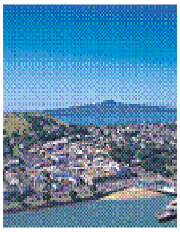
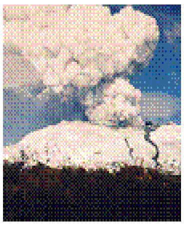
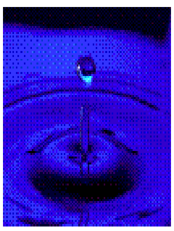
Auckland Engineering Lifelines Group
Project AELG-19







Review of Impacts of Volcanic Ash on Electricity Distribution Systems, Broadcasting and Communication Networks

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EXECUTIVE SUMMARY

The Auckland Engineering Lifelines Group (AELG) has undertaken a series of projects which have summarised available information on the physical damage caused by volcanic ash to Auckland's infrastructure and identified possible physical mitigation measures.

This report completes the series and looks at the impacts of volcanic ash on electricity distribution systems, broadcasting and communication networks.

The focus of this report has been a review of literature as well as accounts from historical eruptions and preliminary results from laboratory testing. The focus has been on identifying the physical damage to different network components (including disruption to signal transmission in the case of the broadcasting and communication networks) and less on indirect or downstream effects such as cellular network overloading. The information summarised has been presented in a format which updates damage and ash mitigation tables presented in earlier AELG reports (AELG, 1997).

Key findings

Conditions creating ashfall hazards

Light misty rain combined with large volumes of fine grained ash is considered the most hazardous combination for electricity distribution, communications and broadcasting infrastructure. Light rain will not wash ash from components but will greatly increase electrical conductivity potentially leading to arcing and flashover.

A phreatomagmatic eruption from the Auckland Volcanic Field is considered to be the most likely source of *large volumes* of *fine grained* (and *potentially wet*) ash to affect infrastructure in Auckland. Such an event has been estimated to have a 5% probability of occurring within a 50 year time period.

The most likely ashfall event (with a 15-65% probability within a 50 year time period) is one from one of the cone volcanoes further south (e.g. Ruapehu, Taranaki). While unlikely to significantly effect electricity distribution systems, broadcasting and communications networks in Auckland in the short-term, infrastructure outside of the region, particularly electricity supply to the region could be severely impacted.

Electical Distribution Systems

Insulator flashover to electricity networks is considered the most likely hazard to cause electricity supply disruption. It is important to note that while Auckland itself may not receive ashfall, it may suffer loss of electricity supply due to failures on the national grid. Ashfall from the cone volcanoes could cause problems for electrical distribution systems close to the source of the eruption. Impacts to electricity generation due to ashfall (e.g. power stations on the Waikato River) may also threaten electricity supply to Auckland, although these impacts are unknown.

Communication and Broadcasting Systems

There are few modern accounts (last 25 years) of ashfall causing disruption to communications and broadcasting infrastructure or service, aside from network overloading which is common in natural disaster events. It is not anticipated that significant electromagnetic signal attenuation will occur during a volcanic ashfall, however this is not well understood. Communications and broadcasting services have a high reliance on electricity supply for normal operation.

Long-term effects

Due to the lack of longitudinal studies it is unclear whether there are long-term (weeks to months) corrosion hazards to infrastructure components following ashfall. Due to the presence of soluble acidic salts on volcanic ash, it is likely some corrosion may occur. Outages could result from corrosion where equipment has not been cleaned or inspected for potential damage.

Indirect and general effects

Although not the focus of this report, the review of available literature indicates indirect impacts have been the most common disruption to telecommunication and broadcasting services following volcanic ashfall, such as telecommunications network overloading and air conditioning system failure. Disruption to vehicle or aircraft transport will significantly reduce the ability of network managers to adequately inspect, service and or clean exposed sites due to the hazards volcanic ashfall causes for transportation (refer AELG posters on transportation and airport disruption).

Mitigation and further work

Exact causes of component failure and identification of suitable mitigation measures is an area requiring further work. In most cases, there are relatively simple mitigation measures available such as covering exposed electrical connections, and changing insulator configurations where practical. Involvement of building services and air conditioning engineers in a study looking at improvements in design to air conditioning and air handling systems to minimise damage would be useful. Rapidly evolving technology and the low frequency of eruptions makes it difficult to know if established impacts and mitigation recommendations are relevant for modern equipment.

This review has highlighted where the current gaps in understanding are. A number of recommendations are outlined both for the wider research community and the AELG. Knowledge of these gaps will inform our research, impact assessments in active volcanic areas and quantitative testing over the next 5 to 10 years.

1.0 INTRODUCTION

1.1 Background

The Auckland Engineering Lifelines Project (AELG, 1999) summarised the effects of direct damage by major natural hazards, including volcanic eruptions, to key infrastructure in Auckland. Up until recently, that study contained the most up-to-date summary of network vulnerability, anticipated damage and mitigation measures.

Over the last 8 years, the Auckland Engineering Lifelines Group has sought to update this information by commissioning a number of summary reports and posters on the impacts of volcanic ash on key infrastructure, in particular:

- Volcanic Ash Review: Impacts on Lifeline Services and Ash Collection/ Disposal Issues (AELG-13, 2001)
- Report on a Volcanic Field Visit to Kagoshima (AELG, 2001)
- Impacts of Ash on Water Supplies in Auckland (AELG-11, 2004)
- Health and Safety Issues in a Volcanic Ash Environment (AELG-7, 2005)
- Poster: Volcanic Eruption – Recommended Actions for Roading Managers (AELG-18, 2008)
- Poster: Volcanic Eruption – Recommended Actions for Airports (AELG-9, 2008)
- Poster: Volcanic Eruption – Advice for Water Supply Managers (AELG-11a, 2009)

These reports are available from the AELG website www.aelg.org.nz.

This recent commission extends the series to a review of the impacts of ash fall events on electricity distribution networks, broadcasting, radio transmission and communications networks.

1.2 Project Objectives and Methodology

The specific project objectives are:

1. Review and summarise information from historic eruptions and research undertaken (nationally and internationally) on the impacts of ash on electricity, broadcasting, radio transmission and communication networks;
2. Identify vulnerable components of the respective networks;
3. Identify mitigation measures to reduce vulnerability prior to a volcanic event, and measures to reduce damage during and post event.

The focus of the project is on the direct damage to physical components of the networks, although the impact of indirect effects such as cellular overloading through elevated usage, have been noted in places.

A literature review (Appendices A2-A6) was undertaken which included numerous published and unpublished accounts of impacts at historic eruptions. Several sector group members contacted their counterpart utilities in other countries with a volcanic hazard to see if additional information could be acquired.

A workshop (Appendix A8) with the AELG Communications and Energy Sector Groups was held in November 2008 to discuss the findings of the literature review, discuss the gaps in information that the literature review highlighted, and to develop a list of vulnerable network components.

This report summarises the findings of the above review and analysis in a format which is intended to enable lifeline utilities to quickly identify likely damage and mitigation measures. The report also provides some comment on how the information could be used to support lifeline utilities' decision to reduce vulnerability prior to a volcanic event by investing in physical mitigation measures and/or measures to reduce damage during and post event through improved response planning.

1.3 Definitions

The following definitions have been used in this report:

Low Voltage	<3.3 kV (domestic supply lines)
High Voltage (regional)	3.3-100 kV
High Voltage (national)	>100 kV
Communication and Broadcasting	• AM and FM broadcasting • Broadcast television • Short wave and amateur radio • Satellite and microwave links • Cellular technology • Landline telephone Appendix A1 outlines the radio frequencies for the above applications (except landline telephone).

1.4 Literature Review

A literature review of the possible impacts of volcanic ash on electricity distribution systems and communication networks was undertaken. Both published and unpublished references were reviewed as well as various historical accounts of past eruptions and mitigation measures. Appendices A2 to A6 contain the literature review findings which are summarised under the following headings:

A2: Summary of Factors Affecting Volcanic Ash Impacts on Electricity Distribution Systems and Communication Networks

A3: Historic Impacts

A4: Other General Quantitative Analysis of Impacts

A5: Mitigation measures

A6: Properties of Ash

The literature review findings were reviewed by Ian Chapman (PowerCo Ltd) and Adam Tommy and colleagues (Kordia Ltd) to ascertain whether there was any other relevant information known to the electricity and communication sectors respectively. Commentary on the literature review by Kordia is contained in Appendix A7.

Reviewers were also asked to comment on the relevance of making a comparison between New Zealand and overseas configurations and whether historical observations were relevant given the changing nature of technology, particularly for communications.

There are some differences in configuration for electrical distribution networks between New Zealand and overseas (e.g. USA uses a greater number of transformers for a given population than in NZ) but none significant enough to make observations from overseas eruptions irrelevant in the New Zealand context. This is also the case for technological advances.

No obvious differences between New Zealand and overseas communications configurations were identified. However rapidly evolving communications technology has changed since many of the eruptions referenced in the literature review. Communication services are often more distributed around a city now than a decade ago, and the technology itself has become more advanced. It is unclear if this has decreased vulnerability (through more redundancy) or increased vulnerability as the effects of ash on more advanced technology is unknown.

Although not the focus of this report, the review of available literature indicates indirect impacts have been the most common disruption to telecommunication and broadcasting services following volcanic ashfall, such as telecommunications network overloading and air conditioning system failure. Disruption to vehicle or aircraft transport will significantly reduce the ability of network managers to adequately inspect, service and or clean exposed sites due to the hazards volcanic ashfall causes for transportation (refer AELG posters on transportation and airport disruption).

In summary, there is limited information available of a quantitative nature, particularly for communications systems. Most of the information from historical accounts is anecdotal and refers to what element failed, but details of specific damage, reason, length of supply outage and corrective measures taken are often limited. Information about what changes utility providers made to internal systems such as maintenance regimes, asset management, response planning and communication processes as the result of the impact of ash on the network are largely unknown.

Sections 3.0 and 4.0 summarise the findings of the report in tabular form for easy reference.

2.0 VOLCANIC RISK IN AUCKLAND

2.1 Frequency and Magnitude of Ashfall Events in Auckland

Many types of hazards may result from a volcanic eruption, often simultaneously. The most likely hazards include pyroclastic falls (ashfalls), pyroclastic flows and surges, lava extrusions (flows and domes), lahars, volcanic gases, volcanic earthquakes and atmospheric effects. However, volcanic ash can be deposited hundreds to thousands of kilometres from its source, making it the product most likely to affect the largest area and the greatest number of people.

Auckland is vulnerable to volcanic ash from all the volcanic centres in the North Island. Exceedance probabilities for volcanoes affecting Auckland are given in Table 2.1:

Table 2.1: 50 year exceedance probabilities for volcanic eruptions affecting Auckland

Source	Return Period (year)	50 yr Exceedance Probability
Distant Andesitic (Taranaki, Ruapehu)	50-300	15-65%
Distant Rhyolitic (Okataina, Taupo)	1000-2000	3-5%
Local Basaltic (Auckland Volcanic Field)	1000[1]	5%

1 Return period based on 20 events in the last 20,000 years

The above probabilities do not take into account the size of the eruption or the volume of ash likely to be produced. For any given eruption the size and extent of the ash plume will depend on the eruption energy, volume of tephra (ash), height of the plume and the prevailing weather conditions.

2.2 Ashfall Properties of Interest

The properties of volcanic ash and environmental conditions at the time of and following the ashfall will determine whether there are significant impacts or not. There is a complex interaction between a number of variables which makes it difficult to predict the exact effects ahead of time. Figure 2.1 illustrates this interaction for flashover potential for electrical distribution systems.

Where ash thicknesses are the same, finer ash generally will cause greater problems than coarser ash. It has greater adherence properties, more easily penetrates electrical equipment, and a higher surface area leading to greater electrical conductivity when moist. Generally, dry volcanic ash will not cause failure to electrical distribution networks. Conversely heavy rain will wash ash from lines and insulators eliminating the hazard. The presence of moisture is required to initiate flash-over however a number of other factors (grainsize, soluble component of ash, thickness, network configurations) will determine whether disruption occurs.

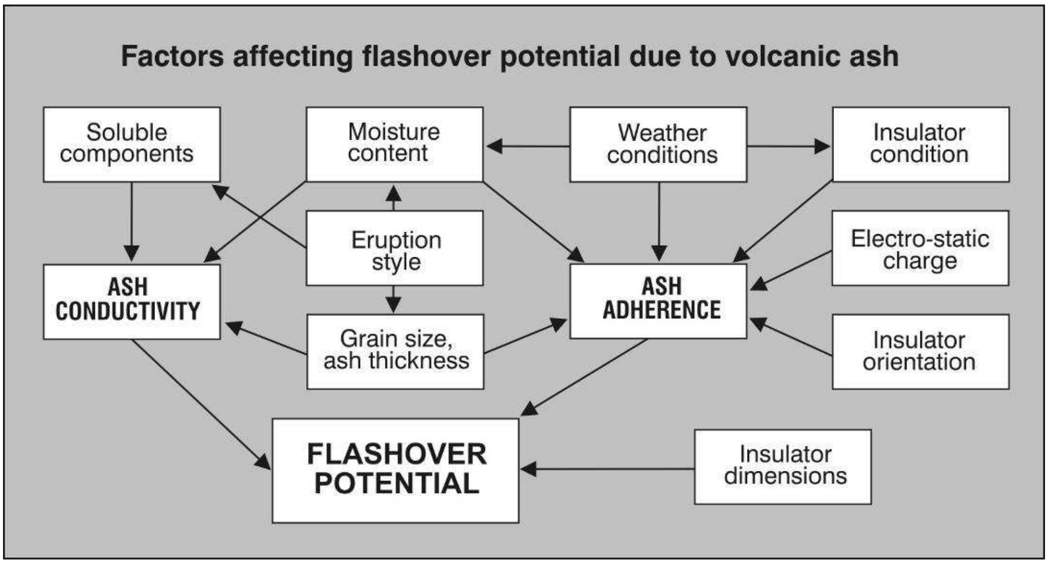

Figure 2.1: Factors affecting flashover potential due to volcanic ash

Like electrical disruption networks, as described above, variations in ash properties will also influence the level of impact. Thickness and grainsize are key parameters.

In Auckland three key factors are anticipated to threaten electrical power distribution, communications networks, and broadcasting:

1. Ashfalls from a magmatic (dry) Auckland Volcanic Field (AVF) eruption are anticipated to be coarse grained, creating a low likelihood of adhering or penetrating to insulators, lines, and telecommunications equipment. Salt build-up on electrical distribution infrastructure from volcanic gases may create flashover hazards however. A phreatomagmatic (wet) eruption could produce sufficient fine, moist ash to create an adherence hazard. In both dry and wet eruptions, near vent equipment will be vulnerable to heavy ashfalls causing failure from burial, loading and service isolation.

2. Ashfalls from distal source are likely to be fine grained, and only a large distal eruption would deposit sufficient thicknesses in the Auckland region to cause disruption causing ash adherence to Auckland electrical distribution networks creating flashover. However, fine ash is more easily ingested by equipment (e.g. air intakes on air conditioning systems) and may cause disruption to communications and electrical equipment.

3. Ashfalls from distal source create a range of impacts near the eruption source, which can have a flow on affect to the wider network.

3.0 VULNERABLE COMPONENTS, RISK FACTORS AND POTENTIAL DAMAGE

3.1 Electrical Distribution Systems

Volcanic ash can cause a number of different problems to electrical distribution systems. Most commonly these are:

1. Insulator flashover,
2. Controlled outages during ash cleaning,
3. Line breakage and transmission line tower collapse (weight of ash),
4. Breakdown of air conditioning/ cooling systems diesel generators (for backup power) in substations and other housing caused by air-intake blockages and corrosion.

All will potentially result in supply outages. Of the above, insulator flashover and breakdown of air conditioning and cooling systems are the most likely causes of outages in Auckland due to volcanic ash.

Figure 2.1 illustrates the factors affecting flashover potential. Other factors such as earthing systems may also play a factor. The distance between the insulator weather shed and the earthing system as well as orientation (horizontal or vertical) of the insulator string could also be factors. However anecdotal reports of damage vary and there is not enough quantitative data to include these as factors at this stage (refer Appendix A4).

Whether or not flashover occurs will depend on all of the above as well as the prevailing weather conditions at the time of the eruption (and over subsequent days and weeks if ash persists in the local environment). However, of these, ash thickness, grain size and moisture content are the primary factors that should alert operators to the possibility of flashover in the first instance (refer section 4.0).

Moistened ashfall onto gravel ballast (substrate) in substation and electrical yards can reduce the step/touch potential of the gravel due to reduced resistivity. This has implications for the health and safety of personnel as reduced resistivity of the gravel substrate could increase the possibility of electrocution (refer Appendix A3 – Mt St Helens). While observed at Mt St Helens, it is not known whether similar observations have been made elsewhere.

While electricity generation has not been considered here, there could be effects on for example the power stations on the Waikato River due to heavy ash loads in the river impacting water intake structures.

Table 3.1 summarises the most vulnerable components of the electricity distribution network to the effects of volcanic ash.

Air conditioning and general structures (common to both electricity distribution and communication and broadcasting networks) are discussed in section 3.3.

