VOLCANIC ASH HAZARDS POSED TO COMMUNITIES, COMMERCE AND DISASTER RECOVERY

A Masters Thesis

Submitted to the Faculty

of

American Military University

by

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In Partial Fulfillment of the

Requirements for the Degree

of

Master of Arts

February 2018

American Public University

Charles Town, WV

DEDICATION

I dedicate my thesis to my wife Karen. Attaining my educational goals would not be possible without her love, support and patience after all these years of school. I wish to thank my parents for the loving examples they set for my family growing up. Thanks Mom and Dad! I miss you every day Dad, but I know you are with us.

ACKNOWLEDGEMENTS

I wish to thank all of my co-workers throughout my Emergency Management career, both military and civilian, who taught me every day by example how an Emergency Management program should operate. Having spent thirteen years as a heavy equipment operator in the military, prior to my emergency management retraining, I made every effort to include the importance of public works clean-up operations. This work is a culmination of both my career paths. I also wish to thank the members of my committee for their support, patience, and good humor. Their gentle but firm direction has been most appreciated. Finally, I would like to thank my major professor, Dr. Robert Dawkins. From the beginning, he had confidence in my abilities to not only complete a degree, but to complete it with excellence.

I have found my course work throughout the Emergency and Disaster Management Master's program to be stimulating and thoughtful, providing me with the tools with which to explore both past and present ideas and issues.

ABSTRACT OF THE THESIS

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American Public University System, February 24, 2018

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The purpose of this research is to ascertain the awareness of the Emergency Services and Emergency Management fields to the unique hazards posed by volcanic ash fall. The concern is the limiting factor volcanic ash places on First Responder assets. Resources such as vehicles, aircraft, back-up generators, electrical utility power grid, computer systems, roads, railroads, and airports are severely impacted in ash contaminated environments. The research objectives are twofold. First, to bring an awareness to the Emergency Services community on the restrictions ash imposes on response to 911 dispatch calls in a post-eruptive environment. Second, to research ash clean-up techniques used during Mount Saint Helens eruption and present them to Emergency Management and Public Works personnel. The method was to conduct research and discover lessons learned by examining technical manuals, first hand accounts and web-based resources to determine which clean-up method techniques worked and why they worked. The conclusion of the research is that techniques learned and proved during the Mount Saint Helens ash clean-up must be brought to the attention to the Emergency Services professionals of today. The community's ability to clean-up ash will speed the reception of needed life saving FEMA commodities for the affected residents.

TABLE OF CONTENTS

INTRODUCTION

Problem Statement

Natural disasters continue to challenge community resilience. Hazards are identified, and local emergency managers submit a mitigation grant proposal to obtain project funding, which reduces the community's vulnerability. Community preparedness efforts are improved upon as Emergency Managers' cross talk and share lessons learned from other communities experiencing the same disasters. The sheer number of these events provide opportunities for emergency managers to revise and improve their respective Emergency Operations Plan.

Communities facing volcanic ash fall hazards are not afforded this frequency of opportunity to improve plan objectives through practical application. Emergency Managers, Public Works officials and Airport Managers may not have experienced an ash fall event during their position-tenure. Prior to 1980, Mount Saint Helens had erupted one hundred and twenty three years ago (USGS, 2015d). Should an eruption occur there again, there would not be a corporate knowledge trust of officials who orchestrated the rescue, response and recovery of surrounding communities during the 1980 eruption and subsequent ash event. Officials at the time were faced with removal of 900,000 tons of ash from highways and airports just in Washington State alone. The cost of removal of ash was $2.2 million dollars over a period of 10 weeks in Yakima, Washington (USGS, 2015a). Flying in the eastern part of Washington after Mount Saint Helens erupted was suspended for two weeks due to airborne ash and ash contamination of airfields in the affected area (USGS, 2015f). Ashfall in Montana landed on railroad tracks and halted 10 freight trains for three days as the ash slickened the track rails (USGS, 2015j).

Volcanic Ash Hazards and Disaster Recovery

A study of past volcanic eruptions and ash fall events, combined with research of current literature will result in a culmination of other communities' successful ash clean-up procedures. Airports pose an exceptional challenge, as ash is very abrasive and can readily damage jet engines. Runways, taxiways and parking aprons accumulate significant amounts of ash due to the large pavement surface areas. One such instance of ash clean-up found an airport choosing to wash down the ash from the airfield. The result was ash clogging the airfield's drainage system. The entire drainage system had to be cleaned, causing further delays to open the airport. If Emergency Managers, Public Works and airport personnel had this prior knowledge, the airfield could have opened earlier and the funds to repair the drainage system not wasted.

