS ON WASTEWATER COLLECTION AND TREATMENT SYSTEMS

VOLCANIC ASH CAN CAUSE SERIOUS DAMAGE TO WASTEWATER TREATMENT PLANTS.

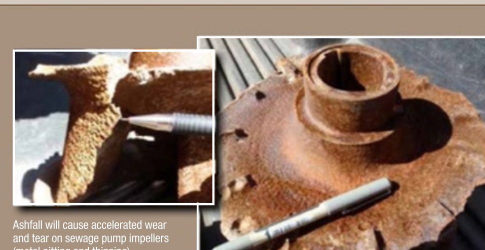
- Cities with combined stormwater and sewer lines are particularly at risk
- Ash will enter sewer lines where there is inflow or infiltration (through illegal connections, cross connections, gully traps, manhole covers, cracks in sewer pipework etc).



SYSTEM COMPONENT	IMPACTS OF VOLCANIC ASHFALL
Sewerage pumping network	• 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	• Expect accelerated wear and tear on pump components (pistons, impellors, seals, etc).
Pre-treatment equipment	• Ash may damage comminutors and grit classifiers. • Coarse (>1 mm) ash is likely to block mechanical screening equipment, overloading motors and gear boxes. Mechanical pre-treatment equipment is highly vulnerable to damage from ash-laden raw sewage. To avoid serious damage, consider bypassing treatment plant.
Primary settling tanks	• Coarse ash will increase volume of sludge for disposal. • Ash will change the proportion of organic to inorganic matter entering the plant.
Secondary treatment	• 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	• Any residual very fine ash may increase suspended solid load of effluent, which may interfere with disinfection.
Sludge treatment	• 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 (1980 value) damage to its plant following the 1980 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)

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 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.ivhhn.org
http://vatlab.org

DRAFTED BY TOM WILSON, CAROL STEWART & JOHNNY WARDMAN.
20 January 2013

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Figure 7 Volcanic Ash: Advice for Wastewater Managers.

VOLCANIC ASHFALL

ADVICE FOR POWER PLANT OPERATORS

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

IMPACTS ON POWER GENERATION FACILITIES

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.

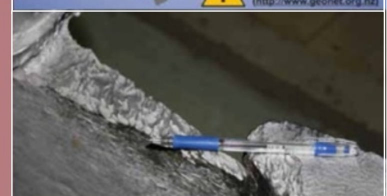
HYDROELECTRIC POWER STATIONS

- 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 grates from Agoyan 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.

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, JOHNNY WARDMAN AND CAROL STEWART.

20 September 2013

UC University of Canterbury · Auckland Engineering Lifelines · Massey University · GNS Science

Figure 8 Volcanic Ash: Advice for Power Plant Operators.

VOLCANIC ASH

ADVICE FOR POWER TRANSMISSION AND DISTRIBUTION SYSTEM OPERATORS

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

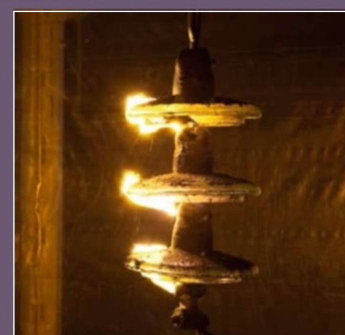
IMPACTS ON TRANSMSSION AND DISTRIBUTION NETWORKS

- **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.

INSULATOR FLASHOVER

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

SUBSTATIONS

- 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

RECOMMENDED ACTIONS

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

UC UNIVERSITY OF CANTERBURY Te Whare Wānanga o Waitaha CHRISTCHURCH NEW ZEALAND — Auckland Engineering Life Lines — Massey University — GNS SCIENCE TE PŪ AO

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

VOLCANIC ASHFALL

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 ashy 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.ivhhn.org

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

7 February 2013

UC University of Canterbury — Auckland Engineering Lifelines — Massey University — GNS Science

Figure 10 Volcanic Ash: Advice for Roading Managers.

VOLCANIC ASHFALL

ADVICE FOR URBAN CLEAN-UP OPERATIONS

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

ASH CLEAN-UP FROM URBAN AREAS & CLEAN-UP METHODS

- 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

ASHFALL ON URBAN AREA

INITIAL SCOPING BY FIELD MANAGERS

PROPERTY CLEAN UP

Buildings and sections are cleaned, and ash is dumped on street. Ash should be placed away from curb and parked vehicles should be moved for easy collection.