Table 3.1: Risk Factors and Likelihood of Potential Damage for Electrical Distribution Networks

Component	Risk Factors		Probability of Failure				Cause	Comments
			Ash thickness 1-5mm		Ash thickness >5mm			
			Fine grained (<1 mm)	Coarse grained (>1 mm)	Fine grained (<1 mm)	Coarse grained (>1 mm)		
Line Insulators								
Composition = Epoxy	**Low voltage** (domestic supply lines) Small surface area (easily coated)	Moist or Wet ash	High	Low	High	Medium	Flashover	Probability increases if ash has high salt concentration (> 2%)
		Dry ash	Low	Low	Low	Low		
	high voltage (regional/ national supply lines)	Moist or Wet ash	Medium	Low	High	Medium	Flashover	Probability increases if ash has high salt concentration (> 2%)
		Dry ash	Low	Low	Low	Low		
Composition = Ceramic/ Porcelain/ Glass	**Low voltage** (domestic supply lines) Small surface area (easily coated)	Moist or Wet ash	Medium	Low	High	Low-Medium	Flashover	Probability increases if ash has high salt concentration (> 2%)
		Dry ash	Low	Low	Low	Low		
	high voltage (regional/ national supply lines)	Moist or Wet ash	Low-Medium	Low	Medium-High	Low-Medium	Flashover	Probability increases if ash has high salt concentration (> 2%)
		Dry ash	Low	Low	Low	Low		

Component	Risk Factors	Probability of Failure					Cause	Comments
Substation insulators – high voltage (*large surface area and irregular shape*)								
Typically high voltage with large surface area and irregular shape		Moist or Wet ash	Medium	Low	High	Low-Medium	Flashover	Probability increases if ash has high salt concentration (> 2%)
Substation and electrical yards (*step/touch potential*)								
Ground ballast (substrate)		Moist or Wet ash	Medium	Low	Medium-High	Low-Medium	Resistivity of ground ballast reduced following ashfall and ash is moistened	Step/touch potential is significantly reduced when ash on the ground is damp and possible electrocution could result.
		Dry ash	Low	Low	Low	Low		
Towers/ Poles								
			Ash thickness 5-100mm		Ash thickness >100mm			
			Fine grained (<1 mm)	Coarse grained (>1 mm)	Fine grained (<1 mm)	Coarse grained (>1 mm)		
		Moist or Wet ash	Low-Medium	Low	Medium-high	Low	Collapse, buckling due to ash loading Collapse due to trees falling	
		Dry ash	Low	Low	Medium	Low		
Lines								
		Moist or Wet ash	Low-Medium	Low	High	Low-medium	Collapse due to ash loading	

Component	Risk Factors		Probability of Failure				Cause	Comments
		Dry ash	Low	Low	Medium	Low	Collapse due to trees falling	

3.2 Communication and Broadcasting Networks

Volcanic ash can cause a number of different problems to communication and broadcasting. Most commonly these are:

1. Breakdown of air conditioning/ cooling systems and diesel generators (backup power) in exchanges and other housing caused by air-intake blockages and corrosion,
2. Indirect effects such as system (landline and cellular) overloading.
3. Insulator flashover on FM/ TV/ HF antennas and AM radio masts where 'live' components are exposed,
4. Loss of electrical power to components through impacts to electrical distribution systems (see above),
5. Damage to satellite and microwave dishes due to weight of ash, corrosion and flashover potential,
6. Above ground line breakage (landline) and tower/mast collapse due to weight of ash,
7. Failure of local exchanges and/or roadside cabinets caused by corrosion to connectors,
8. Signal attenuation caused by airborne ash particles,
    - Affecting mostly low frequency services (also some satellite systems and possibly radar)
9. Interference (commonly static) to signal transmission caused by lightning (rated as a low possibility),
    - Affecting low frequency services, e.g. AM radio, HF Maritime, HF aeronautical

Some historical accounts (typically older than 25 years ago) identify significant disruption to communications during an eruption event, however the causes and timeframe of outages are difficult to ascertain. Recent experiences indicate network overloading is the most common impact, however there have been few other reported problems. It would seem that the effects to transmission of electromagnetic signal (interference and signal attenuation) are fairly small.

Damage to network components (such as electronics) should be expected, however there is no clear trend as to which components are commonly vulnerable. Electrical equipment contaminated or coated with volcanic ash, especially when wet or in very high humidity, is likely to cause arcing. Damage to mechanical switches has also been commonly reported, although with the movement towards solid state electronics, this is perhaps a decreasing hazard.

This report has identified the lack of information available on telecommunications equipment and transmission of electromagnetic signal fragility to volcanic ash. While there is some progress as to the exact mechanisms and their impact on different radio frequency bands, further research is required.

Of the above, indirect effects such as overloading are considered to be the largest single factor in the immediate disruption to the communication network. Insulator flashover and breakdown of air conditioning and cooling systems are also likely causes of communication outages in Auckland due to volcanic ash.

A key consideration however, is the longer term (weeks to month) period post eruption, where outages could result from corrosion to parts where equipment has not been cleaned or inspected for potential damage (e.g. roadside cabinets).

Table 3.2 summarises the most vulnerable physical components of the communication and broadcasting networks to the effects of volcanic ash.

Air conditioning and general structures (common to both electricity distribution and communication and broadcasting networks) are discussed in section 3.3.

Table 3.2: Risk Factors and Likelihood of Potential Damage for Communication and Broadcasting Networks

Component	Risk Factors		Probability of Failure				Cause	Comments
			Ash thickness 1-5mm		Ash thickness >5mm			
			Fine grained (<1 mm)	Coarse grained (>1 mm)	Fine grained (<1 mm)	Coarse grained (>1 mm)		
FM/ TV/ HF antennae and AM radio masts								
Exposed 'live' components such as insulators		Moist or Wet ash	Medium	Low	Medium	Low-Medium	Flashover, shorting Corrosion	Probability increases if ash has high salt concentration (> 2%)
		Dry ash	Low	Low	Low	Low		
Roadside Cabinets (landline)								
Unsealed	Connectors (e.g. IDC Krone-type connectors, especially disconnect type)	Moist or Wet ash	Medium	Low	Medium	Low-Medium	Shorting, corrosion	Probability increases if ash has high salt concentration (> 2%)
		Dry ash	Low	Low	Low	Low		
Satellite and microwave dishes								
Exposed 'live' components such as insulators		Moist or Wet ash	Medium	Low	Medium	Low-Medium	Flashover, shorting Corrosion	Probability increases if ash has high salt concentration (> 2%)
		Dry ash	Low	Low	Low	Low		

Component	Risk Factors		Probability of Failure				Cause	Comments
Lines, Cables, Masts, Aerials, Antennae, Towers								
Above ground			Ash thickness 5-100mm		Ash thickness >100mm			
			Fine grained (<1 mm)	Coarse grained (>1 mm)	Fine grained (<1 mm)	Coarse grained (>1 mm)		
		Moist or Wet ash	Low-Medium	Low	High	Low-medium	Collapse, buckling due to ash loading Collapse due to trees falling	Fine grained ash adheres more to structures; coarser grained ash falls off (wind and rain) Underground cables not affected
		Dry ash	Low	Low	Medium	Low		
Signal transmission and attenuation								
Low Frequency	AM radio, HF maritime and aeronautical	Moist or Wet ash	Low-Medium	Low-Medium	Medium	Medium	Static caused by lightning Signal drop-out	
		Dry ash	Low-Medium	Low-Medium	Medium	Medium		
High frequency	FM radio, VHF, UHF, cellular, microwave linking, satellite	Moist or Wet ash	Low-Medium	Low-Medium	Low-Medium	Low-Medium	Static caused by lightning Signal drop-out	
		Dry ash	Low	Low	Low	Low		
Satellite and microwave dishes								
		Moist or Wet ash	Low-Medium	Low	Medium-High	Low-medium	Collapse due to ash loading	Fine grained ash adheres more to structures; coarser grained ash falls off (wind and rain)
		Dry ash	Low	Low	Medium	Low		

3.3 General Structures and Equipment

Air-handling systems and air conditioners

One of the most at risk components of both electrical distribution and communication/broadcasting networks is the reliance on air conditioning and cooling systems to keep electrical equipment cool (e.g. switching equipment in telephone exchanges and data centres). Air handling systems and air conditioners are vulnerable to ash damage, corrosion and arcing of electrical components, and air-filter blockage, especially if air intakes are horizontal surfaces. The type of air conditioning system in use varies greatly depending on the size of structure (e.g. roadside cabinet versus telephone exchange).

Sealed structures using an internal air conditioning system (with external condenser) are less at risk than structures relying on external fresh air intakes. Fresh air intakes will blow ash directly onto electronics or filters can become blocked. Air filters used at communications sites are typically not designed to cope with the volume of material typically seen in an ashfall, and very quickly become blocked with ash, severely restricting airflow. Self cleaning filters use compressed air, which could become compromised during an ashfall as air compressors need clean air to operate.

Recent testing indicates that airspeed through the condenser has a significant influence on whether blockage from ash ingestion will occur. Modern split-system units typically have a very high condenser surface area, which allows for a slower fan speed (to improve noise pollution) and thus slower airspeed through the condenser, making them more vulnerable to blockage in wet or dry conditions. Older style wall mounted units appear to offer greater resiliency to ashfall, due to their higher air-speed through the condenser and reduced electro-mechanical complexity.

Some major communication sites (e.g. some Kordia sites, telecommunication exchanges, maritime HF site and others) have diesel generators to supply backup power (as well as DC batteries). These generators use large volumes of air and could be vulnerable to overheating, reduced performance and damage from ash ingestion to motors.

Road site cabinets are being updated to contain ADSL2+ broadband equipment, requiring air conditioning systems within the cabinet. This is believed to make them more vulnerable to blocking and subsequent overheating as a result of ashfall.

Electronic Equipment and Systems

Volcanic ash from eruptions of Mt St Helens presented several classes of problems for electric and electronic systems (From F.E.M.A. 1984):

- Abrasion of moving parts, especially rotating elements,
- Jamming of mechanical components,
- Shorting or grounding of circuits,
- Etching of painted and metal surfaces,
- Generation of excessive heat under a blanket of dust or because of obstructed vents.

Quantitative testing to electrical equipment, computers and air conditioning condensers (Appendix A4) has shown that when ash is dry, computer and electrical equipment continue to operate with little difficulty, even in conditions of high suspended ash. When moisture was added, computers began to fail due to the ash's electrical conductivity increasing dramatically; and the moist radiator veins of the condenser became blocked due to heavy ash build up which reduced airflow through the unit.

The most likely way equipment will be damaged by ashfall is from catastrophic entry from for example roof collapse. In the Auckland context, this includes critical plant or infrastructure necessary for example, for electrical transmission to Auckland, which is located outside the region and closer to volcanic sources elsewhere in the North Island.

Exact causes of failure and identification of mitigation measures is an area requiring further work. Rapidly evolving technology and the low frequency of eruptions makes it difficult to know if established impacts and mitigation recommendations are relevant for modern equipment. Involvement of building services and air conditioning engineers in a study looking at improvements in design to air conditioning and air handling systems to minimise damage would be useful.

Table 3.3 summarises the risk factors and likelihood of potential damage for general structures and equipment.

Table 3.3: Risk Factors and Likelihood of Potential Damage for General Structures and Equipment

Component	Risk Factors		Probability of Failure				Cause	Comments
			Ash thickness 1-5mm		Ash thickness >5mm			
			Fine grained (<1 mm)	Coarse grained (>1 mm)	Fine grained (<1 mm)	Coarse grained (>1 mm)		
Air conditioning and air handling systems								
Building (large) e.g. telephone exchange communication data centre	Unsealed air-intake (fresh-air cooling)	Moist or Wet ash	Medium	Low	High	Medium	Clogged in-intakes system shuts down	
		Dry ash	Low-medium	Low	Medium	Low		
	Sealed air-intake (high-speed condenser fan)	Moist or Wet ash	Low	Low	Medium	Low-medium		
		Dry ash	Low	Low	Low	Low		
	Sealed air-intake (low-speed condenser fan)	Moist or Wet ash	Medium	Low	High	Medium	Clogged in-intakes system shuts down	
		Dry ash	Low	Low	Low-medium	Low		
Roadside cabinet (small)	Typically unsealed (vented)	Moist or Wet ash	Medium	Low	High	Low-Medium	Clogged in-intakes system shuts down	
		Dry ash	Low-Medium	Low	Medium-High	Low-Medium		
Diesel generators	Typically air-intake –	Moist or Wet ash	Medium	Low	Medium-High	Low-Medium	Clogged in-intakes system shuts down	

Component	Risk Factors		Probability of Failure				Cause	Comments
	Unsealed	Dry ash	Low	Low	Low	Low		
Electrical equipment & computers								
		Moist or Wet ash	Medium	Low	High	Low-Medium	shorting corrosion	Probability increases if ash has high salt concentration (> 2%)
		Dry ash	Low	Low	Low	Low		
Buildings - flat roofs								
			Ash thickness 5-100mm		Ash thickness >100mm		Weight of ash causing structural failure of roof	Roof collapse is one of the few instances when a catastrophic thickness of ash will enter a building's environment which may damage electrical equipment. Only flat, long span roofs considered as they are the most vulnerable to roof collapse.
			Fine grained (<1 mm)	Coarse grained (>1 mm)	Fine grained (<1 mm)	Coarse grained (>1 mm)		
		Moist or Wet ash	Low-Medium	Low-Medium	Medium-high	Medium-high	Collapse, buckling due to ash loading	
		Dry ash	Low	Low	Medium	Medium		

4.0 MITIGATION MEASURES

Reducing the vulnerability of electrical distribution and telecommunications networks through mitigation and pre-planning

Reducing the impact of the damage summarised in section 3.0 will comprise a combination of:

- Reducing the vulnerability of the networks to ash, for example through upgrading or replacing vulnerable parts ahead of time, ensuring redundancy of the network, etc., and
- Managing the residual risk through effective response procedures.

The decision on the level of acceptable risk will vary between utility operators. Whether to implement physical mitigation measures will depend on the degree of exposure of a network to ash and a cost benefit analysis. This is discussed in more detail in section 5.0.

In many instances, it may be more cost effective to manage the residual risk through effective pre-event response planning with a focus on decisions around shutting down versus maintaining operations.

Long term mitigation of ashfall hazards

Maintaining network infrastructure in a good state of repair and in clean condition is considered best practise for long term mitigation of ashfall hazards. For example, electrical distribution network managers should ensure trees and branches do not overhang lines (similar to snow risk management) and be mindful of insulators vulnerable to flash-over hazards in high salt-hazard areas (e.g. in coastal areas). Sensitive electrical systems should be isolated from dust.

Providing adequate network redundancy is desirable, but is considered beyond the scope of this report.

Mitigation immediately prior to, during and after ashfall

Mitigation actions immediately prior to, during and after ashfall have two basic purposes: 1) preventing or limiting ash entering systems or enclosures; and 2) effective and efficient removal of ash to prevent or reduce damage.

The most effective method to prevent ash-induced damage is to shut down, close off and/or seal off equipment until the ash is removed from the immediate environment. In many cases this is not practical or acceptable. Some mitigation procedures can cause additional problems or may be counter-productive. For example, shutting down parts of a communication network to avoid several thousand dollars of damage to a particular piece of equipment may disrupt service resulting in losses of millions of dollars. Conversely, shutting down a particular piece of equipment might not be an option regardless of the revenue or cost of the damage, for example any disruption to the 111 service is unacceptable and therefore no equipment would be shut off that might impact on emergency calling. Constant monitoring of ash effects and mitigation procedures is required to achieve the most effective balance between operational requirements and damage limitation.

Response plans should include procedures to implement ash mitigation measures such as warning and notification of potential ash falls, reducing or shutting down operations, accelerated maintenance and ash-clean-up operations, including access to filters and cleaning/disposal equipment.

Following an ashfall event, it is recommended that the damage to networks and any mitigation actions carried out are documented. Knowledge of ashfall impacts and mitigation is very limited, so any systematic assessment from technical experts would be valuable.

Tables 4.1 through to 4.3 focus on mitigation actions that could be taken immediately prior to, during and after ashfall to prevent damage to the components outlined in section 3.0 above. The information in these tables is also intended for use as an input into individual utility network vulnerability and cost benefit analyses (refer section 5.0).

Useful websites

There are a number of websites which are a useful resource for mitigation measures. GNS Science is a major contributor to these sites, which are updated on a regular basis.

USGS Ash Impacts Website - http://volcanoes.usgs.gov/ash/

A comprehensive summary of impacts to essential infrastructure.

Cities and Volcanoes Commission - http://cav.volcano.info/

The Cities and Volcanoes Commission aims to provide a linkage between the volcanology community and emergency managers. Volcanic impact reconnaissance trip reports are hosted on this site.

International Volcanic Health Hazard Network - http://www.ivhhn.org/

Provides resources, guidelines and databases on impacts of volcanic emissions to human health.

4.1 Electrical Distribution Systems

Ash that falls dry on dry surfaces is easily cleaned by air blasting or brushing. Ash that falls wet or is wetted before cleaning is not easily removed without high pressure water or hand cleaning. Immediate ash removal seems the best mitigation option to prevent widespread outages. The washing of insulators should start from the bottom up to minimise the chance of wet reworked ash forming a sufficient cover to induce flashover (See Appendix A2). If possible de-ionised water should be used. Mitigation recommendations by F.E.M.A. (1984) are summarised and expanded in Table 4.1.

4.2 Communication and Broadcasting Networks

Most published material on mitigation has been based on the experience gained from the Mount St Helens eruption in 1980. Labadie (1983) produced recommendations for mitigating the effects of volcanic ash on communications systems. As noted in section 3.0, the most serious problems resulted from the conductive and abrasive properties of ash. Subsequent eruptions have not produced the same impact to communication equipment. Mitigation measures available are summarised from this early work, updated and expanded in Table 4.2.