Generally, Emergency Managers work to build resilient communities for more traditional disasters and focus on preparedness. The National Response Framework plans for residents to have enough food, water, and supplies to last for three days (FEMA, 2016). Ash accumulation will stop communities and their commerce, as do other disasters, though ash requires some unusual supplies. A respiratory mask for each family member, a second engine air filter for each car illustrate just some of the unique problems ash presents. Keeping ash out of the home, removing it and collecting it off of the roof, and preparing it for disposal by the city are tasks each resident must know. Unique to volcanic hazards is the need to clean, remove and dump collected ash from nearly every surface in the community. Ash is abrasive as well as corrosive and has the consistency of talcum powder. When in dry form, any motion through it such as sweeping or driving re-suspends the ash and it further spreads it with prevailing winds. Take caution not to use water to rinse ash off of roofs as one square foot of ash, one-inch deep weighs ten pounds (Klickitat County, 2012). Wetting ash with water or from rain can nearly double its weight (Mayer, 1984). The accumulated ash must be removed from the community and collection area sited. Large amounts should be placed in areas coordinated with the state Environmental Protection Agency to ensure compatibility with the environment.

Background Data

Planning for ashfall clean-up, even during the two months of seismic activity prior to the eruption of Mount Saint Helens in 1980 did not result in an ashfall recovery plan by local communities (USGS, 2015c).

> The May 18, 1980 eruption of Mount St. Helens marked the first natural disaster of its kind in the western United States in recorded history. Precisely because it was unprecedented, there were few, if any, local plans for handling the resulting ashfall damage to public facilities. Given the potential for future volcanic eruptions in the Cascade Chain and elsewhere, it is imperative that as much benefit as possible is derived from our recent experience, especially as it relates to the clearing of volcanic ash and repair of ash damage to public facilities. By examining the ashfall problems experienced by local governments and the methods used to deal with those problems, we can avoid many of the hardships they encountered should future eruptions occur (Mayer, 1984).

Mount Saint Helens deposited approximately 200, 000, 000 cubic yards of ash over 26,000 square miles of Washington and 13,000 square miles of Idaho (Mayer, 1984). To help quantify the extent of the ash coverage, 49 percent of the state of Washington received ashfall (Mayer, 1984). Interstate 90, which runs east to west across Washington state, was closed due to ash contamination for five days after the initial eruption of Mount Saint Helens (Mayer, 1984). The closure of Interstate 90 left 5,000 people stranded in their cars (Mayer, 1984). Officials managed to move them to shelters in nearby towns (Mayer, 1984). Washington state's Yakima

Airport reported 16,000 tons of ash removed from runways, taxiways, parking ramps, and facility roofs (Mayer, 1984). Should a volcanic eruption occur in the future, the clearing, cleaning and quick recovery of local airports are critical to the delivery of lifesaving FEMA commodities for affected communities.

Ash fall from erupting volcanoes can endanger passenger liner jet aircraft and further cause economic problems to air commerce while hundreds of miles away. Today's air corridors track over a long series of volcanoes (Wilkinson, Dunn & Ma, 2010). Many countries share a global economy and could suffer as a result. Illustrating this point is the volcanic eruption of Eyjafjallajokull, Iceland, in April of 2010. Ash escaping from this volcano cost the aviation industry alone, $250 million dollars a day (Gudmundsson et al. 2010). Figures in the range of $1.7 billion United States dollars were lost by all air carriers operating from airports directly affected and those air carriers who utilized the affected air corridors from 15 to 21 April of 2010 (Wilkinson, Dunn & Ma, 2010). While nothing can be done to stop the eruptions and subsequent ash cloud, better orchestrated planning to more quickly recover airports and their communities can help mitigate finical loss and speed life saving commodities into the disaster area.

The difficulty this situation presents is a volcanic eruption hazard that occurs with low frequency, but when it does happen, the response and clean-up must be well executed to open airports and highways to receive FEMA commodities to help the community to recover. Emergency Managers and Public Works officials charged with preparing for this hazard may serve their entire career without experiencing first-hand the challenges presented when cleaning up volcanic ash. Breathing these particles can send people to seek medical attention and further complicate those with pre-existing respiratory diseases (Wagner, 1980).