ROAD CLEAN UP

Roads and other paved surfaces are cleaned, in order of importance. This may require several passes, especially if property clean-up is on-going.

FINAL ROAD CLEAN

Paved areas are swept. Thin ash falls <2mm may only require this step.

DISPOSAL SITE

Ash is transported to disposal site for temporary or permanent storage.

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

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)

Heath and Safety

- Workers and volunteers involved in clean-up operations can be exposed to high concentrations of airborne ash particles
  - » See www.ivhhn.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.

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 MARLENE VILLEMURE.

20 September 2013

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

Figure 12 Volcanic Ash: Advice for Airport Operators.

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

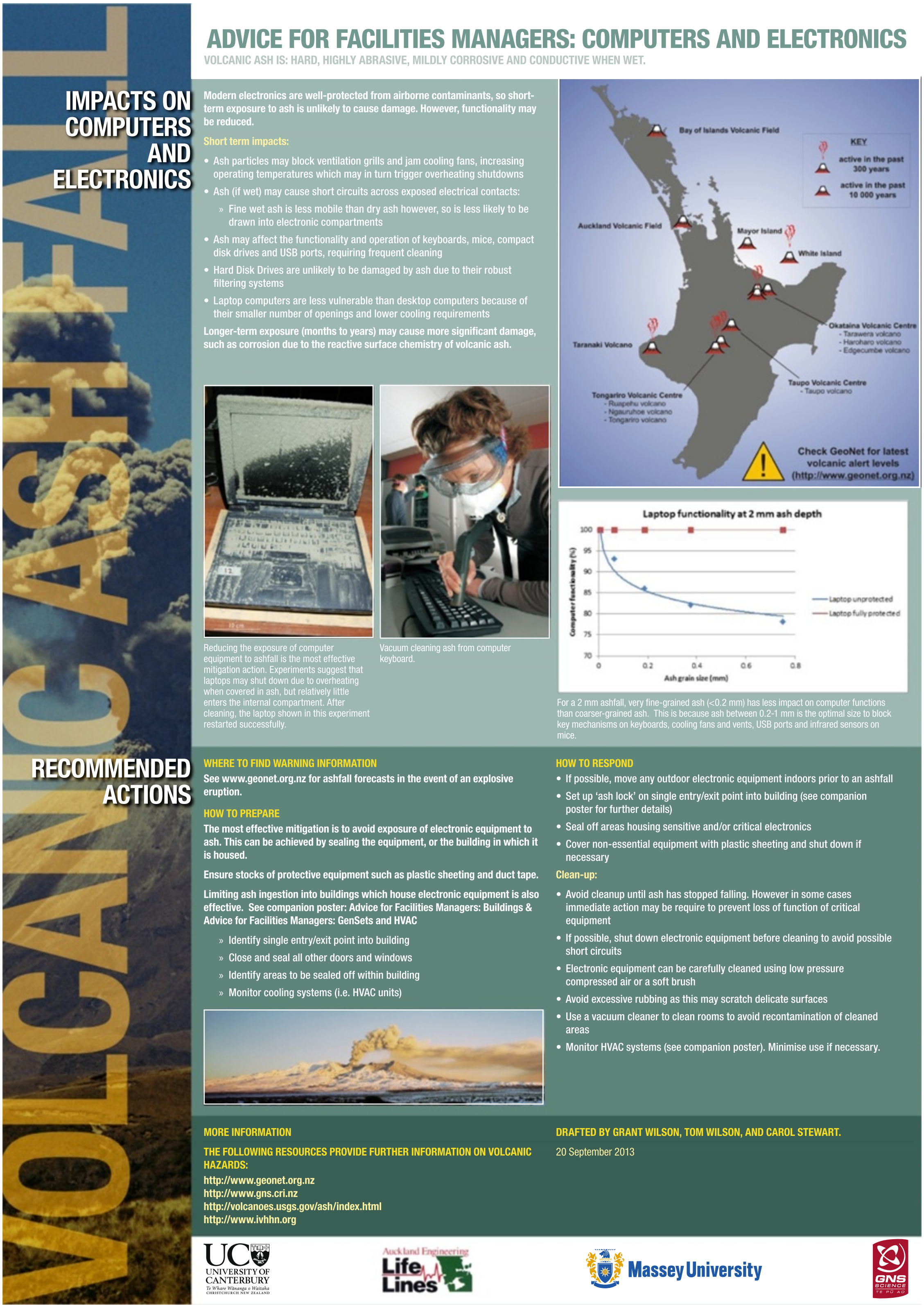


Figure 14 Volcanic Ash: Advice for Facilities Managers: Computers And Electronics.