Table 4.1: Physical Mitigation Measures for Electrical Distribution Networks

Component	Before	During	After	Comments
Electrical Sites	Maintain in good state of repair and in clean condition.	Monitor site. Protect backup and auxiliary units to avoid starting problems when they are activated.	Immediately after an ash fall, dispatch personnel to substations to dust, sweep, and blow ash from electrical equipment. Prompt and adequate maintenance of the mechanical and electrical systems is essential. Shut down all electrical systems before any attempt is made to clean or service them. Isolate any substations or electrical equipment before any attempt is made to enter the site or equipment for cleaning or servicing purposes. Remove dry ash immediately from the most sensitive systems by blowing it off using air pressure of 30 psi or less, to avoid a sandblasting effect. Avoid saturating electrical components when hosing dust off. Many of these systems can handle rain and moisture, but not the effect of water jets from hoses. Avoid rubbing or brushing equipment, as that will damage many surfaces. Be careful not to blow the ash to other places that should be kept clean. Vacuum ash when possible and change filter bags regularly. Maintain protection and cleaning programmes continuously until the threat of windblown ash is over.	Step/touch potential is significantly reduced when ash on the ground is damp and possible electrocution could result. When cleaning use low pressures for sensitive equipment. Wet ash which has subsequently dried and can be difficult to remove, hand cleaning may be required.
Line Insulators	Maintain insulators in good state of repair and in clean condition.	Monitor network to track if ash is adhering to insulators.	Assess network to determine if hazard exists. Check and keep insulators clean. A moderate wind, while the ash is still dry, will clean most insulators on outdoor distribution lines and equipment. Light rain, which does not wash the ash away, is harmful and can cause flashovers and short circuits. Ash	Insulators often exhibit good resiliency. Ensure good impact assessment has

Component	Before	During	After	Comments
	Especially in areas with high salt-hazards (e.g. coastal).	Controlled cuts may be appropriate to mitigate damage (cost/benefit).	that has hardened may require special cleaning methods such as hand cleaning or water jetting. Make controlled cuts to allow cleaning if hazard suspected (hand, air or water cleaning where appropriate). Ensure all surfaces are cleaned, such as underneath insulators. Replace damaged insulators. Cost benefit analysis should dictate whether cleaning or total replacement most appropriate.	been conducted before beginning precautionary controlled cuts.
Substation Insulators	Maintain insulators in good state of repair and in clean condition. Especially in areas with high salt-hazards (e.g. coastal).	Monitor substations to track if ash is adhering to insulators. Controlled cuts may be appropriate to mitigate damage (cost/benefit).	Assess substations to determine if hazard exists. Make controlled cuts to allow cleaning if hazard suspected (air or water blasting where appropriate). Ensure all surfaces are cleaned. Replace damaged insulators	Should be a priority as substation insulators are a vulnerable component.
Towers/poles	Maintain in a good state of repair.	Monitor network to track if ash is adhering to lines and towers (loading hazard). Controlled cuts may be appropriate to mitigate damage	Assess network to determine if hazard exists. Controlled cuts to allow cleaning if hazard suspected (air or water blasting where appropriate). Ensure all surfaces are cleaned Replace or repair damaged towers	

Component	Before	During	After	Comments
		(cost/benefit).		
Lines	Maintain in a good state of repair and in clean condition. Ensure trees and branches do not overhang lines (similar to snow risk management).	Monitor network to track if ash is adhering to lines. Controlled cuts may be appropriate to mitigate damage (cost/benefit).	Assess network to determine if hazard exists. Controlled cuts to allow cleaning if hazard suspected (air or water blasting where appropriate). Ensure all surfaces are cleaned Replace or repair damaged line Cost benefit analysis should dictate whether cleaning or total replacement most appropriate	Lines often exhibit good resiliency. Ensure good impact assessment has been conducted before beginning precautionary controlled cuts.

Table 4.2: Mitigation Measures for Communication and Broadcasting Networks

Component	Before	During	After	Comments
FM/ TV/ HF antennae and AM radio masts	Where practical seal repeater stations and other installations; shut air intakes. Use internal air circulation for cooling. Keep moisture out of equipment. Where appropriate, seal equipment that is not already watertight.	Where possible, clean equipment regularly.	Brush off, blow out or vacuum out electronic and radio equipment. Magnetic particles that stick to relay cores should be blown off.	
Roadside Cabinets (landline)	Keep moisture out of equipment. Where appropriate, seal equipment that is not already watertight.	Where possible, clean equipment regularly.	Blow out or vacuum out radio equipment; brush off.	The potential number of cabinets exposed to volcanic ash will require their prioritisaton (depending on location of critical community infrastructure and populations requiring minimal disruption to service).
Satellite and microwave dishes	Install covers; plastic tarp will do in an emergency.	Where possible, clean equipment regularly.	Clean ash from dishes, feed horns, wave guides with brush, vacuum or compressed air (<30 psi to avoid sandblasting).	
Lines, Cables, Masts, Aerials, Antennae, Towers	Trim branches and trees.	Where possible, clean	Clean with dry methods.	

Component	Before	During	After	Comments
		equipment regularly.	Magnetic particles that stick to relay cores should be blown off.	

4.3 General Structures and Equipment

Electronic Equipment

Volcanic ash from eruptions of Mt St Helens presented several classes of problems for electric and electronic systems (From F.E.M.A. 1984):

- Abrasion of moving parts, especially rotating elements,
- Jamming of mechanical components,
- Shorting or grounding of circuits,
- Etching of painted and metal surfaces,
- Generation of excessive heat under a blanket of dust or because of obstructed vents.

All attempts should be made to keep ash out of computer and electronic environments, and clean and remove any ash that has infiltrated (Table 4.3). In the long-term corrosion may set in and cause more severe damage to the computers. Filters and purifiers should be used for large operations and even for single standard PCs where important information is being stored (Gordon et al. 2005). Simple ''low tech'' procedures can used to improve the robustness of computers to the effects of volcanic ash.

In general, the severity and frequency of such problems can be reduced through maintaining a clean site and equipment, and regular and thorough maintenance programs. These measures apply to mechanical as well as to electrical systems (Table 4.3). Programs of protection or cleaning should be continuous because of the recurrence of blowing ash. The foregoing is confirmed by reports from power and communications organizations operating in the ash fall area.

The most likely way electrical equipment will be damaged by ashfall is from entry due to catastrophic roof collapse. Key buildings containing electronic equipment should be situated away from areas most likely to receive ash. These buildings should be structurally sound, and be able to cope with ash loading. In extreme situations it may be appropriate to install air conditioning and purifying units (e.g., Purafill) designed especially to remove fine particles and gaseous contaminants. They can be used within rooms to scrub the air that has already passed through outside air conditioning units. In addition, short-term (or long-term) dust shields designed to house single computers are available (Gordon et al. 2005).

Air-handling systems and air conditioners

Damage can be prevented by turning off such systems before an ash fall begins or immediately at first signs of ash fall. In many cases damage can be avoided by taking steps to avoid use (if possible), avoid ash contamination during ashy conditions and by thorough cleaning of equipment (Table 4.3).

Table 4.3: Mitigation Measures for General Structures and Equipment

Component	Before	During	After	Comments
Computers and electrical equipment	Attempt to keep ash out of the building. Techniques include sealing doors and windows; creating positive internal pressure; providing brushes and mats to clean people and cargo before they enter; frequent vacuuming around entrance, preferably with the vacuum exhaust outdoors; and reducing traffic and the number of entrances.	Sensitive systems should be isolated from dust. Insulators should be kept clean. Rubbing and brushing should be avoided. Keep sealed units sealed. Many solid-state devices are well protected as are most computer cabinets, except for fan ducts. Filters can be applied to the ducts but care must be taken to avoid overloading the fans or they could catch fire. Units not in use should be kept well sealed either in storage container designed for the purpose or with plastic material well sealed with tape.	Electrically isolate all systems before attempting to clean or service them. Throw circuit breakers, not merely a wall switch. Small portable vacuums can be used to remove the ash. All vacuums should be equipped with High Efficiency Particulate Air (HEPA) filters to catch fine ash particles. During cleaning the casing should be removed as well as expansion boards. Clean edge connectors in isopropyl alcohol and a cloth. Re-application of stabilants to improve contacts and shield contacts from corrosion. Blow or vacuum ash off. Rubbing and brushing can damage many surfaces, but uncontrolled use of air hoses can also cause problems. 30 p.s.i. or less is generally proper for blowing items clean as more pressure may sandblast. Care must be used to avoid blowing it onto other places that should be kept clean. Be sure to clean or change filters and vacuum bags frequently when operating in an ashy environment. Keep electric components clean. Excess heat can be generated when blanketed with dust. This shortens operating life and can cause fires. The dust should be vacuumed or blown off.	
Air-handling systems and air	If concerned, shut down non-essential air-	Regularly monitor and maintain air-	Before re-starting air-handling system, clean and remove ash from near external air intakes and roof area adjacent to the	

Component	Before	During	After	Comments
conditioners	handling and air-conditioning systems prior to or during the initial ash fall. Close and seal windows, doors, and other openings of buildings. Consider installing intake hoods that extend higher above the ground.	conditioning systems during ashfalls. It is likely to be cheaper to keep air-conditioning running as long as possible and repair, clean or replace later than shutting it down and losing goods, productivity, or services. Restrict vehicle and foot traffic near air intakes. Ash may be kept out by using internal circulation to create positive pressure inside buildings.	intakes; clean or replace filters; inspect, clean or lubricate moving portions of the system following prescribed routine maintenance procedures. **To restart air-handling systems:** 1. Clean the air intakes and the roof area adjacent to the intakes. 2. Clean or replace filters. 3. Inspect, clean or lubricate moving portions of the system following prescribed routine maintenance.	
Buildings – flat roofs		Monitor ash thickness on roof. If greater than 50-100 mm begin roof cleaning – especially if contemporaneous heavy rain or snowfall. See directions (left).	Clean roof with brush and shovel. Use small volumes of water to consolidate ash. Where possible, shovel into bags for easy removal. <u>Use extreme care</u>. Most injuries following an ashfall are from falls sustained during roof cleaning.	Wet ash is much heavier than dry ash.

5.0 DECISION SUPPORT TOOLS

This report summarises the current information and knowledge available with respect to the impacts of volcanic ash on electrical distribution systems, communication networks and broadcasting.

It has suggested a range of mitigation options ranging from physical (asset replacement or protection) to updating maintenance and response plans.

The decision of whether to reduce overall exposure through physical mitigation measures or accept and manage the residual risk through contingency and response plans (or a mix of both) will depend on a range of factors including:

- the probability of ashfall,
- the degree of exposure of the network to volcanic ash (location of critical parts of the network with respect to volcanic sources, to what extent they include vulnerable components as identified in section 3.0 above and whether current protection mechanisms are adequate, which facilities must be kept operative versus those that can be shut-down during and after ash falls),
- what physical mitigation measures are possible and their cost,
- the impact of damage in terms of cost on service outage with and without mitigation measures.

We recommend that the information in this report be used by network operators as the basis for a vulnerability analysis of their respective networks. A process chart, flow diagram or matrix could be developed which allows for a pictorial and tabular representation of the network highlighting those parts most at risk from volcanic ash. Estimates of service outage should particular components fail would need to be made and compared to costs to implement specific mitigation options.

Such a tool would assist in supporting a decision to implement physical mitigation measures and would also identify why in many instances contingency and response plans maybe be more cost effective options.

6.0 CONCLUSIONS AND RECOMMENDATIONS

This report summarises the current information and knowledge available with respect to the impacts of volcanic ash on electrical distribution systems, communication networks and broadcasting.

Key conclusions are:

- Light misty rain combined with large volumes of fine grained ash is considered the most hazardous event for electricity distribution, communications and broadcasting infrastructure. Light rain will not wash ash from components but greatly increase electrical conductivity potentially leading to arcing and flashover hazards.
- A phreatomagmatic eruption from the Auckland Volcanic Field is considered to be the most likely source of large volumes of fine grained (and potentially wet) ash to infrastructure components in Auckland. It is important to note that while Auckland itself may not receive ashfall, it may suffer loss of electricity supply due to failures on the national grid (from ashfall from the cone volcanoes for example on electrical distribution systems close to the source of the eruption).
- There are few modern accounts (last 25 years) of ashfall causing disruption to communications and broadcasting infrastructure or service, aside from network overloading which is common to natural disaster events. It is not anticipated significant electromagnetic signal attenuation will occur during a volcanic ashfall, however this is not well understood. However, communications and broadcasting services have a high reliance on electricity supply for normal operation.
- Due to the lack of longitudinal studies it is unclear whether there are long-term corrosion hazards to infrastructure components following ashfall. Due to the presence of soluble acidic salts on volcanic ash, it is likely some corrosion may occur. Outages could result where equipment has not been cleaned or inspected for potential damage.
- The review of available literature indicates indirect and general equipment impacts have been the most common disruption to telecommunication and broadcasting services following volcanic ashfall, such as telecommunications network overloading and air conditioning system failure. Disruption to vehicle or aircraft transport will significantly reduce the ability of network managers to adequately inspect, service and or clean exposed sites due to the hazards volcanic ashfall causes for transportation (see AELG posters on transportation and airport disruption).

Information and knowledge is slowly increasing, however there remain a number of areas where more research and application are required, specifically:

1. There is limited quantitative information available, which inhibits advancing the understanding of network and component performance in ashfall conditions, particularly for communications systems. It would seem that the effects to radio signals themselves (interference and signal attenuation) are fairly small. However there is limited information

available and while there is some progress as to the exact mechanisms and their impact on different radio frequency bands, further research is required.

2. Exact causes of failure and identification of mitigation measures for air conditioning and air handling systems is an area requiring further work. Involvement of building services and air conditioning engineers in a study looking at improvements in design to air conditioning and air handling systems to minimise damage would be useful.

3. Most of the information from historical accounts is anecdotal and refers to which element failed, but details of specific damage, reason, length of supply outage and corrective measures taken are often limited. Information about what changes utility providers make to internal systems such as maintenance regimes, asset management, response planning and communication processes as the result of the impact of ash on the network are largely unknown. Studies investigating in detail the specific corrective actions overseas operators have taken or are currently taking would be beneficial. Following an ashfall event in New Zealand, network operators should be encouraged to document the damage to networks and any mitigation actions carried out.

4. There is limited information on the impact new and emerging types of technologies might have on increasing or decreasing the vulnerability of networks. Further work in this area is needed.

5. There is limited information on the effects of ash on power generation (e.g. determining ash loads in the Waikato River and effects on water intake structures).

6. Fragility functions[1] for the most vulnerable components should be developed. There is probably enough information about the impact of the different components of ash for these to be developed for electrical distribution systems. This is likely to be an outcome of the DEVORA[2] research programme.

7. The vulnerability of Auckland's electrical and telecommunications networks to ash is unknown. Criticality audits could be undertaken of each network by the network operators themselves to determine the level of exposure the different networks have. This exercise could be supported first by a workshop on the findings of this report. Information could then be combined to enable a vulnerability assessment of the combined networks to volcanic ash. This exercise could be undertaken in partnership with the RISKSCAPE[3] research programme.

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[1] Fragility Function – a loss curve (mathematical expression) of the damage of a certain element to a specific hazard intensity, e.g. number of houses that are expected to collapse given various weights of ash. These relationships can then be input directly into risk models.

[2] DEVORA (DEtermining VOlcanic Risk in Auckland): – a research programme aimed at a much-improved assessment of volcanic hazard and risk in the Auckland metropolitan area, and which will provide a strategy and rationale for appropriate risk mitigation. This will be based on increasing the understanding of the Auckland Volcanic Field through an integrated, multi-disciplinary, multi-agency study. htpp://www.iese.co.nz/

[3] RISKSCAPE – a research programme aimed at developing an easy-to-use multi-hazard risk analysis tool. It converts hazard exposure information into the likely impacts for a region, for example, damage and

Recommendations for the AELG

As a follow on from this study, we recommend that the AELG consider building one or more of the following projects into its business plan:

1. Undertake a survey, or summarise criticality audits, to broadly ascertain the level of exposure the different networks have to volcanic ash in order to be able to make an initial assessment of the risk to Auckland from ashfall. The survey could include questions relating to e.g. approximate percentage of the different types of insulators; air-conditioning types in the different buildings; number of roadside cabinets; estimate of masts with live components; location of particularly at risk facilities to volcanic ash; and the extent of infrastructure outside of the Auckland region (e.g. main transmission lines) that is at physical risk and which if damaged would have an impact on service to Auckland. This project could be undertaken in partnership with DEVORA and RISKSCAPE research programmes.

2. Support a project with one of the AELG members to partner with a similar overseas operator (e.g. telecommunication or electrical distribution operator) with experience in working with ashfall to investigate mitigation measures and systems changes in more detail.

3. Encourage AELG members to review the information in this report against their installation standards (i.e. assess whether any changes to installation standards are required for installations in areas at risk from volcanic ash).

4. Develop the information on effects of ash on electrical distribution systems and general equipment (e.g. computers and air conditioning) into two posters (estimated at $2K per poster). A poster summarising the effects on broadcasting and communications is considered less of a priority (less information), although a poster on general equipment will be relevant to both.

5. Ensure reviews of the posters are carried out on a regular basis (e.g. every two years). These reviews should be built into the business plan as part of the Volcanic Impact Study Group's activity at no financial cost to the AELG. Reviews would be undertaken as part of GNS Science and Canterbury University's (and others) research programmes.

6. Advocate and support more utility operator representation on reconnaissance trips with a view to specifically looking into details of failure, damage and mitigation methods.

7. Advocate and support quantitative experiments of key infrastructure components in simulated volcanic ashfall to reduce the uncertainty of what the potential effect volcanic ashfall may have on performance. For example, key information gaps are the performance of insulators for electricity distribution, vulnerable components in telecommunications exchanges and diesel electrical generators in volcanic ashfall.

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replacement costs, casualties, economic losses, disruption, and number of people affected. http://www.riskscape.org.nz/

APPENDICES

A1 Radio Frequencies

Source: Wikipedia

Name	Symbol	Frequency	Wavelength	Applications
Extremely high frequency	EHF	30–300 GHz	1–10 mm	Microwave data links, radio astronomy, remote sensing, advanced weapons systems, advanced security scanning
Extremely low frequency	ELF	3–30 Hz	10,000–100,000 km	Directly audible when converted to sound, communication with submarines
High frequency	HF	3–30 MHz	10–100 m	Shortwave, amateur radio, citizens' band radio, skywave propagation
Low frequency	LF	30–300 kHz	1–10 km	AM broadcasting, navigational beacons, lowFER
Medium frequency	MF	300–3000 kHz	100–1000 m	Navigational beacons, AM broadcasting, maritime and aviation communication
Super high frequency	SHF	3–30 GHz	1–10 cm	Wireless networking, satellite links, microwave links, satellite television, door openers
Super low frequency	SLF	30–300 Hz	1,000–10,000 km	Directly audible when converted to sound, AC power grids (50–60 Hz)
Ultra high frequency	UHF	300–3000 MHz	10–100 cm	Broadcast television, amateur radio, mobile telephones, cordless telephones, wireless networking, remote keyless entry for automobiles, microwave ovens, GPR
Ultra low frequency	ULF	300–3000 Hz	100–1,000 km	Directly audible when converted to sound, communication with mines
Very high frequency	VHF	30–300 MHz	1–10 m	FM broadcasting, amateur radio, broadcast television, aviation, GPR, MRI
Very low frequency	VLF	3–30 kHz	10–100 km	Directly audible when converted to sound (below ca. 20 kHz; or *ultrasound* otherwise)

A2 Literature Review: Summary of Factors Affecting Volcanic Ash Impacts on Electricity Distribution Systems and Communication Networks

Electrical Distribution Systems

Volcanic ash can cause many different problems to electrical distribution systems. Most commonly these are: (1) supply outages resulting from insulator flashover; (2) controlled outages during ash cleaning; and (3) line breakage. Investigations of these effects have been reported by Nellis & Hendrix (1980), Stember & Batiste (1981), Sarkinen & Wiitala (1981), Blong (1984) and Heiken *et al.* (1995). The factors affecting flashover potential of insulators are primarily ash conductivity, ash adherence and insulator dimensions (Figure 2.1) which are here discussed in turn.