Ash is composed of small fine particles that are ejected thousands of feet in the air during a volcanic eruption. Winds aloft can carry the ash cloud hundreds of miles away. During the 1989 to 1990 eruption of Mount Redoubt in Alaska, five jet passenger carrying aircraft were damaged by unknowingly flying through the resulting ash cloud causing $80 million dollars in damage to a new Boeing 747-400 airliner in one instance (Casadevall, 1994).

Airfields covered in ash are not able to support FEMA Incident Support Base operations, thereby slowing the logistical flow of resources needed to recover the community. Emergency Managers and Public Works officials must be aware of the complexity of First Responders to 911 rescue calls, instructing community protective actions and to quickly start the clean-up of airports and roadways to facilitate recovery efforts.

A variety of techniques have been employed by communities who have experienced ashfall with today's modern equipment and computer technology. Presenting a comprehensive research of the unique hazards posed by ashfall, Emergency Managers and Public Works officials would have the advantage of seeing the lessons learned from their counterparts as they performed the same mission. The pros and cons of various clean-up techniques would be clearly illustrated. Ash particles carry a static charge that can damage computer systems. Ash is abrasive and can cause heavy equipment involved in clean-up, mechanical failure due to ash overwhelming engine air filters and entering the engine cylinders. Mitigating the multiple hazards ash possesses are relatively straight forward. Protocols must be developed to address the prevention of ash from entering facilities, minimizing the amount of ash tracked into facilities and the clean-up of exterior surfaces of ash accumulation (Casadevall, 1994). Officials may have no experience of the nuances, difficulties and hazards ash presents in day to day operations. Key operations such as First Responders conducting emergency response, and the cleaning of ash from airports and roads will happen concurrently. Operating in an ash contaminated environment is a logistically intensive undertaking, both in equipment and personnel. An ash contaminated environment is especially problematic in that vehicle movement and winds can resuspend the ash into the air all over again. When ash accumulates on electrical utilities exposed to rain or high levels of humidity, arcing of the lines can occur, resulting in electrical outages (Casadevall, 1994). The Bonneville Power Administration in Washington State experienced "25 momentary and 25 sustained outages in the initial 10 days following the eruption" of Mount Saint Helens (USGS, 2015e, p. 1). Vehicles operating in past ash events show a propensity for damage to "…bearings, brakes and transmissions to wear out very quickly" (Casadevall, 1994, p. 125). Ash also is very difficult to operate vehicles, aircraft and locomotives, as it is slippery and results in poor traction which explicitly means slower speeds for First Responders (Casadevall, 1994). Vehicular upkeep, operator's inspection, maintenance and observance for degraded equipment performance in ash will have to be increased in frequency (Casadevall, 1994). Regarding techniques to minimize ash intrusion into facilities, workspaces and homes, "No single technique will be absolutely effective; a combination of techniques has been found to provide the best results for managing volcanic ash" which drives the need for a repository of this type of mitigation (Casadevall, 1994, p. 126). Should all participating agencies not have Emergency Operation Plans addressing these issues, this would compound the complexity of preparing for reception of lifesaving supplies from FEMA.

Expected Research Value

The expected research value is to identify ash related planning shortfalls during an ash clean-up event. "Mount Rainer poses the highest risk of any volcano in the continental United States…Such an eruption would be classified as explosive and involve roughly one million cubic meters of ash" (National Research Council, 2000, pg. 94). Ash presents unique challenges to First Responder personnel and operation of fire trucks, police cars, ambulances, performing response and rescue operations in an ash contaminated environment. Identify community Emergency Operations Plans lacking a coordinated and approved ash clean-up annex. Recognize the need for increased maintence to public works and airport heavy equipment while working to remove and transport ash. Bring awareness to the vulnerability of aviation commerce air traffic corridors by airborne volcanic ash clouds. Exhibit the criticality in opening community businesses, roads, railways and airports as quickly as possible to begin resumption of commerce in order to return essential services and employment. Point out commonalities in communities who lack ash preparedness protective action measures and those lacking in educational products posted to community websites. Identify a lack of ash required Disaster Supply kit contents. Specifically, dust masks and extra automobile engine air filters for those communities subject to an ash fall hazard.

Research Questions

RQ1: Do current community Emergency Operations Plan have provisions for the coordinated removal and disposal of ash from airports, roadways, railways and area communities to facilitate reception of life saving FEMA commodities?