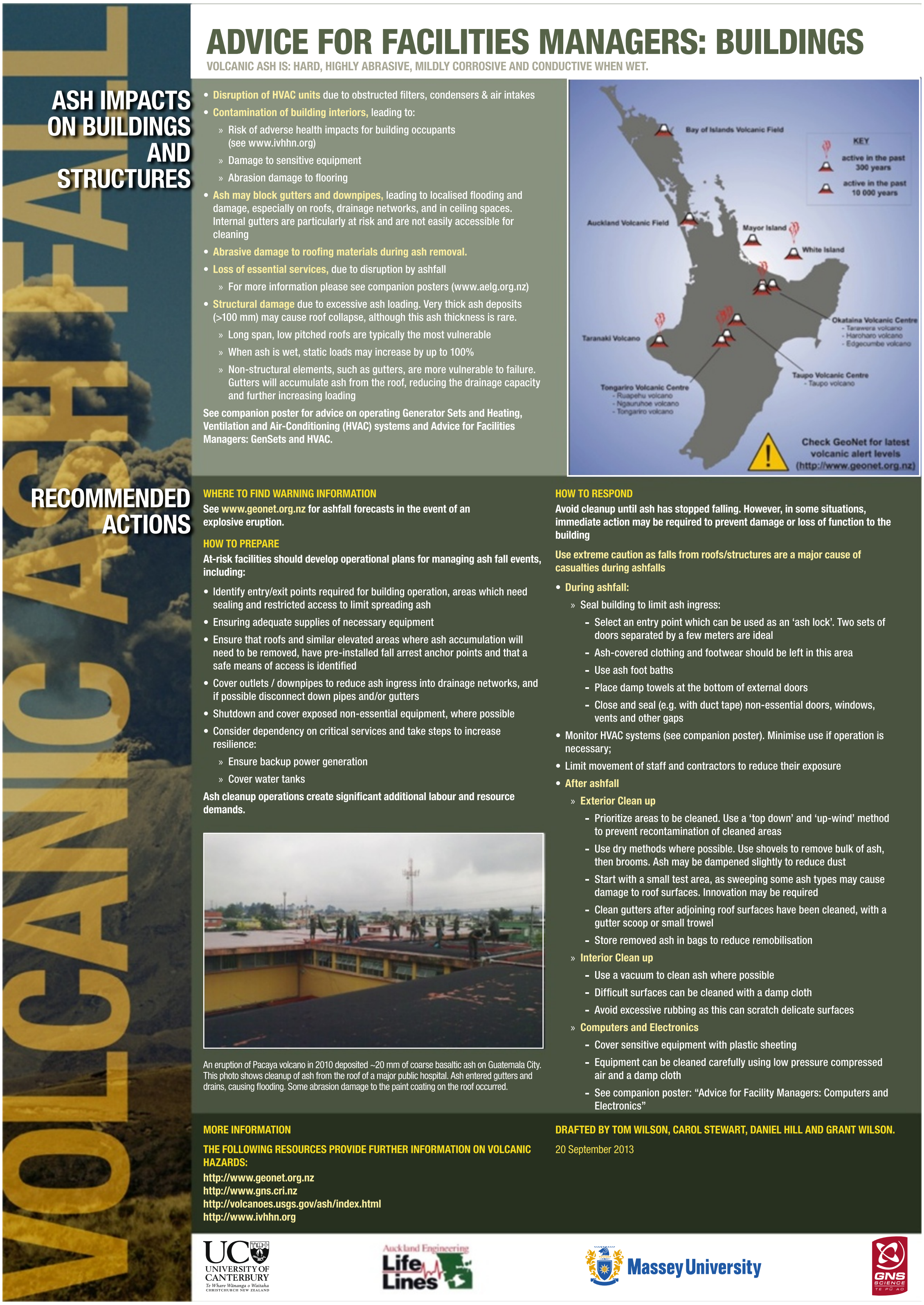