Ash conductivity

Dry volcanic ash is not conductive enough to cause insulator flashover problems. However, if insulating surfaces are completely coated in ash, the presence of moisture in association with soluble ash coatings can be critical factors in initiating insulator flashovers (Figure A1 & A2). Moisture may be derived from the atmosphere, in the form of rain (during or after the ash fall), or from the eruption plume itself. The soluble coatings are derived from aerosols in the eruptive column (refer to appendix 1). With time rain will dilute the soluble components.

Bebbington et al. (2008) note that non-volcanic ash flashover of contaminated insulators is a well known phenomena from many locations, due to sea spray (e.g., Higashhiyama et al. 1999), industrial dust (Aulia et al. 2006) and natural dust (Rizk and Assaad 1971). Typically a combination of fine-grained (<100 µm) dust, together with high salt concentrations (up to 1.25 wt.% salts) has shown the greatest potential for contamination (e.g., Chen and Chang 1996). This material has around ten times the conductivity of the typical Mt St. Helens ash described by Sarkinen and Wiitala (1981), which notably caused many flashovers and power outages on sub 115 kV distribution systems. By comparison, Ruapehu Volcano during 1995–1996 contained total salt concentrations typically between 0.4 and 2.1% (Cronin et al. 1998; Cronin et al. 2003), between four and twenty times that of the 1980 Mt. St. Helens ash. Flashover did occur on electrical distribution systems during these eruptions but only in several isolated cases due to the relatively thin ashfalls and mitigation treatments by power companies (discussed further below).

Many volcanic ash samples show that even after long periods of repeated wetting soluble components such as Sulphate and Fluoride may be extracted over long periods (Cronin and Sharp 2002; Cronin et al. 2003). Ash could thus potentially pose a contamination threat for weeks following an eruption (Bebbington et al. 2008).

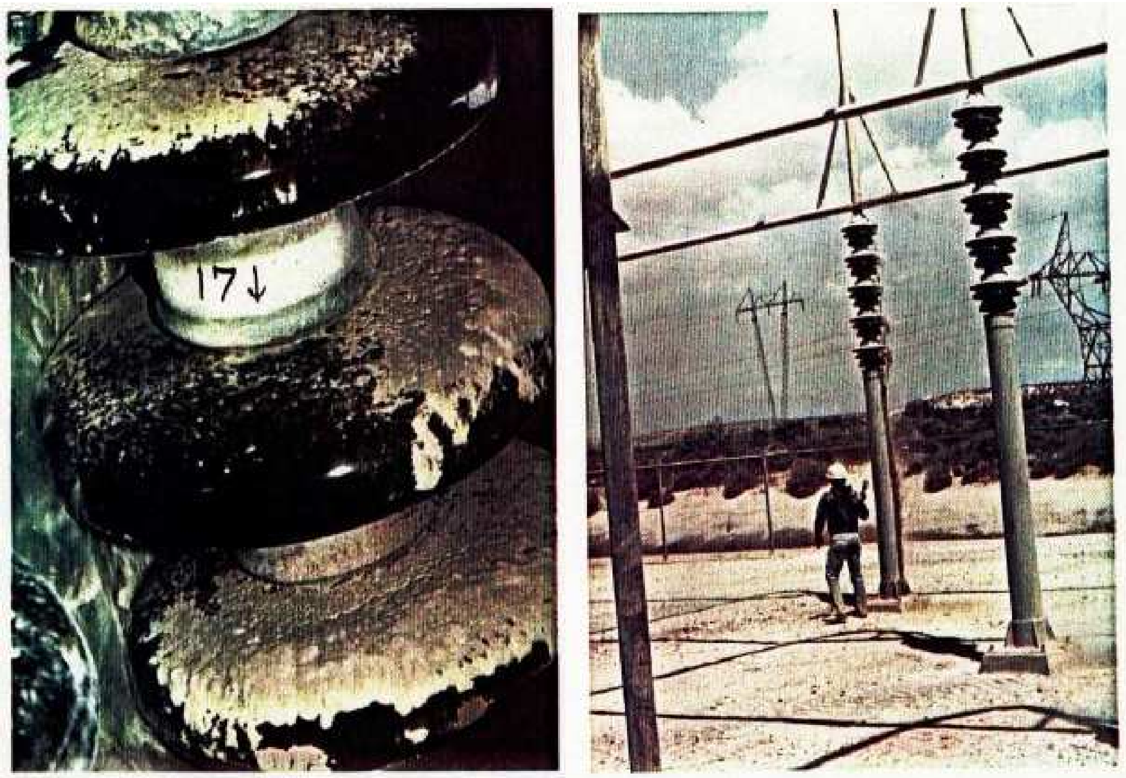


FIGURE A1: Photographs illustrate volcanic ash deposits on electrical equipment at Vantage Substation, 21 May, 1980 (from Nellis & Hendrix 1980). Note in the second photo a man striking a pedestal trying to remove ash.

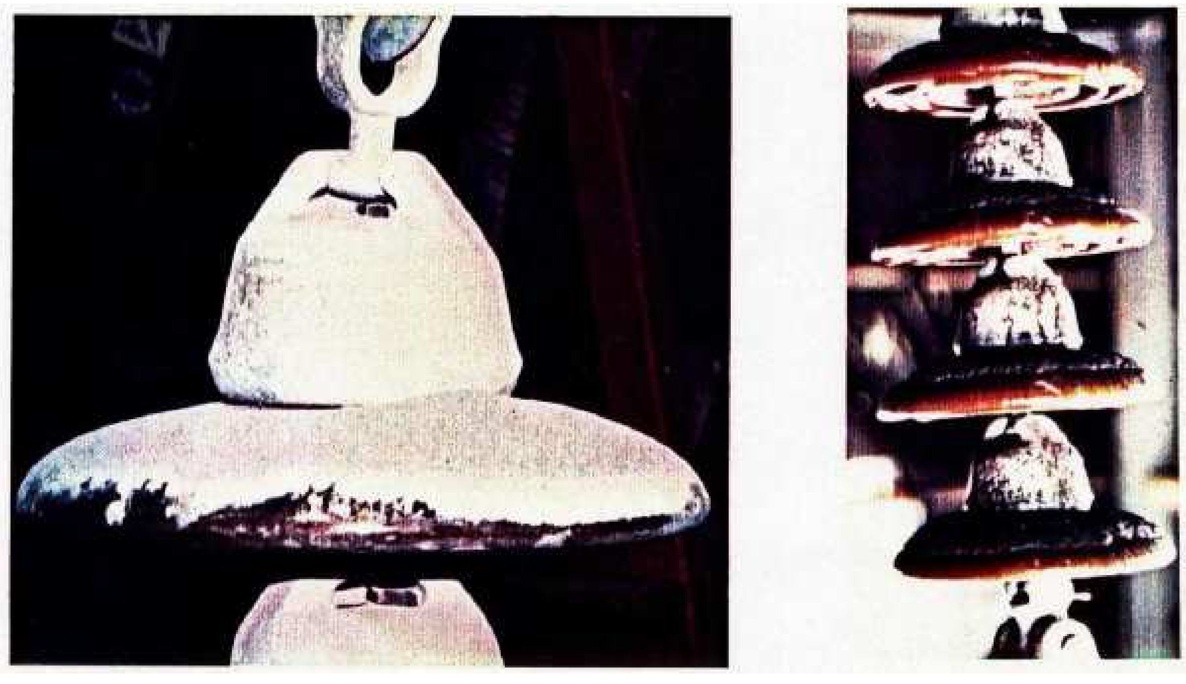


FIGURE A2: 115 kV rig covered in ash during testing by Nellis & Hendrix (1980)

Ash adherence

Weather conditions at the time of ash fall influence ash adherence to insulating surfaces. Dry ash generally tends to rest on horizontal or gently sloping surfaces but causes no immediate electrical problems. In contrast wet ash sticks to all exposed surfaces. In experiments reported by Nellis and Hendrix (1980) heavy rain washed off about 66% of ash from insulators, whereas light rain removed little ash.

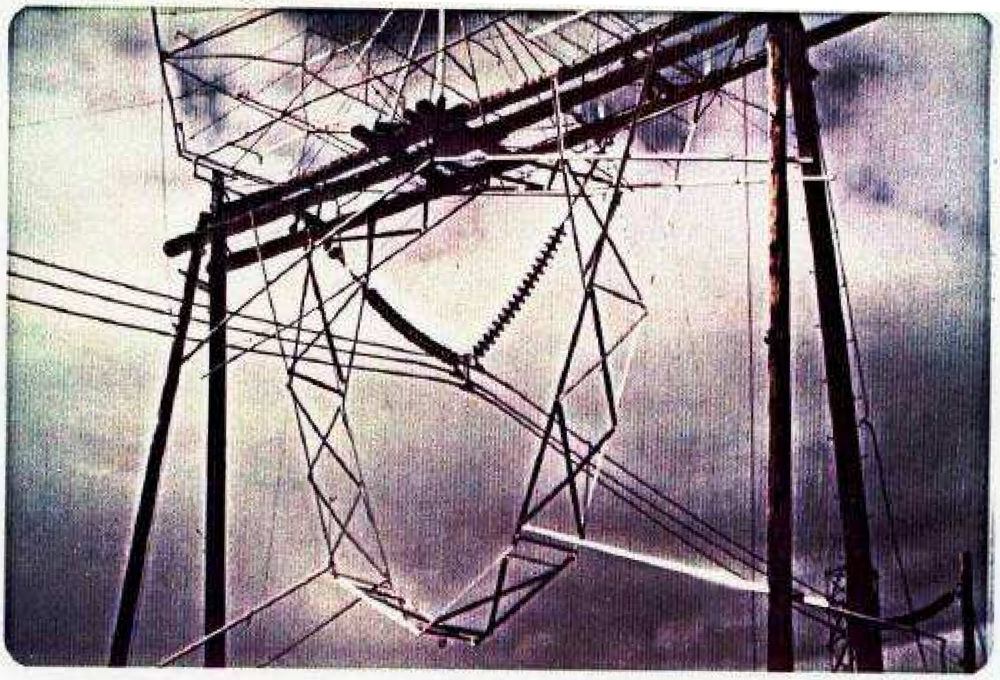
In tests it has been shown that winds of up to 55 km/hr removed 95% of dry ash (Nellis and Hendrix 1980). The type, condition and orientation of insulators have also been found to influence the adherence of ash. Epoxy insulators are more vulnerable to flashovers than porcelain insulators due to increased ash adherence (Heiken *et al.* 1995). Nellis and Hendrix's (1980) experiments also showed that if insulators were wet prior to ash falls, adherence was enhanced. Especially significant was the ability for ash to accumulate on the underside of wet insulators.

Insulation that has 30% or more of its creepage distance (shortest distance on the surface of an insulating material between two conductive elements) either clean or dry has a low probability of initiating insulator flashovers.

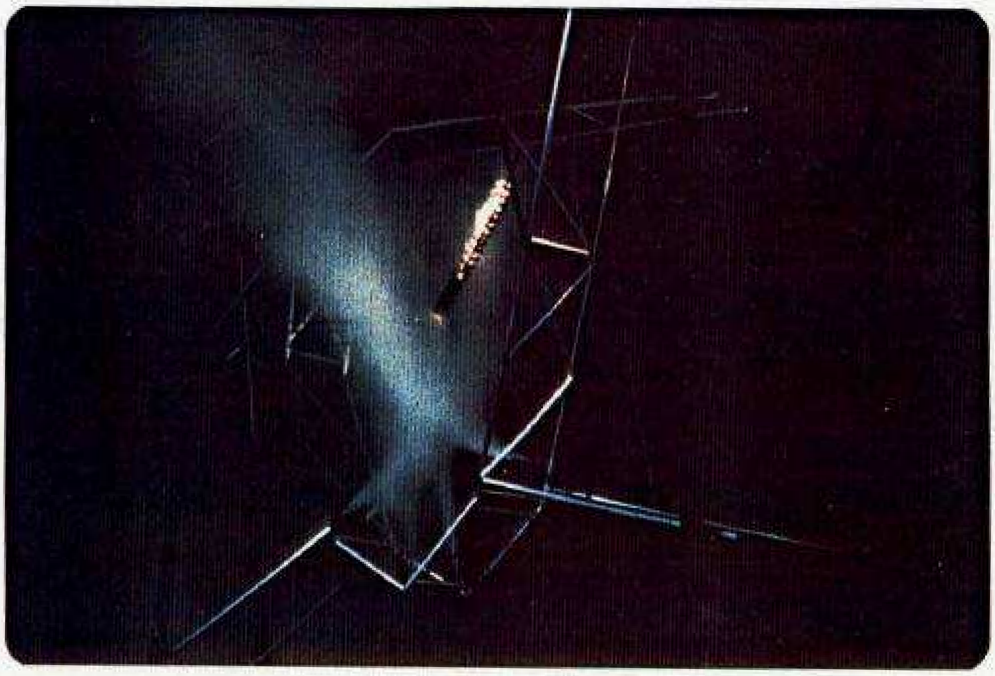
On large (500–110 kV) electrical transmission networks, many insulators were able to withstand ash build-up from the Mt St. Helens, 1980 eruption to a thickness of 6–9 mm before serious flashovers began (Figure A3; Sarkinen and Wiitala 1981). As the distribution voltage reduces from 33 kV down to domestic supply voltage of 400 V, the surface areas of the insulators reduce accordingly, which leads to increased risk of flashovers and sustained power outages of several hours or longer (Sarkinen and Wiitala 1981). Lower voltage insulators also have smaller weather-sheds so have been thought to be more prone to becoming completely covered with ash and water, and therefore are more vulnerable to flashovers than higher voltage insulators (Nellis & Hendrix 1980). Substation insulators are more exposed to ash and rainfall due to their shape and often horizontal orientation, which makes them more susceptible to flashovers than line insulators.

Other problems include:

- Ash covering surface rock in substation area may significantly reduce ground resistivity, Step-touch potential, once wetted by rainfall, creating a hazard for maintenance crews (Sarkinen and Wiitala,1981; Bebbington et al. 2008).
- Ash contamination on insulators and conductors increases corona activity which in turn causes increase in audible noise (around 10-15 dB) and radio interference (Nellis & Hendrix 1980).
- Volcanic ash is a contaminant which abrades and clogs mechanically moving parts. Precautionary measures may be needed to service and maintain substation equipment after ash falls.
- Wet ash-laden tree limbs may fall on distribution lines (e.g. in Rabaul in 1994 (A.I.D.A.B. 1994)).
- Ashfall can adhere to lines. Following ashfalls of several tens of mm, especially when wet, line and/or pole collapses are likely (e.g. Chile Chico following the 1991 Hudson eruption, Chile (Wilson et al. in prep; Bebbington et al. 2008)).



(a)



(b)

FIGURE A3: Photographs from Nellis & Hendrix (1980) showing (a) setup for testing 500 kV Vee string, and (b) current scintillation (flashover) activity for ash contaminated insulators with steam fog at 1.9 PU applied voltage.

The consequences of loss of electricity supply are widespread, and many other public utilities (e.g. water supply pumps, radio and telecommunication facilities) may be inoperative for the duration of the power loss unless local backup power supplies (batteries and generators) are available.

Diesel powered generators

Diesel powered generators are important for maintaining vital services during electricity outages. There are few accounts of their usage during ashfalls, with the only known instance in Los Antiguos, Argentina, during the 1991 Hudson eruption. The generators were turned off to protect against possible ash ingestion into the diesel engines.

Communications Systems

Communications have been reported to be disrupted around an erupting volcano. Such disruptions may result from overloading of telephone systems due to increased demand, direct damage to communications facilities, and indirect impacts resulting from disruption to electricity supplies or transportation of operations or maintenance workers. There is little or no evidence of modern electromagnetic transmission systems (e.g. cellular, microwave data-links, broadcast and satellite TV, AM/FM radio, aviation or maritime communications) being disrupted by ash plumes; however this is an area of some uncertainty.

Large quantities of electrically-charged ash can be generated in an eruption column (Anderson *et al.* 1965; Gilbert *et al.* 1991; Gilbert & Lane 1994). These have been known to cause interference to radio waves in historic eruptions, but not to modern telecommunications equipment. For days following the 1912 Katmai eruption radio communications were inoperative on Kodiak Island, 160 km from the vent (Erskine 1962). During the 1963 Surtsey eruption (Iceland) clicks of radio static were observed by a passing ship (Anderson *et al.* 1965). Problems with radio communications around Pinatubo in 1991 were possibly due to electromagnetic disturbances from the fine volcanic ash (Rodolfo 1995). However, there are numerous examples of modern radio and telephone communications continuing to function around an erupting volcano and in areas receiving ash falls (e.g. Mount St. Helens 1980, Ruapehu 1995-1996 and Chaiten 2008). Rodolfo (1995) reports "*surprisingly, the telephones continued to work...*" in the Philippines after 150 mm of ash fell from the 1991 Pinatubo eruption.

During most natural disasters telephone and radio communications are susceptible to overloading by public and emergency services use. Overloaded telephone systems were recorded in communities receiving ash during the 1953 Mt Spurr eruption (Wilcox 1959), the 1980 Mount St Helens eruption (Dillman *et al*. 1982) and the 1995/96 Ruapehu eruption (Johnston 1997b). Response organisations report frequent overloading of their telephone lines even in cases where the general system remains operative (e.g. during eruptions of Mount Spurr 1992 and Ruapehu 1995-1995)

Most modern telephone exchanges require air-conditioning units to keep electronic switching gear below critical temperatures. Exchanges with external air-conditioning units are thus vulnerable to over-heating if these units fail or are switched off (due to ash falls), even if the exchange itself is sealed. Some exchanges are specially sealed to keep out corrosive geothermal gases such as H_2S

(e.g. in Taupo and Rotorua). However, any ash entering telephone exchanges can cause abrasion, corrosion and /or conductivity damage to electrical and mechanical systems.