RQ2: Do health providers and hospital facilities have contingency plans to treat the "worried well" who have been exposed to ash without the wearing of a protective mask and does the Public Health office have educational materials on the health hazards of inhalation of ash?

RQ3: Are officials aware of the difficulties operating in an ash contaminated environment to first responders, public works, utilities infrastructure, airport and hospital employees and the difficulties to operating each agency's vehicles and back-up generators, are there any mention of this in contingency emergency operations plans?

RQ4: Are aviation officials aware that ash clouds can cause passenger and cargo airline flights to crash, or be re-routed and respective airports closed until the ash stops or wind direction changes?

RQ5: Do Cascade Mountain Range emergency managers address ash fall in their community preparedness education program, such as the inclusion of dust mask respirators for each family member in their disaster supply kit?

LITERATURE REVIEW

There are a variety of written materials on the hazards involved with volcanic ash and its effect on communities, their supporting utilities, transportation infrastructure and health and well-being of the residents. One of the problems the research hopes to identify is that many Emergency Managers, Public Works officials and Airport Managers are unaware of this compiled knowledge of the effects of volcanic ash hazards on their communities. Another problem is that these written research materials must be actively searched for. Many of the subjects are of a specific technical nature, not easily found in a web search. The research will show that the solution will be to locate these materials at a single portal or web page.

Emergency Operations Plans in Ash Contaminated Environments

The National Response Framework is the corner stone for Emergency Managers throughout the country. It directs the way communities will plan for and respond to hazards identified for their respective geographic region. Regarding catastrophic natural disasters, the document focuses on, protection of lives, property and preventing damage to the environment as basic tenants of emergency management (DHS, 2016). Key to any natural disaster response is addressing scene stabilization, resumption of basic utilities service, begin operations to recover the community and facilitate reopening of area commerce (DHS, 2016). Each of these efforts form a network which facilitates agencies operating in a logistically favorable environment. This allows federal agencies to deliver urgently needed lifesaving rescue teams and sustaining logistical materials to support local officials in recovery activities. Based upon these tenants, local Emergency Managers must be aware of the severe restrictions volcanic ash hazards place on use of airports, highway road networks, railways and waterways. While the National Response Framework mentions various types of natural disasters, volcanic eruption is not mentioned nor is ash (NFR, 2016). This is important because it speaks to the hazards of volcanic eruption as a hazard unique to a geographical area. This suggests a planning gap to see that ash fallout could affect other portions of the country.

The United States Geological Survey uses the Smithsonian's Global Volcanism Program to define geologically active volcanoes, listing 169 such sites (Ewert, Guffanti, & Murray, 2005). Of these, 18 are listed as having a very high threat in the United States (Ewert, Guffanti, & Murray, 2005). Ten of the very high threat list volcanoes are in the Cascade Range in Washington, Oregon, and California, which are: Baker, Crater Lake, Glacier Peak, Hood, Lassen, Newberry, Rainier, Shasta, South Sister, and Mount Saint Helens (Ewert, Guffanti, & Murray, 2005). The Cascade Range volcanoes are described by the United States Geological Survey as, "…whose explosive behavior and lahar potential can impact both large populations and extensive development on the ground as well as heavily traveled air-traffic corridors" (Ewert, Guffanti, & Murray, 2005, pg. 18). Many of the Cascade Range volcanoes are snowcapped which poses a significant challenge to scientist who are only able to access these peaks during summer months (Ewert, Guffanti, & Murray, 2005).

Creation of the Cascades Volcano Observatory

After Mount Saint Helens erupted in 1980, the United States Geological Survey created the Cascades Volcano Observatory, in Vancouver, Washington, in 1982 (Ewert, Guffanti, & Murray, 2005). The University of Washington Geophysics program and the United States Geological Survey's Northern California Seismic Network partnered to watch Cascade Range volcanoes (Ewert, Guffanti, & Murray, 2005). During 1980, the Long Valley caldera, in California, increased in seismic activity so much so that the Long Valley Observatory was also created in 1999 (Ewert, Guffanti, & Murray, 2005). An observatory was also opened in

Yellowstone National Park in 2001, referred to as the Yellowstone Volcano Observatory which works in cooperation with the University of Utah (Ewert, Guffanti, & Murray, 2005).