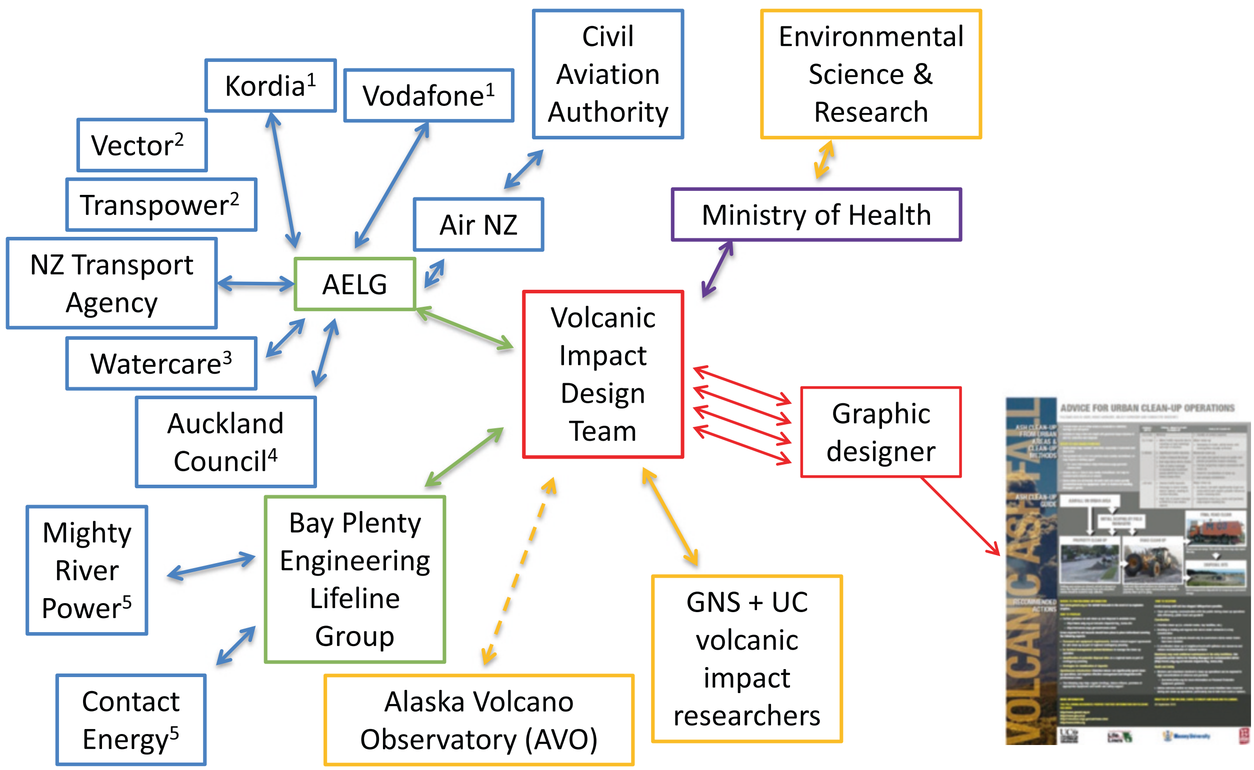