Electric and Electronic Equipment

The abrasive and mildly corrosive nature of ash can damage mechanical and electrical systems. Air-handling systems and air conditioners are vulnerable to ash damage and air-filter blockage, especially if air intakes are horizontal surfaces, although severe damage is commonly avoided by shutting down systems. Penetration of ash into the electrical system can lead to short-circuiting and fires. Shorting of switch points was the most common source of failure in equipment in urban areas following the Mt St Helens eruption (Blong 1984).

Quantitative testing to electrical equipment by Gordon et al. (2005) to computers and Wilson and Cole (2007) to air conditioning condensers illustrated that when ash was dry both types of equipment operated with little difficulty, even in conditions of high volumes of suspended ash in the atmosphere. But when moisture was added to the testing environment computers began to fail due the ash's electrical conductivity increasing dramatically; and the moist radiator veins of the condenser became blocked due to heavy ash build up dramatically reducing airflow through the unit.

A3 Literature Review – Historic Impacts

Published details of volcanic impacts on electricity supply systems and communication systems are limited to a few recent examples and very few quantitative measurements of the impacts exist.

Mt St Helens 1980 (USA)

On 18 May 1980 an earthquake-triggered sector collapse removed much of the north flank of the Mt. St. Helens to form a massive debris avalanche, followed by a plinian eruption for 9 hours, with the column reaching 25 km in height (Lipman & Mullineaux 1981). Heavy ash falls occurred over much of northern USA, in particular Washington State. Five more explosive eruptions followed during the remainder of 1980.

Electrical

The distribution of electricity in the state is carried out by the Bonneville Power Administration (BPA), equivalent to New Zealand's TransPower. The BPA on-sells to local power companies. During the 1980 eruptions of Mount St. Helens volcanic ash disrupted the electricity supplies of several communities in Washington State. The BPA reported that before and during the eruption there was a complete lack of knowledge on the affects of ash falls and much anxiety about the potential impacts.

The impacts were largely dependent on the weather prevailing at the time. The main 18 May eruption occurred during dry weather and ash did not cause immediate problems except for a few short-duration outages and ash adhesion to horizontal surfaces. No outages were reported on the day of the eruption although outages occurred a few days later in other areas that received rain. Later eruptions affected other parts of Washington. Ash falls from the smaller 25 May eruption occurred to the south-east of the volcano, accompanying rainfall. Low voltage lines and substations experienced numerous outages from insulator flashovers in areas of >5 mm ash thickness when the ash was wet. It was reported that a number of wooden electricity poles caught fire. On large (500–110 kV) electrical transmission networks, many insulators were able to withstand ash build-up from the Mt St. Helens, 1980 eruption to a thickness of 6–9 mm before serious flashovers began (Sarkinen and Wiitala 1981). The ash's conductivity was found to increase with decreasing grain size and the problem of insulator flashovers increased with distance from the volcano. The 12 June ash fell dry but later rain wet the ash sufficiently to cause outages.

In addition to line insulators, ash from the Mount St Helens eruption of May 18, 1980 covering surface rock in substation areas caused a major decrease in the ground resistivity once wetted by rainfall. Resistivity was observed to decrease from approximately 3000 Ωm (ohm meter) to 50 Ωm. This was identified as potentially a serious danger for technicians entering the area and equipment was isolated before cleaning/repair to avoid electrocution (Sarkinen and Wiitala 1981; Heiken et al 1995; Bebbington et al. 2008).

Communications

Except for short circuits caused by conductive ash and abrasion of moving parts, few serious radio problems were reported (Labadie 1983). Teflon insulators on communications antennas were covered with dust and shorted out. These were very difficult to clean as residue would adhere, requiring replacement with ceramic insulators. Plastic switches and push-buttons (especially those with self-cleaning contacts) were found to abrade quickly and required replacement (Labadie 1983).

Electric and Electronic Equipment

Shorting of switch points was reported as the most common source of failure in equipment in urban areas (Blong 1984). Slight damage was also reported to air conditioning units following 18 May ashfalls. Some computers were reported damaged, with ash reported to be particularly harmful to disk drives (Blong 1984), however this is regarded to be less of an issue following testing by Gordon et al. (2005) and is discussed in the following section.

Specific difficulties reported included (from FEMA 1984):

- Difficulty in operating electro-mechanical items, such as unprotected switches.
- Insulator flashover (and resultant fires in wooden power poles) due to wet ash deposits.
- Corrosion of copper/brass and ferrous metals by wet ash (confirmed by laboratory tests).
- Irrigation pumps burnout due to heat build-up caused by ash deposit.
- Higher rate of drive belt wear.
- Contamination of protected spaces by air conditioners that use outside air.

Redoubt 1989 (USA)

Redoubt volcano, located on the west side of Cook Inlet in Alaska erupted explosively on 20 separate occasions between December 1989 and April 1990 (Miller & Chouet 1994).

Electrical

In December 1989 power outages resulting from insulator flashover occurred in the Twin City area, Kenai, after receiving ~ 6mm of ash in conjunction with rain (Johnston 1997a). Prompt cleaning of substations was recognized as the most effective protective measure (Tuck *et al.* 1992).

Mt Spurr 1992 (USA)

Mt Spurr began a sequence of eruptions on 27 June 1992, after 39 years of inactivity (Keith 1995). Two further episodes occurred on 18 August and 16-17 September. All three episodes lasted around four hours and sent eruption columns to around 14-15 km in height.

Electrical

The city of Anchorage is 120 km from Mount Spurr and is the largest city in Alaska, with a population of over 300 000. The August 1992 eruption deposited about 3 mm of fine sand-sized volcanic ash on the city (Johnston 1997a), but no electricity outages were recorded (The Municipal Light and Power Company *pers. comm.*). The lack of rain during the ash falls and prompt cleaning prevented insulator flashovers at substations. Wind removed most ash from power lines.

Communications

Telephone services in Anchorage are provided by ATU Telecommunications. Major problems with intakes for air-conditioning at exchange sites were reported (Johnston 1997a). All air-handling units were shut down during the ashfall and conditions were monitored from the ATU Emergency Command Centre. The problem continued for some days after the ashfalls due to airbourne ash levels. The cool ambient temperatures at the time of the year meant temperatures within the exchanges did not reach critical levels and all systems remain operative. Most key buildings at ATU had positive air (internal air pressure exceeding atmospheric pressure) and air conditioning units were turned off. Staff were also sent home for health and safety reasons.

Despite having to shut down air-conditioning equipment and operating with reduced staff levels, no major system problems occurred. Increased phone demand was recorded but did not overload the system (Johnston 1997a). Following the ashfall, some problems with blocked air-filters on remote equipment were noted.

Rabaul 1994 (Papua New Guinea)

Rabaul sits between Tavurvur and Vulcan volcanoes. Following a volcano-seismic crisis in 1983 and 1984 both volcanoes erupted on 19 September 1994. Much of the town of Rabaul (17,000 residents) was covered in heavy ashfall, with ashfalls of 2-3 metres covering the southeastern suburbs (Blong & McKee 1995; SMEC International 1999).

Electrical

The power supply was shut down at the start of the eruption (Carlson 1998). The Rabaul Power Station suffered little damage from ashfall hazards, however the station was decommissioned and the diesel generators removed (SMEC International 1999). Falling trees and buildings damaged large sections of the reticulation system. Some transformers were damaged from ashfall hazards. In 1999 approximately 40% of the original 47 transformers are in operation (SMEC International 1999).

Although most of the poles in Rabaul are steel, and exposed to corrosion, SMEC International (1999) reported that most had remained intact 8 years after the eruption and could be reused.

Communications

The roof of the local telephone exchange collapsed and the equipment was completely destroyed. Underground cabling network was not impacted, however most cross-connection units were damaged or destroyed (SMEC International 1999). The underground cables were installed in conduits and the cable joints are sealed with a waterproof heat shrink sleeve. SMEC International (1999) determined that the majority of cables could be reused even in the most damaged areas of the Town.

Ruapehu 1995-1996 (New Zealand)

A sequence of eruptions began on 18 September 1995 (Bryan *et al.* 1996) followed by a spectacular explosion through Crater Lake on 23 September 1995 which received worldwide media coverage. Further significant peaks of activity occurred on 25 September and 7, 11 & 14 October 1995. Eruptions continued through late October and early November. On 15 June 1996 seismic activity resumed and a second sequence of eruptions commenced on 17 June. Over 17-18 June ash fell over a wide sector north and west of Ruapehu. Eruptions continued through July and the first week of August, again spreading ash over much of the North Island. The last eruptive activity occurred on the evening of 1 September 1996, producing a minor ash fall on the Turoa skifield.

Electrical

Falls of volcanic ash and mud on 25 September 1995 caused shorting on high-voltage electrical power lines at the base of the volcano (Figure A4; Johnston et al. 2000). Fine ash (particles typically < 250 µm diameter) coated insulators, pylons and high voltage power lines (220–110 kV) east (downwind) of the volcano (Cronin et al. 2003; Bebbington et al. 2008). This caused voltage fluctuations and problems for electrical equipment throughout the North Island. For example, fluctuations in supply tripped the emergency power at Wellington Hospital causing non-essential supplies to be shed. Included in this, by error, was a water pump in a block containing dialysis machines (K. McIntyre, Wellington Hospital pers. comm.). Thermal power stations to the north were started to ensure security of the system.

Electricity supply companies were required to hand clean insulators and towers following every ash fall event (Johnston et al 2000) and towers required repainting afterwards to reduce the acid-induced accelerated corrosion (Figure A5). In addition, the auto recloser system used by the main lines company, Transpower, which breaks electrical supply to a circuit when there is an earth or fault, had to be operated manually during the 1995–1996 eruptions of Mount Ruapehu (A. Joosten, pers. comm 2006). A major concern at the time was that ash fall could cause one circuit to trip out of service, leading to a cascade tripping of remaining circuits transmitting electricity to the upper North Island (Bebbington et al. 2008). Cleaning of 18 towers (and insulators) was undertaken on 27 September 1995 by four crews of four men (Powermark 1995). The ash was found to be dry and easy to remove. Strain towers were the most affected due to their insulator configurations (i.e. horizontally strung). It was found that subsequent rains (on 26 September 1995) had washed the northern side of towers and insulators. It was concluded that normal rainfall would clean ash from structures, conductors and insulators except the undersides of strain strings. Three strings of insulators were found to have widespread flashover damage but with no electrical problems.

After ash falls, electricity generation and supply companies routinely cleaned ash from affected substations. On 17 June 1996 electricity supplies were disrupted in parts of Rotorua city after an explosion of a 11 kV ground mounted distribution transformer at a local substation caused by ash and water settling on a transformer due to a resident's hosing ash from the roof of a neighbouring building (*Daily Post*, 19 June 1996; Bebbington et al. 2008). There was a focused effort to make sure that all of the 11 kV bus-bars were clear and free of any ash before they were put back in to service (N. Goodwin., pers com 2007).

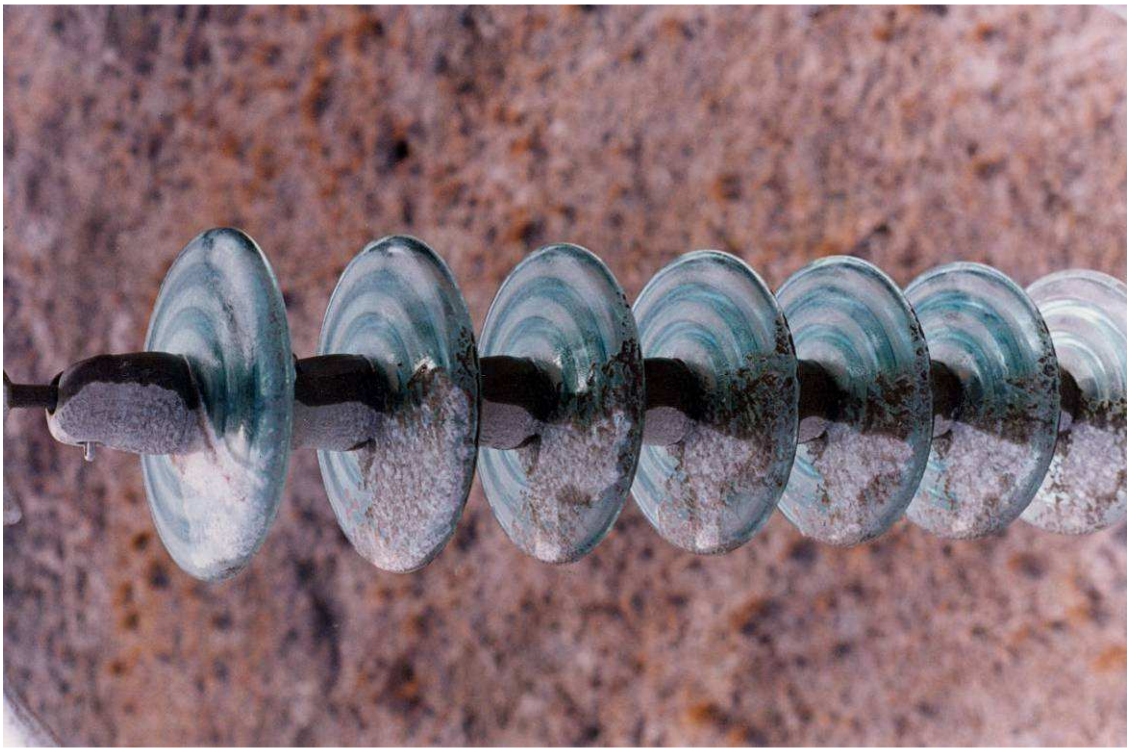


FIGURE A4: Flashover damage from falls of volcanic ash and mud on 25 September 1995 caused on high-voltage electrical power lines at the base of the volcano (from Powermark 1995, unpublished, "*Report on volcanic ash contamination*").

FIGURE A5: Cleaning the power lines/pylons

Communications

Telecom New Zealand reported over-heating alarms were triggered following ashfalls in exchanges at Ruatoria.

Hudson 1991 (Chile)

The August 1991 eruption of Mt. Hudson (Chile) was one of the largest eruptions of the 20th century, when an estimated 7.6 km^3 of pyroclastic material was erupted. Ash was erupted to ~18 km and distributed ash over 150,000 km^2 in Chile and Argentina, and reaching the Falkland Islands (Inbar et al. 1995).

Electrical

Electricity networks were disrupted in several communities impacted by the Hudson ashfall (Wilson et al., in prep). Chile Chico (~100 km from the volcano) reported electricity outages, both controlled and due to eruption impacts following 80-120 mm of ashfall (Narajo and Stern 1998). Anecdotal accounts reported ash accumulation caused electricity lines to collapse in Chile Chico during the ashfall. Ash accumulation on insulator cups also led to several reported instances of electrical flashover (Wilson et al., in prep).

Los Antiguos is located 120 km from the volcano and received 80-100 mm of ashfall (Narajo and Stern 1998). Electricity was generated in by diesel powered generators in 1991. The municipality cut the electricity because of fears lines may collapse and possible damage to the generator. Lines did not collapse in Los Antiguos, with ash typically just falling off them, however they were closely monitored by linesmen throughout the eruption (Deputy Mayor, Los Antiguos). Amador Gonzalez (Secretary of Public Works for Los Antiguos) said the large amount of static electricity in the eruption plume impacted voltages, creating voltage surges and lightening hazards for both the 220 V domestic supply and the 360 V three phase supply (Wilson et al., in prep).

There was no loss of electricity at Perito Moreno (120 km) following 60 mm of ashfall. Electricity was turned off for 1 month in Rio Gallegos following the eruption, so that there was no risk of damage to the electrical network. This was apparently due to the severe remobilisation problems associated with the strong winds. During the eruption Tres Cerros and Puerto San Julian did not lose electricity, as they had their own diesel generators. These apparently worked successfully throughout the ashy conditions (Wilson et al., in prep).

Communications

The eruption cloud created severe lightening hazards (Inbar et al. 1995). High Frequency (HF) and Very High Frequency (VHF) radio receivers within 80 km of the volcano (main regional communication network at the time) were commonly hit by lightning strikes which rendered them useless (Luis Fernando Sandoval Figueroa - emergency manger at Coihaique, Chile). Some electrical appliances were also ruined due to lightening strikes (Luis Fernando Sandoval Figueroa, pers comm. 2008). Radio telephones (RT) and HF/VHF radios were predominantly affected by the lightening hazards. Luis Fernando Sandoval Figueroa recalled the ash plume could be effectively tracked by monitoring which localities still answered their RT.

In the Chile Chico area (90 km from vent; 80-120 mm ashfall) radio communications were reported to be generally reliable throughout the eruption, but telephone lines were cut which Wilson et al. (in prep) speculate was due to collapse from ash accumulation on the lines. Sn. Juan Mercegui (former Chilean provincial governor) said radio operators were invaluable for communication with each town in Chile which was usually the school headmaster.

Satellite communications in Los Antiguos failed during the ashfall, as occurs in a snow storm. HF radio still worked however. The service of the one phone at the time was lost for several days, although emergency mangers were not sure why (Wilson et al., in prep).

There was no loss of telephone services in Perito Moreno during the ashfall (Joses Guillermo Bilardo, pers comm. 2008).

Chaiten 2008-present (Chile)

The May 2008-present eruption of Vulcan Chaiten (Chile) was the first pyroclastic eruption of a rhyolitic volcano in over 50 years. A series of plinian eruptions occurred in May 2008 erupting ash up to 30 km high, with continuing lava dome growth and associated small pyroclastic flows and ashfalls continuing to present. Ash was distributed across 175,000 km^2 of Chile and Argentina (Watt et al. 2008).

Electrical

Many electrical distribution networks exhibited resiliency to various thicknesses and grainsizes of ashfall hazards. However, there were several instances of electricity supply being disrupted in several communities.

A 68 km stretch of 33 kV line to Futaleufu (75 km from volcano) was affected by fine grained rhyolitic ashfalls between 20 mm to over 300 mm in some areas. Local linesmen reported that 10-20% of insulators (porcelain) suffered flashovers from fine volcanic ash accumulation following light misty rain between 6-9 May 2008. The ash covered lines and insulators had operated without problem until the light rainfall. Subsequent heavy rain had reportedly washed much of the ash off, but significant volumes of ash remained underneath insulators where flash-over strikes had occurred (Figure A6). Following initial inspections, the lines company decided to totally replace all insulators on the line, as it was too laborious to clean or assess damage to each insulator. Many of the insulators which had suffered flashover were cracked and exhibited burn marks at the base where it screwed onto the supporting metal pin (Figure A6). Only vertical insulators suffered flashover. Horizontal string insulators did not suffer problems. Isolators and transformers on the line were also reported to have suffered flashover damage. It took 20 days to repair the line.