The Cascades Volcano Observatory is charged with watching volcanoes from British Columbia to California (National Research Council, 2000). The primary concern is the proximity of heavily populated communities to volcanoes in the Cascades Range. Observatory staff monitor these volcanoes and work with community officials to teach citizens about the hazards of these seemingly dormant mountains (National Research Council, 2000). Communities of the Cascade Range drew attention in volcanic hazards after the eruption of Mount Saint Helens in 1980 (National Research Council, 2000). Since then, almost four decades later, after Mount Saint Helens erupted, public concern has declined. "Seven eruptions of Cascades Range volcanoes have taken place in the past 200 years…there is an approximately a 30 percent chance of an eruption in the region every 10 years and an 18 percent chance of an eruption whose influence extends beyond the base of the volcano" (National Research Council, 2000, pg. 43). The Cascades Volcano Observatory monitors many volcanoes, however attention is given to Mount Saint Helens, Mount Lessen, as well as Mount Baker and Mount Hood (National Research Council, 2000).

Creation of the National Volcano Watch Office

To monitor all the 169 volcanoes in the United States, the United States Geological Survey proposed the creation of a National Volcano Watch Office (Ewert, Guffanti, & Murray, 2005). On November 28, 2017, House Resolution 4475 of the 115th Congress, 2017 to 2018, was presented by Representative Don Young, (R-AK-At Large) the National Volcano Early Warning and Monitoring System Act (National Volcano Early Warning and Monitoring Systems Act, H.R. 4475, 115th Cong., 2017). The purpose of this act is to incorporate the Alaska

Volcano Observatory, California Volcano Observatory, Cascades Volcano Observatory, Hawaii Volcano Observatory and Yellowstone Volcano Observatory into "a national volcano watch office that is operational 24 hours a day and 7 days a week" (National Volcano Early Warning and Monitoring Systems Act, H.R. 4475, 115th Cong., 2017, pg. 1). The Consortium of United States Volcano Observatories is a working group composed of scientists who voluntarily choose to improve collaboration efforts amongst, "federal, state and academic representatives of the five United States volcano observatories" (Ewert, Guffanti, & Murray, 2005). The formation of a national watch office will codify the joint operations of the volcano observatories and serve to streamline reporting of volcanic activities to federal, state and local authorities.

Ash Threats to Community Utilities Infrastructure

Just as mechanisms are in place to monitor volcanic activity in the Cascade Mountain Range through the Cascade Volcano Observatory, so must Emergency Operations Planning consider the vulnerability that ash presents to the community's utilities infrastructure. Electrical infrastructure is a key foundation to Emergency Services and provides vital 911 Dispatch, emergency communications through cellular networks, and supplies electrical power to area hospitals. Ash on electrical lines when exposed to moisture or rainfall, conduct electricity. This can cause insulator flash, breakage of transmission lines, abrasion damage to turbine generation drives, and the respective cooling system (Wilson, Wilson, Deligne, Blake, & Cole, 2017).

Electrical providers may choose to shut down portions of the grid experiencing ash deposition to avoid catastrophic damage. Loss of electrical power to the community must be announced through the Public Information Officer. This message must be well crafted to explain the reason why and work arounds explained to residents, such as for charging smart phones using a car charger. Special medical needs citizens who have medical devices that they depend upon to maintain their health, should register with their respective county officials. Utilities other than electrical, such as drinking water and waste water treatment systems are also prone to damage from ash.

Water demands for clean-up of the community may stress the water utility system. During the 1980 Mt Saint Helens eruption, officials in various towns issued an odd/even rationing system based upon house number to reduce the stress on the water distribution system to provide adequate pressure to fire hydrants (USGS, 2015g). Ash can cause water quality issues, abrasion to water pumping systems, and clogging of water filtration at the treatment plant (Wilson, Wilson, Deligne, Blake, & Cole, 2017). Waste water treatment infrastructure can also be damaged due to ash intrusion. A great amount of ashfall is not necessary to damage waste treatment facilities. After Mount Saint Helens erupted, over 80 miles away, the city of Yakima was covered in a layer of 0.4 inch of ash (USGS, 2015g).

The Yakima Waste Treatment Facility experienced an increase of solids 15 times greater than normal (USGS, 2015g). "Ash was present in the raw sludge in the primary clarifiers, which led to damage of the grit classifier and gearbox of the mechanically cleaned bar screen" (USGS, 2015g, Wastewater, para. 1). Waste treatment systems that are connected with storm runoff are especially vulnerable to ash clogging (USGS, 2015g). Most communities are equipped with storm water collection and waste water treatment systems separated, which protects the waste system from exposure to ash washed from city streets (USGS, 2015g). Damage to pumps due to the extreme grit of ash degrades drive mechanisms and bearings. Pipes can become blocked as heavy ash particles form sediment deposits and diminish capacity to maintain the system's water volume. This ash intrusion can interfere with the biological water waste treatment process and result in untreated waste water being released into the environment. (Wilson, Wilson, Deligne, Blake, & Cole, 2017).