Figure 15 Volcanic Ash: Advice for Facilities Managers: Buildings.



1: Telecommunications utility
2: Electric power distribution/transmission utility
3: Water supply and wastewater utility
4: Municipal authority – responsibilities include ground transportation, municipal clean-up and management for broad range of other municipal assets
5: Electric power generation company

Figure 16 Diagram summarising extent of consultation process for volcanic impact and mitigation posters. Blue: critical infrastructure organisations who chose to actively participate in process; Green: critical infrastructure advisory groups; Red: poster design team; Purple: government agency; Yellow: science groups (both government and academic).

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/; http://www.gns.cri.nz/Home/Learning/Science-Topics/Volcanoes/Eruption-

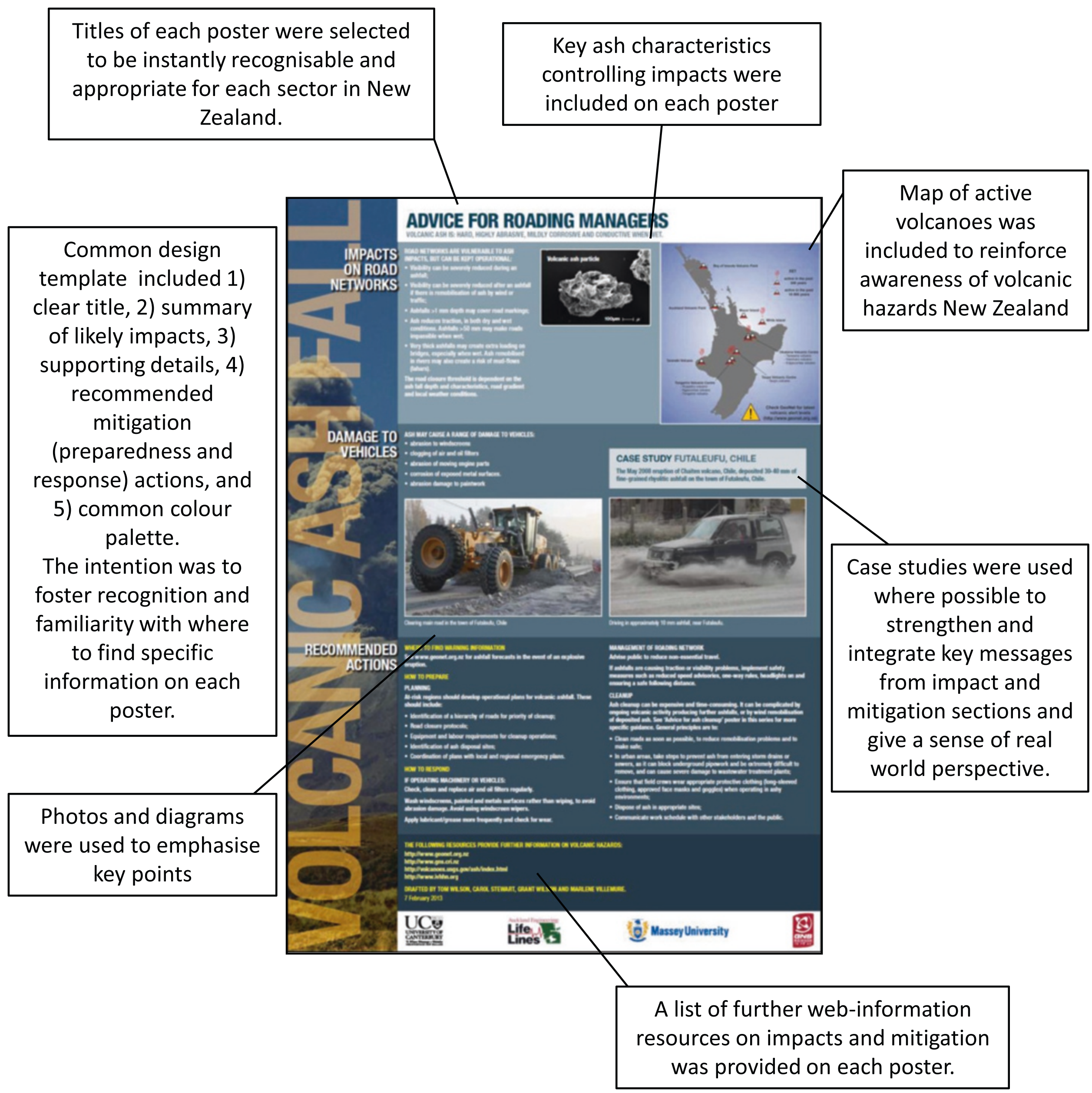


Figure 17 Overview of the current (Series 2; Figures 6, 7, 8, 9, 10, 11, 12, 13, 14, 15) volcanic impact poster design elements. Compare with Series 1 to see changes (Figures 1, 2, 3, 4, 5).

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 sand LR contributed to poster design and review and to manuscript preparation. All authors have read, reviewed and approved the final manuscript.

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