The same stretch of line was affected again following heavy snowfall on 18 May. The snow accumulated with the ash on lines and poles created a significant load causing lines to break and poles to collapse. The 6 mm lines were described as looking like ‘20 mm tubes’ with the ash and snow accumulation. In addition ash and snow laden branches collapsed onto lines resulting in further damage. In total approximately 20 km of line and poles required replacement. Normally only 1 or 2 poles collapse, despite heavy snowfall hazards common in the area. Repairs were stalled by shortages of posts, with the total period of repair taking approximately 6 weeks.

Figure A6: Insulators used on 33 kV line, with ash contamination (left) and flashover damage (right)

At Futaleufu hydroelectric power (HEP) dam, Argentina, (86 km from volcano) a major fault occurred on breaker columns at the powerhouse transmission station and on the 240 kV transmissions lines following light rain (estimated at 2 mm/hour) on 6 May. The insulators exploded and metal pins fused, requiring total replacement. Only flashover affected insulators were replaced. Subsequently insulators were cleaned at the power-house and on the transmission lines every 10 days for several months to mitigate build-up from further ashfalls and wind remobilisation of ash deposits. The ash reportedly did not wash off easily having formed cement like paste following wetting and drying, even when high pressure hoses were used. The HEP dam was unaffected by the ashfall, remaining generating during the ashfalls. However, when the transmission lines were disrupted generation had to cease.

No line insulators suffered flashover damage in Futaleufu, Chile, (75 km from the volcano) despite receiving >200 mm of ashfall. At least 1 transformer failed, reportedly due to flashover occurring on the vertical insulators following ash build up. This was replaced.

Approximately 50 mm of ashfall was received in Esquel, Argentina (110 km from the volcano). The local municipal utility provider reported no damage occurred to the four electricity distribution networks it manages: 33 kV, 13.2 kV, 222 V, and a 3 phase 380 V. Several scheduled cuts to electrical supply were scheduled to allow cleaning of transformers, after it was found ash accumulation was creating the potential for flashovers. There was no problem with either porcelain or polymer insulators, both shedding ash equally well.

In Chaiten town (Chile), electricity networks remained functioning following 20-30 mm of fine rhyolitic ashfall prior to the town being inundated by lahars. The lahars knocked down or eroded the foundations of power-poles causing them to fall over, which pulled over poles down, cutting the supply in some parts of the town. The town was successfully operating an improvised diesel generator network, using undamaged parts of the distribution network in late January and early February 2009.

Communications

There were no reports of transmission disruption anywhere during the eruption crisis. Cellular phones were heavily relied on for emergency communication with no reported transmission problems. There were no reported transmission problems for UHF, VHF, FM, and AM radios and satellite phones. Telemetered data-links suffered no reported problems in Esquel. Satellite television signals were reported resilient in all areas visited. In some cases ash needed to be cleaned out of the dishes to maintain a clear signal.

The telephone network (cellular and landline) was reported to have overloaded during the early phase of eruption crisis in Futaleufu, Chile.

The main problems with communications was where fine ash penetrated electronic equipment, creating problems for cellular phones and other sensitive electronics. In some instances phones could be repaired by cleaning out ash with gentle compressed air and a damp cloth. There were no reports of exchanges or transmitters suffering damage from ash ingestion.

Merapi 2006 (Indonesia)

Merapi volcano, located in central Java, Indonesia, is one of the world's most active volcanoes and has erupted frequently throughout the 20th Century. Over the past decades eruptive activity at the volcano has been characterised predominantly by the repeated expulsion of viscous, highly crystalline lavas to form bulbous lava domes and thick, stubby lava flows. The gravitational instability and collapse of these extrusions tends to generate violent, although modestly-sized, pyroclastic flows commonly defined as 'Merapi-type' (Voight et al. 2000). In 2006 eruptive activity steadily increased and a series of damaging block-and-ash flows impacted rural communities. The flows created an on-going ashfall hazard from May to July with communities several kilometres downwind affected by repeated ashfalls of several ashfalls.

Electrical

The only report of disrupted electricity service during the 2006 eruption came from the village of Kaliadem, where power poles and lines were snapped by the block and ash flows of 14 June. The destroyed buildings suffered permanent electricity loss, but the areas adjacent to the flows, which lost power initially, regained it within several hours (Wilson et al. 2007).

The light, but on-going, ashfall hazard reportedly had no impact on electrically distribution systems (Wilson et al. 2006).

Communications

As with electricity, Kaliadem was the only site of loss of telecommunications Wilson et al. (2006) observed during the 2006 eruption. Immediately following a large damaging block and ash flow on 14 June, cellular telephone service in the village and surrounds suffered a sharp decrease in quality. No loss of service occurred however. Whether this resulted from over-usage, physical destruction of communications infrastructure or the presence of ash in the air obscuring signals was unclear.

Kagoshima (Japan)

Since 1955 Kagoshima city (300,000 residents) in southern Kushu, Japan, has been subjected to ashfall generated by Sakurajima, an active volcano lying ~10km to the east of the city centre. The current eruptive phase at Sakurajima began in 1955 and has been characterised by frequent vulcanian eruptions and passive ash and gas venting throughout this period. This activity peaked in 1985 when ~92 million tons of ash were erupted, but mean ash generation has been 10-30 million tons per year (Durand et al. 2001). Until 1990 ashfalls occurred up to twice per week, although this has since decreased in frequency.

Electrical

Kagoshima is mainly supplied from the Sendai Nuclear Plant 50 km west of the city by 500kV overhead transmission lines on towers in the same manner as much of New Zealand. Within the city power is distributed at 6,600 volts and transformed down to 110 volts for normal household supply. Durand et al. (2001) did not observe underground cabling in the city area, noting many power poles having significant wiring.

Durand et al. (2001) noted there were no reported problems of ash interrupting normal supply during major ashfalls. The lines had some resiliency to ashfall as normal Japanese practise is to insulate overhead cables and fully enclose pole-mounted transformers (Figure A7). Sub-stations are also fully enclosed, which Durand et al. (2001) speculated was possibly to mitigate the effects of ash. Power lines 3 km from the Sakurajima's cone (which were regularly exposed to ashfall) appeared no different from those in the city.

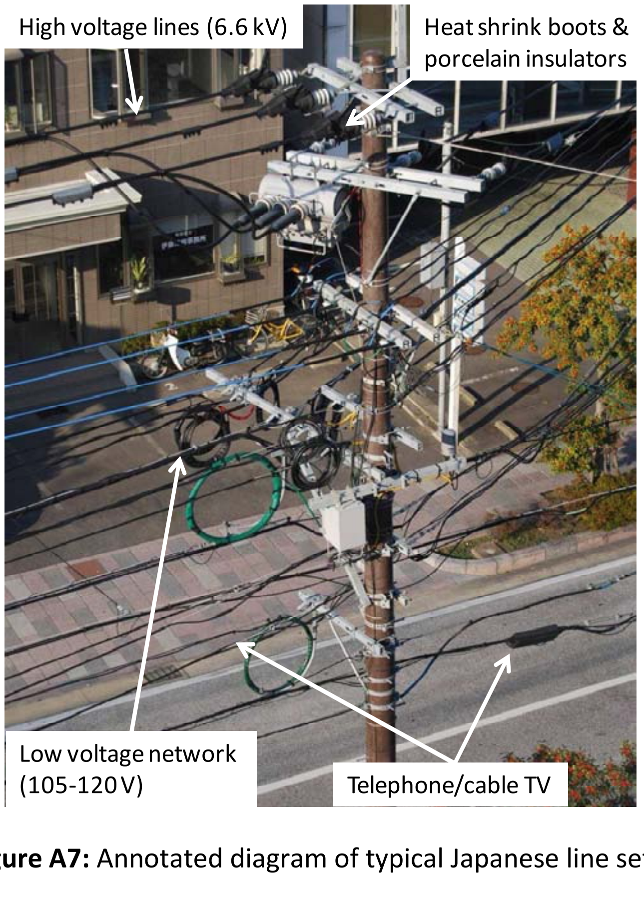


Figure A7: Annotated diagram of typical Japanese line setup

During the peak of volcanic emissions in the mid-1980's the Kyūshū Electric Power Company cleaned its transmission towers following heavy ash fall events. This practise has now ceased in response to the decline in volcanic activity. The tram system was known to fail during heavy ashfall events due to shorting of the overhead wires during the mid 1980's. Visual observations suggest that there are no special measures taken to protect the overhead tramlines from shorting. These cables were, however, the only un-insulated power cables we observed during the visit.

Communications

The volcanic observatories and public organisations utilise modern electronic communication systems extensively on Sakurajima volcano and throughout Kagoshima city. Communication cables are typically insulated and mounted above ground on poles with electric cables. However, Durand et al. (2001) did not find any evidence of the light ashfalls from Sakurajima disrupting microwave, cellphone or telephone cable transmissions. Sakurajima International Volcanic Sabo Centre (2 km from the vent of Sakurajima) was observed to have no special protection for its external communication systems, although some satellite communication dishes were understood to have dome covers to protect against ash.

Electric and Electronic Equipment

Residents and public officials spoken to by Durand et al. (2001) did not recall any instance of volcanic ash or gas affecting computers.

Reventador 1999 & 2002 (Ecuador)

Revenator volcano is a forested stratovolcano located in remote jungles of the western Amazon basin (Siebert and Simkin 2002). It erupted explosively in November of 2002 resulting in ashfall affecting rural areas and Quito, the Ecuadorian capital of 1,900,000 people. Between 2 to 5 mm of ash was deposited on the city, causing significant disruption (Leonard et al. 2005)

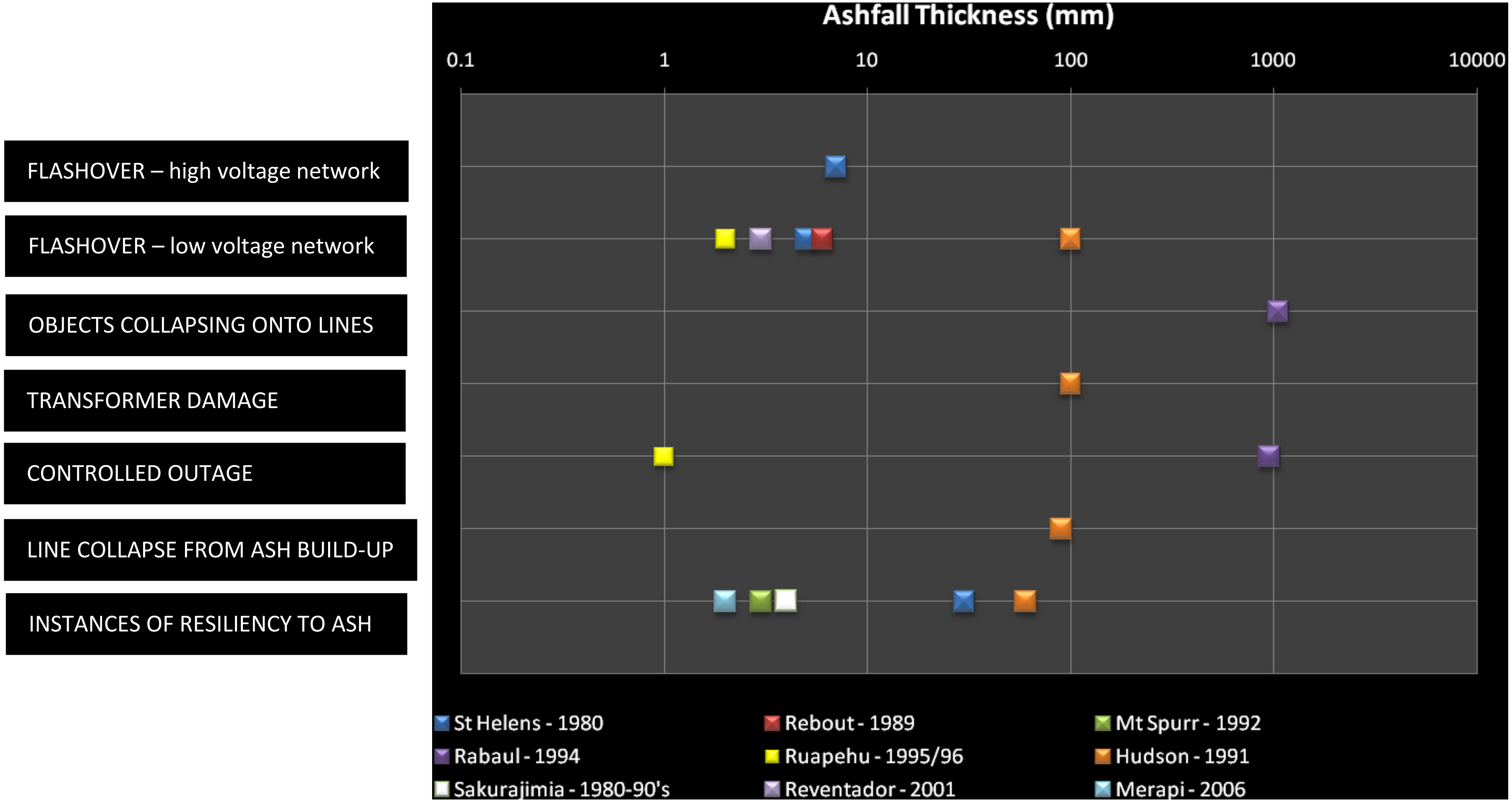
Electrical

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

Communications

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

TABLE A1: Summary of impacts to electrical distribution systems from volcanic ashfall



A4 Literature Review: Other General Quantitative Analysis of Impacts

Electricity

Aside from research undertaken by Nellis & Hendrix (1980) following the 1980 Mt St Helens eruption, there is little other known quantitative analysis of the vulnerability of electrical distribution systems to volcanic ashfall. The work of Nellis & Hendrix (1980) is covered in the above sections, so is not further discussed here.

Bebbington et al. (2008) highlight the little known about potential impacts and make a precautionary estimate (following discussions with electrical engineers at Powerco Ltd.) that 2 mm of dry or 1 mm of wet fine ash would be sufficient for flashovers to start to occur on the 33 kV sub-transmission networks. In the dry ash case, a higher threshold is given as it would depend on the ash being wetted by later fog, dew or rain before significant flashover were to occur. The review here of historical impact data suggests electrical distribution systems have a higher resilience to ashfall than stated by Bebbington et al. (2008). The examples of other countries resilience to ashfall impacts can be due to the earthing systems they are using which makes the system more tolerant to faults, whereas in New Zealand we utilise a different earthing system which is not as tolerant. Given the lack of sufficient quantitative data it is probably correct to take this precautionary approach however.

Research at the University of Canterbury, in collaboration with GNS Science and Massey University, aims to quantitatively test New Zealand electricity distribution systems under laboratory conditions. Variables known to influence flashover potential will be analysed by the testing program. These include:

- Ash grain-size (multiple grain sizes focusing on fine grained ash - i.e. 100 µm;
- Attached soluble aerosols (concentration of acid and ion availability);
- Moisture content;
- Adherence of ash to insulators and lines (different insulator brands and models and line types in New Zealand);
- Thickness/volume of ashfall required to induce insulator flashover.

Each factor will be tested individually to analyse its influence on flashover generation. Results will give a greater understanding of how vulnerable high-voltage electricity distribution systems would be to volcanic ashfall.

Communications

There is no known quantitative analysis of the vulnerability of communications systems to volcanic ashfall. Duststorms can be used as an example for possible communication problems that could affect the electrical lifeline utilities and their microwave SCADA systems. Zain Elabdin et al, 2008 state that in a telecommunications aspect dustorms directly effect the radio propagation especially at high frequencies. Lower frequencies are affected by absorption or scattering from the particles within the sand/Duststorms. If the particulates within the storms rise high enough into the atmosphere there could be a loss of energy within the signal which results in interruption and possible system outages (Zain Elabdin et al, 2008).

Electric and Electronic Equipment

Computers

Gordon et al. (2005) conducted a series of experiments with different types of volcanic ash to experimentally assess their abrasiveness, conductivity and corrosiveness to computer equipment. Ash was poured on to computers and cooling fans in a sealed 0.216 m^3 perspex box, with the effects on both the ash and the equipment monitored. Three different types of ash (1996 Ruapehu andesitic ash, Sakurajima andesitic ash and Kaharoa rhyolitic ash) were used in the experiments.

The bearings within the computer cooling fan continued to work even after 720 h of testing and there was no significant abrasion of the fan-shaft bearing. The ash was however fragmented, suggesting that the brittle ash shattered to fine ‘dust’, which caused significantly less abrasion to the bearings or shaft than expected.

Three computers were tested in the sealed box. Ash was introduced at increasing rates, with computers tested throughout using the BURNIN_ testing programme which placed extreme work requirements on the computer (Gordon et al. 2005). After initial tests failed to produce computer crashes, tests were conducted using volumes of ash well in excess of that would normally be expected to enter facilities, unless there was a complete collapse of roof sections and catastrophic entry of ash. Failure times ranged from 100 to 150 h following multiple runs of the three computers used (Figure A8). Most failures occurred when humidity was increased by spraying water mist into the airflow. Significantly, if dried out the computers continued to operate again if failure was not catastrophic. Card slot edge connectors proved to be one of the weakest links, as a bridge of ash formed across the gap (Figure A9). They were also subject to abrasion with some of the gold plating being removed. This did not however cause operating difficulties.

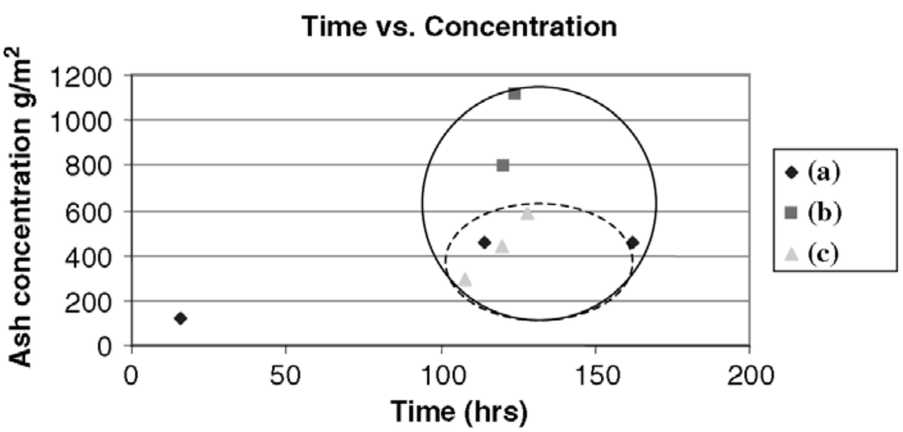


FIGURE A8: Time (hrs) versus concentration of ash (g/m2) for computers crashing (from Gordon et al. 2005).