Surface Transportation Recovery from Ashfall

Repairing ash damaged utilities and ordering replacement parts requires all modes of surface transportation supporting logistical operations for the entire community. When planning for recovery from ashfall, though roads, interstates and airports first come to mind, consideration must be given to reclaiming functionality of the community's railroad network. "Impacts to rail networks are poorly documented…" (Wilson, Wilson, Deligne, Blake, & Cole, 2017, p. 17). Ash can cause automated switches to malfunction, and make communication signals not read correctly, sending conflicting messages to locomotive engineers. Tractive effort is also reduced and can interrupt track schedules as locomotives may experience slippage on grades with heavy loads. Should ash accumulations reach the 90mm to 200mm mark, the train's drive wheels will no longer make contact with the rail surface (Wilson, Wilson, Deligne, Blake, & Cole, 2017). Freight locomotives traveling through Montana were forced to stop as 1 to 2mm of ash covered the rail tracks from the 1980 Mount Saint Helens eruption. A total of ten freight trains had to wait for 3 days before the rails could be cleaned, allowing the trains to resume their route (USGS, 2015j).

The scope of ash clean-up efforts can be articulated to public works officials by explaining the workload experienced after Mount Saint Helens erupted. A total of 706, 250 cubic yards of ash had to be hauled away from highways alone (Montz, Tobin, & Hagelman, 2017). Ash may be present for weeks as opposed to days should the eruption continue (Casadevall, 1994). Emergency Operation Plans must address ash mitigation efforts and be identified in not only the plan itself (Casadevall, 1994). Having trained staff know clean-up procedures as well as stocking supplies on hand such as dust masks and extra engine air filters must be the new norm for those near volcanoes. Without extra dust masks and engine air filters as an example, these materials will be consumed at a quicker rate than the normal supply ordering routine can maintain (Casadevall, 1994).

Clean-up crews must also realize that once cleaned-up, another eruption could place additional ash deposits again on those surfaces just cleaned (Casadevall, 1994). Combating ash does not require complicated methods, but rather common sense or low tech, as described by Casadevall (1994). During the 1980 Mount Saint Helens eruption, 19 of 39 counties in Washington State had interactions with ashfall (Casadevall, 1994). Of those 19, five counties to the east of Mount Saint Helens reported that they were, "severely impacted" (Casadevall, 1994, p. 125). During this period, "Government agencies, airports, utilities, and private corporations were all forced to cope with ash deposits ranging in depth from 3 to 75mm while maintaining essential services and continuing normal activities" (Casadevall, 1994, p. 125).

Emergency Operation Plans are not limited to just those communities near volcanoes. Mount Saint Helens upon initial eruption rose to a height of ash cloud ranging from 80,000 to 160,000 and expanded to just over 231 square miles, in just four minutes (Casadevall, 1994). The eruption happened with such force that the ash cloud traveled 15 miles upwind (Casadevall, 1994). The average eruption lasts seven weeks according to data from Casadevall (1994). Agencies having emergency essential facilities identified that must be operated during ashfall, can better direct resources to keep them operating (Casadevall, 1994). Personnel shortages should be considered for external augmentation of clean-up teams, especially if operations are carried out on a 24/7 work basis (Casadevall, 1994).

Health Concerns and the Worried Well in Ash Contaminated Environments

Volcanic Ash Hazards and Disaster Recovery

According to Wagner (1980), the product of a volcanic eruption, ash is present in the form of very fine particles and constitutes a health hazard as identified in the Volcanic Ash Information sheet number 5, (para. 2). These fine particles closely resemble talcum powder and therefore are easily suspended in the air and moved about by prevailing winds. The amount of ash in the air can be so heavy as to turn day into what resembles night, effectively blocking out the sun. Mount Saint Helens deposited so much ash on Yakima, Washington, that the City Manager Dick Zais (2015) made the following observations:

> By noon, the City was engulfed in darkness and communications by home telephone were impossible. It was like an eclipse of the sun that lingered, a blinding blizzard and electrical storm all in one. Light-sensitive street lights came on automatically, traffic stopped, and a strange quiet fell on our community; and everywhere a talcum-like sandy gray powder kept accumulating. From noon until 6:00a.m. the following morning, the City was in total darkness. Three types of ash fell alternatively on the City: dark grey sand, medium gray sand, and a light gray cement-like dust. All three grades were gritty and light, difficult to sweep or shovel, especially when dry. To make matters worse, shifting winds blew the ash everywhere, severely impairing visibility and driving in our area. It was exceedingly harmful and abrasive to mechanical and electrical equipment, especially motors of vehicles, aircraft and electronic systems (USGS, 2015a, Eyewitness Accounts, para. 1).

Over 100 miles away from Mount St. Helens is the Port of Moses Lake, which was directly in the ashfall path (Port of Moses Lake, 2012). Personnel working at the port described the ash cloud traveling towards them as similar to a very dark thunderstorm (Port of Moses Lake, 2012).

The entire port and runway were then covered in three inches of ash, and the Operations Manager directed the closure of the airfield (Port of Moses Lake, 2012). "People were afraid to step outdoors, as nobody knew if the ash was toxic or not" (Port of Moses Lake, 2012, p. 38).

The Free Silica Content of Ash and the Worried Well

During the Mount St Helens eruption, there was media confusion over the amount of free silica content of the ash (USGS, 2015a). The free silica content of the ash can initially be vetted through the local Health Department office. Ash will irritate the lungs of those persons who are healthy (USGS, 2015a). Persons who suffer from pre-existing respiratory conditions such as, will experience symptoms such as increased breathing difficulties (USGS, 2015a). Remaining indoors for these persons during ash fall is critical. Persons respiratory maladies must wear a dust mask to reduce the amount of ash particles inhaled into the lungs. Infants must be kept inside away from ash environments. Even after the volcanic eruption has ceased and ashfall stopped, winds can still resuspend ash from covered surfaces. Washington State authorities requested the Center for Disease Control and Prevention as well as the National Institute for Occupational Safety and Health. Both agencies sent doctors and industrial hygienists to determine the health hazards of ash and the resulting air quality (Federal Coordinating Office, 1980).

To quell local reports circulating that the ash effected areas of Washington were in 60 percent free silica range, it became necessary for federal agencies to accurately assessed levels (Federal Coordinating Office, 1980). The actual amount of silica in the ash which could be inhaled was 3 to 7 percent (USGS, 2015g). Hence, "the worried well" syndrome did appear and was inflamed by these inaccurate free silica media reports (Stone, 2007, p. 11). "The general public should not be unduly alarmed by scare stories about silicosis" (Federal Coordinating

Officer, 1980, p. 30). The CDC team did not find numerous patients with respiratory complaints despite the worried well health claims (Federal Coordinating Office, 1980). Though local authorities instructed citizens to stay inside during the ashfall, doctor's offices were also closed (Federal Coordinating Office, 1980). Contrary to a lack of health findings in Washington, ash caused health issues in other countries around the world. Days after the 2010 Eyjafjallajokull volcanic event, Icelander's experienced health problems from winds blowing previously settled ash on surfaces, which caused a resuspension of ash into the air (Dunson, Pedersen, Vogfjörd, Thorbjarnardóttir, Jakobsdóttir, & Roberts, 2010).

After Mount Saint Helens erupted on 18 May of 1980, some persons did in fact report to medical authorities for treatment of respiratory difficulties. These patients did not have a previous history of respiratory difficulties. According to Wagner, this pattern continued for several weeks after the eruption, though not in staggering numbers (Wagner, 1980). Additionally, patients with pre-existing breathing difficulties sought medical care as the ash only served to exacerbate their symptoms. These patients were treated and released.

The potential for those exposed and unprotected workers cleaning up the ash is a disease of the lungs known as silicosis (Wagner, 1980). This is a chronic disease which causes scaring of the inner lining of the lung. This scaring restricts its ability to freely expand and contact. This effect on the lung diminishes its ability to oxygenate the blood stream (Wagner, 1980). Those working in ash contaminated environments must be advised to wear a dust mask. Mass warning and notification messages to those living in an ash contaminated community must contain content regarding the protective actions authorities' direct citizens to take. According to Wagner, outdoor activities should be restricted (Wagner, 1980).