Labadie (1994) listed hard disk drives as being susceptible to volcanic ash fall during the 1980 Mt. St. Helens eruption. However, Gordon et al. (2005) assessed hard disk drives as being relatively resilient to volcanic ash, due to modern filtering techonology. When the seal on the head disk assembly was removed, it took only 2.34 min before the HDD emitted strange noises and the disk failed, showing a 'command.com' error on the screen. Fine ash particles were found in the HDD and, more importantly, under the read–write head, with small ash grains being located underneath.

Gordon et al. (2005) concluded the computers tested were able to withstand significant amounts of ash without severe problems, which suggests computers are relatively resilient to volcanic ash ingestion unless humidity levels are extreme.

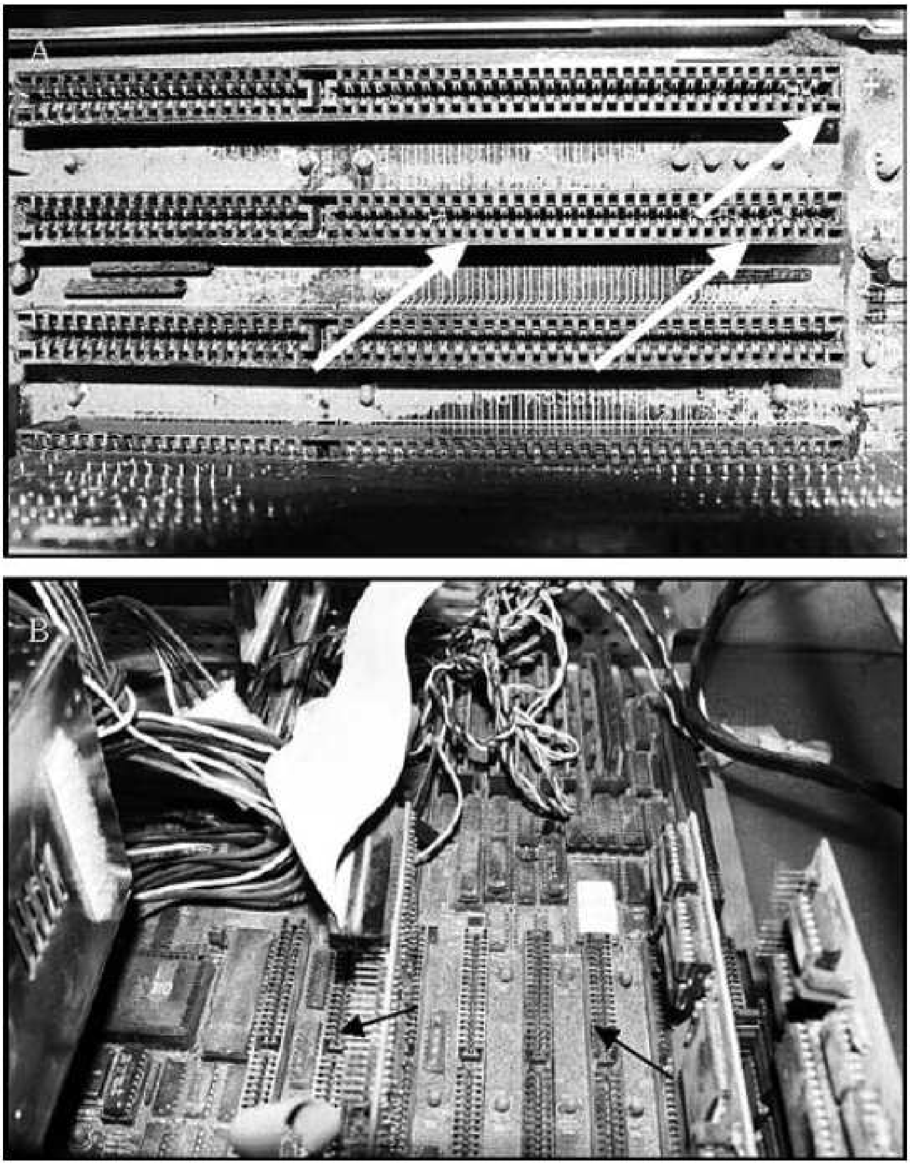


FIGURE A9: (A) Card slots on the motherboard with ash bridges pointed out (above). Note substantial amounts of ash; and (B) Mother board with large quantities of ash scattered over it (from Gordon et al. 2005).

Air conditioning condenser

Wilson and Cole (2007) conducted tests on the condenser of an air conditioning unit (Figure A10). The study focused on this component which is typically outside and thus vulnerable to ashfall. Laboratory testing used both with wet and dry Kaharoa ash (rhyolitic) to determine the condenser's resilience to ash ingestion – note that no soluble salts were still present on the ash however. The condenser was placed inside a 0.96 m^3 perspex box and ash slowly released into the box atmosphere. The condenser was found to perform satisfactorily during dry ash testing, with only 10-15% blocked after seven hours. But when moisture was introduced into the box environment, especially when the surface of the condenser was moistened, significant clogging of the radiator veins occurred. This caused a dramatic reduction in airflow through the condenser by up to 75-80% over four hours (Figure A11; Wilson and Cole 2007). The electronically driven fan however continued to operate successfully through all experiments. Some abrasion occurred to the tips of the plastic fan blades from the ingested ash slightly reducing efficiency, but no other impacts occurred to the condenser (Wilson and Cole 2007).

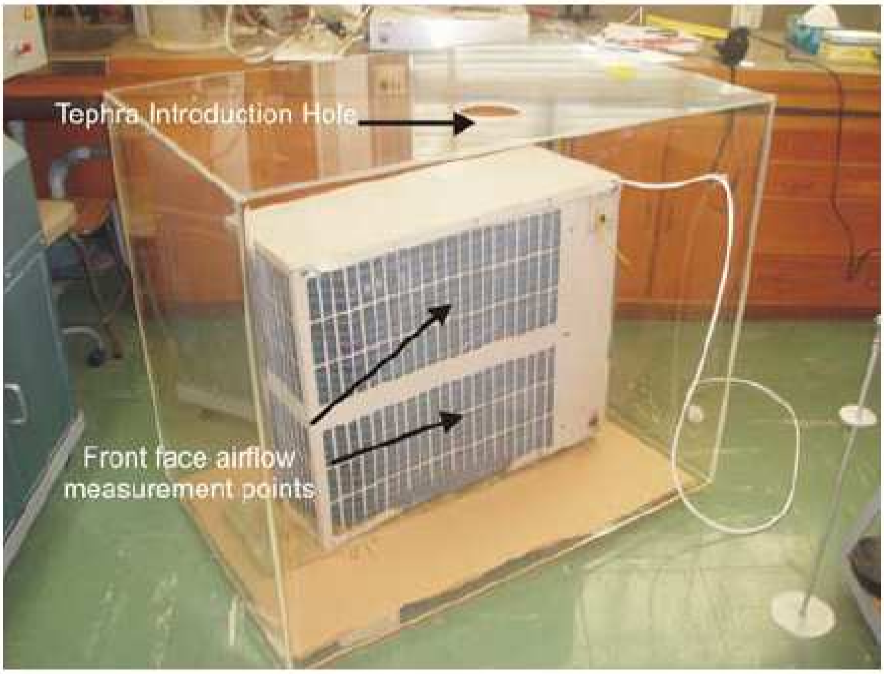


FIGURE A10: Condenser located inside in the test box (from Wilson et al. 2007).

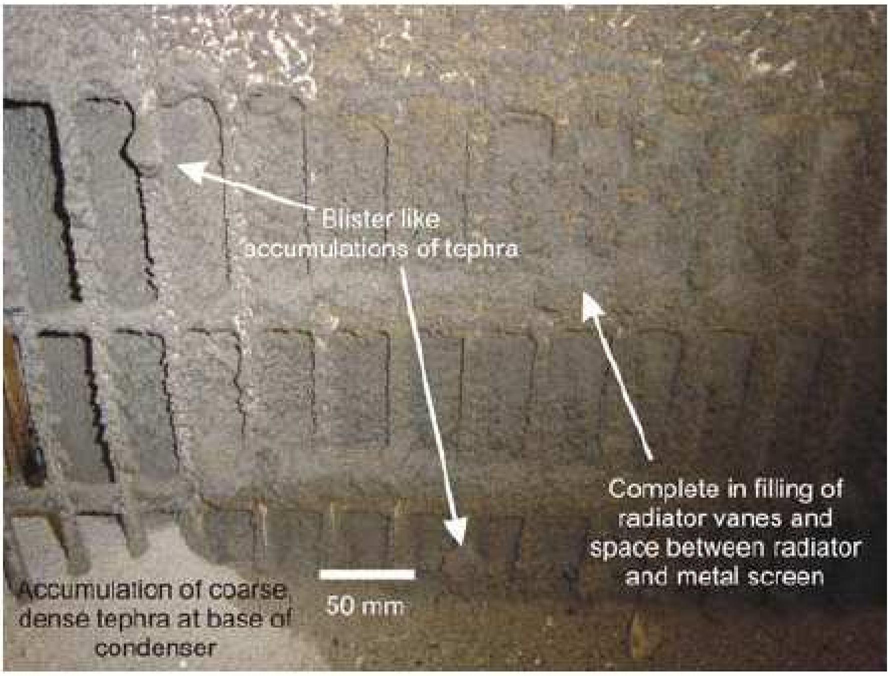


FIGURE A11: Surface of the condenser's intake face following the wet test (from Wilson et al. 2007).

A5 Properties of Ash

(modified from Johnston 1997)

Finer material (ash < 2 mm and lapilli 2-64 mm) is convected upwards in an eruption column (Self & Walker 1994) before settling out downwind to form pyroclastic fall deposits. Pyroclastic fall deposits are composed of various proportions of vitric, crystal or lithic particles (Fisher & Schmincke 1984). Vitric particles are glass shards or pumice derived from magma (Heiken & Wohletz 1985), while crystals are minerals derived from phenocrysts or mircolites developed in the magma. Different minerals reflect the composition of different magmas. The most common minerals are shown in Table A2. Lithic particles can be divided into three types: cognate (derived from non-vesicular juvenile magmatic fragments), accessory (derived from co-magmatic volcanic rocks from previous eruptions) or accidental (derived from basement and therefore of any composition).

TABLE A2: Composition of major phenocryst phases in magma (from Thorpe & Brown 1985)

	Basalt	Basaltic andesite	Andesite	Dacite	Rhyolite
plagioclase	**	***	***	***	**
olivine	**	**	*	-	-
pyroxene	**	**	**	*	-
hornblende	*	*	**	**	*
biotite	-	-	*	**	**
alkali feldspar	-	-	*	**	***
quartz	-	-	-	**	***
Fe-Ti oxide	**	**	*	-	-

*** often present, ** frequently present, * rarely present, - absent or rare

Thickness and Particle Size: It is well known that thickness and median grain-size of ash deposits generally decrease exponentially with distance from a volcano (Walker 1971). The distribution of ash (Fig. A1) will depend on the initial grain-size distribution of the ejecta (reflecting fragmentation during the eruption), dynamics of the eruption column and the column's interaction with wind (Carey & Sparks 1986, Bursik *et al.* 1992, Sparks *et al.* 1992, Koyaguchi 1994). Pyle (1989) and Fierstein & Nathenson (1992) have shown that pyroclastic fall deposits display an exponential decrease in thickness with the square root of the area enclosed within an isopach contour.

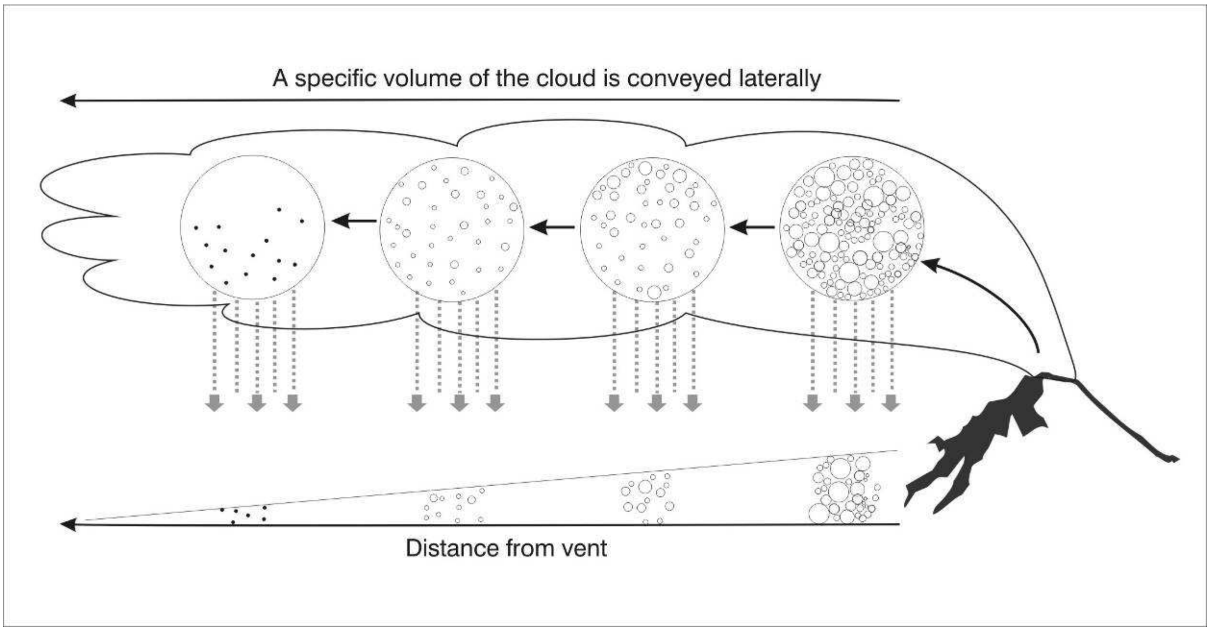


FIGURE A12: Schematic illustration of the fall-out of particles from an umbrella eruption cloud showing decreasing thickness and mean grain-size with distance from source.

Density: The density of individual particles may vary from 700-1200 kg m^{-3} for pumice, 2350-2450 kg m^{-3} for glass shards, 2700-3300 kg m^{-3} for crystals and 2600-3200 kg m^{-3} for lithic particles (Shipley & Sarna-Wojcicki 1982). Pumice fragments may form mats of floating material if deposited on water. Since coarser and more dense particles are deposited close to source, fine glass and pumice shards are relatively enriched at distal locations (Fisher & Schmincke 1984).

The bulk density of any pyroclastic fall deposit can be variable, with reported dry bulk densities of newly fallen and slightly compacted deposits ranging from between 500 and 1500 kg m^{-3} (Kienle 1980; Moen & McLucas 1980; Scott & McGimsey 1994). Both increasing and decreasing bulk densities with distance from source have been reported (Scasso *et al*. 1994), but distal ash falls most commonly show slight increases in bulk density with distance from a volcano. Grain-size, composition (proportions of crystal, lithics, glass shards and pumice fragments) and particle shape appear to be the main features controlling bulk density. Less spherical particles (more irregular) will pack relatively poorly resulting in higher porosity and lower bulk densities. Particle aggregation (Gilbert *et al.* 1991) prior to deposition will result in higher particle packing and therefore higher densities.

Abrasiveness: The abrasiveness of volcanic ash is a function of the hardness of the material forming the particles and their shape. Hardness values (on Moh's scale for hardness) for the most common particles are shown in Table A3. Ash particles commonly have sharp broken edges (Heiken & Wohletz 1985) which makes them a very abrasive material.

TABLE A3: Moh's scale of hardness (mineral hardness from Deer *et al.* 1980).

Scale Number		Mineral	Metal	Minerals in volcanic ash and their hardness (H)
1	----	Talc		
2	----	Gypsum		
			Aluminium	
			Copper	
3	----	Calcite		
			Brass	
4	----	Fluorite		
			Iron	
5	----	Apatite		
			Steel	volcanic glass,
				pyroxene, hornblende (H 5-6)
6	----	Orthoclase (Feldspar)		plagioclase, alkali-feldspar (H 6-6.5)
				olivine (H 6.5-7)
7	----	Quartz		quartz (H 7)
				magnetite (H 7.5-8)
8	----	Topaz		
9	----	Corundum	Chromium	

Soluble components: Freshly fallen ash grains commonly have surface coatings of soluble components (salts) and/or moisture (Rose 1977). It is these components that make ash mildly corrosive and potentially conductive. These soluble coatings are derived from the interactions in an eruption column between ash particles and aerosols which may be composed of sulphuric and hydrochloric acid droplets with absorbed halide salts (Fig. A2). This process is most active close to a volcano (i.e. <50 km), although the amount of available aerosols varies greatly even between eruptions of similar volumes (Bernard & Rose 1990).

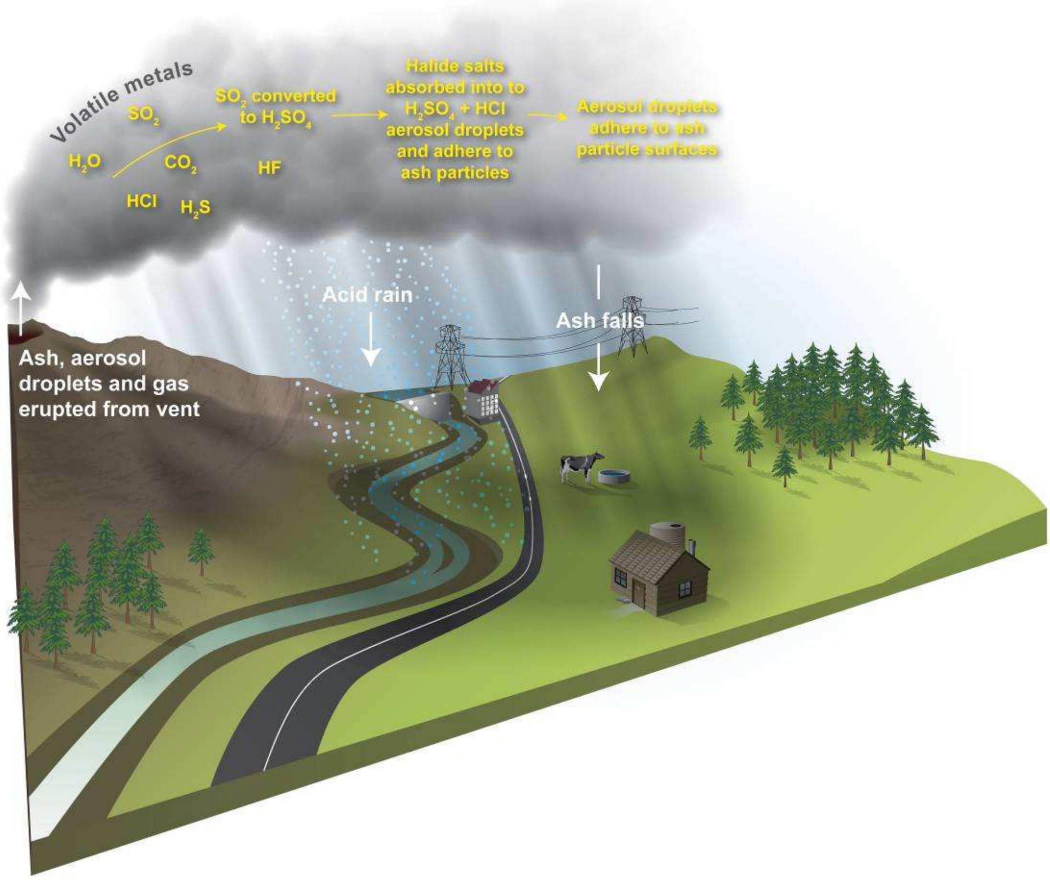


FIGURE A13: Volcanic eruptions inject water vapour (H_2O), carbon dioxide (CO_2), sulphur dioxide (SO_2), hydrochloric acid (HCl), hydrofluoric acid (HF) and ash into the atmosphere. HCl and HF will dissolve in water and fall as acid rain whereas most SO_2 is slowly converted to sulphuric acid (H_2SO_4) aerosols. Ash particles may absorb these aerosol droplets onto their surfaces providing an acid leachate after deposition.

A6 Review of AELG19 Literature Review Search Report - Communications

kordia
people & technology as one

MEMO

TO	Michele Daly	COMPANY	Kestrel
FROM	Adam Tommy	DATE	24 November 2008
CC	David Johnston, GNS		
SUBJECT	Review of AELF19 Literature Search Report - Commnuications		

Summary

The Auckland Engineering Lifelines Group (AELG) contracted Kordia™ to review a literature review of the possible impacts of volcanic ash on broadcasting, radio transmission and communication networks. In summary, the literature review covers most communications systems, but it is acknowledged that much of the information is anecdotal and there is little quantitative analysis available.

In terms of effects on radio signals, lightning-originated interference to low frequency services (e.g. AM radio, but not FM radio) does occur, but it is not certain whether there are any ongoing effects from the ash to radio signals after lightning has stopped.
It is unlikely that airborne ash particles will have any significant attenuating effect on higher frequency services. Most communications services above 10 GHz are terrestrial links operating only tens of metres above the ground, and wouldn't be affected by ash suspended higher in the atmosphere - they also have signal "fade margins" to account for signal losses. Satellite systems may be affected (e.g. SKY TV, Freeview), but we doubt it would be significant enough to have a major effect. Weather RADAR and wind profiler RADAR may also be affected.

With regard to equipment, the main issues appear to be well covered in the case studies - clogged air inlet filters, overheating, weight of ash on buildings, corrosion, phone system overloading etc. However, some FM / TV / HF antennas and AM radio masts have "live" components open to the air, usually involving insulators. The proposed mitigation in the report of replacing insulators with ceramic insulators may not be helpful for FM and TV antennas, where it is not practical to replace Teflon insulators with ceramic or glass insulators. Protection with fibreglass radomes (covers) would be more appropriate in this case.

We do not expect there to be many issues with the landline themselves (apart from related issues such as pole failure, corrosion and overheating of equipment in cabinets).

No obvious differences between New Zealand and overseas communications configurations were identified. However, communications technology has changed since many of the eruptions referenced in the literature review. Communications services are often more distributed around a city now than 13+ years ago, and the technology itself has become more advanced.

Introduction & Scope

The Auckland Engineering Lifelines Group (AELG) is currently assessing the possible impacts of volcanic ash on electricity, broadcasting, radio transmission and communication networks. Kordia™ has been contracted to review the literature review document and to[1] provide comments. Specifically the scope is:

1. Review of literature review, identifying any obvious gaps from a communication/ broadcasting perspective and any other information sources that you know of that we could follow up. Another question as discussed was how similar overseas comms and broadcasting configurations were to NZ, so when comparing ash mitigation measures used overseas (if any) we can usefully apply these in the NZ context.
2. A list of key comms and broadcasting network/ component vulnerabilities. As discussed we are wanting to be able to focus on those parts of the network that might be most vulnerable to ash (dust is a useful comparison).

Kordia has not undertaken specific studies directly related to volcanic ash impacts on telecommunications (and it appears to be an area of limited study), but has instead drawn on Kordia's engineering expertise in telecommunications as a basis for review and comment.

General Comments on Literature Review

In summary, the literature review covers most communications systems, but most information appears to be anecdotal and the report acknowledges that there is no known quantitative analysis of impact to communications systems. Kordia™ is not immediately aware of any new or better information sources.

A variety of issues and mechanisms are discussed in the report, but not all are alike, and it may be helpful to distinguish between problems affecting immediate communication (e.g. interference to emergency services) versus longer term problems that may occur some time after the volcanic activity (e.g. corrosion). Distinguishing between effects on radio signals themselves (e.g. lightning-originated interference) versus effects on equipment (e.g. ash in filters) can also be helpful, since the former may only affect a subset of systems, while impacts to equipment probably apply to all communications systems in some way.

It is suggested that the literature review contains a table or bullet points that summarises the effects and impacts described throughout the document in one place. It may also be helpful to show a chart of radio frequency spectrum with frequencies used by various communications services, and the likely frequency bands affected by various volcanic ash imp[acts.

[1] "AELG/19 Project: Review of Impacts of Volcanic Ash on Electricity Distribution Systems, Broadcasting and Communication Systems. Literature Review - Draft", October 2008, D.M. Johnston, T.M. Wilson, M. Daly, A. Kidd, P. Bodger, I. Chapman, S.J. Cronin

Effects to Radio Signals

In terms of effects on radio signals, the literature review suggests that lightning-originated interference to low frequency services may occur (e.g. AM radio, HF Maritime, HF aeronautical), but perhaps only as long as there is lightning. Some reports refer to charged ash particles in the atmosphere - these would encourage lightning - but it is not certain whether these charged particles still affect radio signals after lightning has stopped.

Lightning causes a brief burst of electrical noise throughout the frequency band and can be heard as a burst of static on AM radio, but it predominates at lower frequencies - this mechanism shouldn't affect higher frequency services (e.g. 100+ MHz - FM radio, cellular, microwave linking, satellite).

The 1912 Katmai case referred to in the literature review appears unusual since radio communications were reported as inoperative for days afterwards at 160 km from the vent, but communications would have presumably been on very low frequencies with primitive receivers using simple AM modulation systems that are sensitive to impulse interference.

Airborne ash particles are another effect on radio signals that may attenuate higher frequency services (10+ GHz). This is similar to that described in the Sudan dust-storm paper by the [2] literature review. However, we believe that the density is probably thicker than volcanic ash deposits and may not be directly relevant (while it is acknowledged that volcanic ash deposits could easily be as thick as a dust-storm, there would probably more significant problems than just communications failure). Most communications services above 10 GHz are terrestrial links operating only tens of metres above the ground, and wouldn't be affected by ash suspended higher in the atmosphere. Additionally, such services usually have large signal "fade margins" to account for signal losses due to rain - these margins should be sufficient for any losses caused by modest amounts of volcanic ash in the atmosphere (severe dust-storm attenuation is typically 0.5 dB/km c.f. 30+ dB fade margin).

The only system we believe that may be affected are satellite systems (e.g. SKY TV, Freeview) whose radio path goes up through the atmosphere and potentially through greater volumes of ash, but we doubt it would be significant enough to have a major effect (satellite systems also have fade margins, albeit smaller).

Weather RADAR and wind profiler RADAR may be affected by volcanic ash activity.

It would seem that effects to radio signals themselves may be fairly small. There is limited information available, and while we may have made some progress as to the exact mechanisms and their impact on different radio frequency bands, further research is required.

[2] "Duststorm measurements of attenuation on microwave signals in Sudan", Zain Elabdin, Md., et al, 2008 Proceedings of the International Conference on Computers and Communications Engineering, May 13-15. 1181-1185

Effects to Equipment

With regard to equipment, the main issues appear to be well covered in the case studies - clogged air inlet filters, overheating, weight of ash on buildings, corrosion, phone system overloading etc (the latter is more an effect to the system rather than equipment itself).

We do not think weight of ash on towers/structures is a problem, but more consideration is required (it may be an issue with overhead wires). Ash adhering to structures, increasing the risk of collapse due to windload issues, may be a more significant problem (similar to the issues with ice forming on structures).

One area which should be covered in more detail are antennas and cables that are open to the air. The "live" parts of most antennas are usually covered/protected by a fibreglass or plastic radome (e.g. most microwave dishes, cellular antennas). However, some FM radio antennas, lower frequency television antennas, HF antennas and AM radio masts have "live" components open to the air, usually involving insulators. Ash build-up on these insulators can cause arcing / shorting etc. The proposed mitigation in the report of replacing insulators with ceramic insulators may not be helpful - most, if not all, AM and HF antennas and systems already use ceramic or glass insulators. However, for FM and TV antennas, where Teflon insulators are common, the use of ceramic or glass insulators is not practical and protection with fibreglass radomes (covers) would be a more appropriate solution in this case.

Some major communications sites (e.g. some Kordia sites, Telecom exchanges, Maritime HF site and others) have diesel generators to supply backup power (as well as DC batteries). Obviously, these generators use large amounts of air and could be vulnerable to overheating / damage from ash. However, it is more likely that air conditioning / air handling systems would have failed before a backup diesel generator failed (or was even started).

While our main experience is in radio systems, we do not expect there to be many issues with the landline themselves (apart from related issues such as pole failure, corrosion and overheating of equipment in cabinets). The majority of communications landlines (e.g. copper phone lines, cable TV) should be insulated. Cables below ground shouldn't be affected. Corrosion to ID connectors in cabinets may become an issue, especially with landline cabinets becoming more prolific (e.g. IDC Krone-type connectors, especially disconnect types).

Differences Between New Zealand and Overseas Communications Configurations

Regarding differences between New Zealand and overseas communications configurations, no obvious, constant differences were identified. There were a variety of different overseas locations involved (U.S.A, Japan, P.N.G, Chile etc).

One comment we do have is that the time difference from the eruptions referenced in the literature review to present day means that newer and more modern communications systems are now being used. Particularly, communications services are often more distributed around a city now than 13+ years ago - for example, large numbers of cellsites cover Auckland and can have significant area overlap (redundancy) with other cellsites. Recent moves to improve broadband speeds by installing ADSL cabinets throughout suburbs instead of their current location at suburban exchanges will distribute this equipment more widely throughout the area.

Additionally, communication technology has become more advanced - lower efficiency analogue systems are being replaced by higher efficiency digital systems and techniques - this can make systems both more rugged and more fragile than earlier systems.

Communications Network Vulnerabilities

With regard to a list of key communications network/components that may be most vulnerable to ash (dust is a useful comparison), the items discussed above would be most likely:

- air conditioning issues
- corrosion
- damage to buildings
- phone system overloading
- disruption to AM, HF services
- possible disruption to satellite services
- antennas with active components open to the air

Adam Tommy

Engineering Consultant, Kordia™

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A7 Project Worksop Notes – 7 November 2008

AELG19 – Project Meeting

7 November 2008

11:00-12:30, Old Government House, University of Auckland

Workshop Notes

Meeting Purpose:

1. To update AELG members from the communications and power sectors on project progress and findings from the literature review.
2. To discuss feedback on gaps and remaining issues.
3. To develop a list of vulnerable components.

Attendees:

Robert Burley (Vector), Brigitte Theuma (Telecom), C K Phang (Counties Power), Murray Dixon (Vodafone), Stuart Graham (TVNZ), Lisa Roberts (AELG Project Manager), David Brunsdon (Natl Engineering Lifelines Committee), Jeremy Gibbons (NZ Fire Service), Bruce Parkes (BP Consulting), Elva Leaming (University of Auckland), Alex Steele (IESE)), Elaine Smid (IESE), Kate Kennedy (IESE), David Johnston (GNS), Tom Wilson (Canterbury Uni), Alisha Kidd (Kestrel), Michele Daly (Kestrel) (17 total participants)

Workshop Format:

1. Presentation on Project (overview and update) and Literature Review findings (Michele Daly and David Johnston) ***(presentation attached)***
2. General discussion/feedback on Literature Review (pre-circulated) and general gaps in information (preliminary feedback and comments also noted from Kordia)
3. Discussion on vulnerable components
4. Discussion on next steps

Summary of Discussion:

1. Gaps/ Issues/ General Comments

- Would be good to be able to differentiate between immediate versus longer term effects and between impacts on signal (transmission) versus equipment
- Often historical accounts don't go into enough detail about actual damage (e.g. lightening strikes disrupt comms during the period the ash cloud passes but not a lot of info on operability of equipment afterwards)
- Also difficult to get information on any design changes made as the result of experiencing an event (though this information would be invaluable)
- Some comparison/contrasts can be drawn between ash/ dust/ snow, though it was noted that from a density perspective 1cm of wet ash equivalent to about 10cm snow and chemical properties of all three very different
- Not much information on signal attenuation – generally thought not to be a problem except with satellite (Sky or Freeview).

- Comms and power antennae with open (live) components more at risk e.g. AM radio antennae – what % of respective networks in areas at risk from volcanic ash have live components?
- Terminology – final report will need a glossary and also a comms frequency / bandwidth diagram (VHF vs UHF vs HF etc). Definition of LV and HV from Electricity Act.
- Ash distribution for Akl: two types – fine ash, thin coating (distal) versus coarse and thick (local). Also compositional differences. Both types present different challenges – consider how to bring these out more.

2. <u>Relevancy of comparisons with overseas networks and historic accounts</u>

Communications:

- General thinking was that comparisons with overseas networks were relevant (global technology).
- Comms technology has become more advanced (analogue to digital) making systems both more rugged and more fragile than before.
- There is rapid growth in communications sector technology and equipment, though it was noted that Telecom for example still was using gear that was over 70 years old in places. Asset upgrading is a gradual process. (Difference in landline vs radio)
- As well as access to spare equipment parts, stocks of equipment such as air filters for vehicles a problem. Unlikely telcos would hold stocks of these.
- Communication services now more distributed around a city than 13+ years ago (e.g. cellsites; ADSL cabinets)

Power:

- Also some older infrastructure in place and also a wide variety of components used (e.g. Counties Power used a wide variety of types of insulators).
- Comparisons with overseas networks also considered relevant – not a lot of difference. Noted that U.S. uses a larger number of transformers for a given population size than NZ.

3. <u>Urban versus Rural networks</u>

- Of greater significance is probably the urban/ rural difference in configuration and age of networks. Auckland would have more underground power networks than rural – also greater number of ceramic insulators (cf. epoxy)
- Telecommunications generally use fan cooling in rural areas – different forms of cooling (water; fan; air conditioning; interior; exterior) are used in different locations depending on a range of factors (age; building type; size etc). This might be a more useful split in the report than differentiating between urban and rural networks.

4. <u>Adding Value for Lifelines</u>

- More research is needed in many areas – highlight where these areas are (specifics). *Comment that current research underway (Canterbury Uni) involves testing the vulnerability of actual components to ash. Lab testing on telecommunications aircon equipment has been recently carried out and is being written up. Request for any spare equipment was made so that other tests can be carried out - contact Tom Wilson (thomas.wilson@pg.canterbury.ac.nz).*
- Can more information be acquired on actual causes of damage (many accounts are anecdotal and assumptions about actual damage and duration have to be made – e.g. what caused non-operability versus a requirement for accelerated access to spare

parts)? *Comment here that reconnaissance visits would greatly benefit from more people with specific industry knowledge and background*.

- More information would be good (though difficult to obtain) on design changes after an event (some info here from Japan).
- Better decision support tools for lifelines are needed to assist in their risk management (e.g. event tree analysis – flow diagrams – damage/fragility functions). What are the triggers for lifelines in terms of info/ damage/ probabilities that will influence them to make a change to the way their networks or response processes are managed?
- How could lifelines use the information to build a case for CAPEX versus improving response processes? Need to consider also when the community versus revenue is at risk.
- Consider looking at the current vulnerability of networks in Auckland as part of the project – a questionnaire or similar based around what % of vulnerable components comprise each network. Should be relatively easy to obtain from asset registers.
- Consider identifying risk factors L/M/H (highlight H in table).
- Damage does not always equal service disruption (consider highlighting this in a separate column)

5. Vulnerable Components

A draft list was developed as follows (in addition to components listed in tables in presentation):

- Portable vs fixed generators
- Air conditioning – list types separately (water; fan; air; internal; external)
  Comment here that aircon manufacturers have been approached for comment on ash vulnerability as part of other studies, however there was no information and a low level of interest shown.
- Sealed vs not sealed buildings
- Manned vs not manned
- Insulators – list types (ceramic; epoxy)

Communications network vulnerabilities:

- air conditioning issues
- corrosion
- damage to buildings
- phone system overloading
- disruption to AM, HF services
- possible disruption to satellite services
- antennas with active components open to the air

6. Actions

Lifeline agencies to approach relevant (in active volcanic areas) overseas contacts for any anecdotal, experience or published information they may have access to.

- Focus on cause of damage; service outages; changes to network as a result
- Forward any information/ contacts for follow-up to Michele at md@kestrel.co.nz

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