Residents should not cut their grass, run or jog outdoors and unneeded trips should be avoided at all costs (Wagner, 1980). Mowing and car traffic in areas contaminated with ash will result in its re-suspension into the air. Normally heavily traveled roadways in the community will suffer from a continuous re-suspension of ash. Wagner (1980), further warned that smokers are at greater risk of respiratory irritation due to having to remove their protective dusk mask while smoking cigarettes. Wagner's (1980) article highlights the risks to not only residents of the community, but to First Responders and Public Works officials who must work outdoors in ash contaminated environments.

The article establishes baseline respiratory health concerns. May 18th, of 1980, was the last time the United States had communities contaminated by ash fall. It has been thirty-seven years since Emergency Managers, First Responders and Public Works officials have had to operate in an ash contaminated environment in the continental United States. After Mount Saint Helens erupted, 23 bodies were recovered. Of these 23 deceased, 18 had succumbed to suffocation due to ash inhalation (Montz, Tobin, & Hagelman, 2017). "Even persons living some distance from an eruption can develop bronchial and respiratory difficulties" (Montz, Tobin, & Hagelman, 2017, p. 87).

Health Advisories and Warnings During Mass Notification

Volcanic eruptions and ash fall represent an unknown to most people and even more compounding is the respiratory hazard ash presents. This hazard can be seen, and the resultant ash fall will likely cover the entire community, and may get so heavy as to block out the sun during daylight hours. Upon breathing the ash particles without a dust mask, many people may seek medical treatment to receive a "clean bill of health" just as they would do if they were involved in a chemical, biological, radiological or nuclear incident (Stone, 2007, p. 11). Unlike terrorist incidents involving chemical, biological, radiological and nuclear materials, there is information available to medical professionals on the effects of inhaling volcanic ash particles.

The key aspect is for Emergency Managers and Public Health officials to know these health effects and have a pre-scripted template of information dictating protective actions to be taken during ash exposure. Often erroneous information or worse yet, a lack of information on the health hazards of ash could result in mistrust of officials. An example of this would be the anthrax incidents during September to October of 2001. Officials first reported the cases as naturally occurring and not of a terrorist attack (Stone, 2007). Once the cases were confirmed as an anthrax terror attack, officials lost credibility with those living in the communities where these events occurred (Stone, 2007). Emergency Managers must strive to provide community preparedness education and educational materials to citizens in their township. Materials addressing preparation for any other natural disaster or manmade incident are available at Ready.gov.

Dust Masks in Ash Susceptible Areas

Emergency Management officials in communities within ash fall range of neighboring volcanoes must include these items and craft directive protective action verbiage to be utilized during ash fall. Educating the public as to the reason why these are needed and encouraging everyone to participate in a dust mask drill, where the entire community wears a dust mask for a ten-minute period will help residents feel more involved (Stone, 2007). Public Information Officials must provide this same information to local media members so that a unified health message on ash inhalation is presented to the community. Noted community Public Health officials must also present the same information during press conferences on ash fall. Other community demographic and religious leaders should be present as citizens whom residents consider to be trustworthy (Stone, 2007).

Communities generally have an existing communications plan of some form to disseminate disaster information to the public. This same plan must be executed during an eruption to educate and inform residents on protective health actions to be taken. Education on community preparedness of residents and a unified message to the community on protective health actions by officials and media personnel will mitigate worried well personnel from overwhelming medical care centers (Stone, 2007). Officials will then be able to utilize these same principles for an ash fall event or for a terrorist attack event, doing so results in a repeatable process that officials can execute for a natural disaster or terror attack.

Medical healthcare facilities and providers must be made aware that ashfall can cause difficulties for delivery of electrical power to area hospitals. Hospital administration staff must ensure hospital auxiliary generator maintenance is performed at a greater frequency during ashfall. Ash may cause interruptions, if not failure while accumulating on power lines and exposed to rainfall (Wilson, Wilson, Deligne, Blake, & Cole, 2017). Hospitals may also see problems with city water supply shortages. Water may also be in short supply as ash can cause problems with water infrastructure systems as the community uses even more water to clean ash from exterior surfaces. Damage to the water supply can take many forms, "changes in water quality, increased water demand, abrasion of water pumps, and blockage of filters at water treatment plants may all be experienced" (Wilson, Wilson, Deligne, Blake, & Cole, 2017, p. 13).

Community Response, Rescue, & Recovery in Ash Contaminated Environments

"Plan for the possibilities of supply lines (railroads, airports, roads) being closed and the need to request and organize delivery of needed supplies to affected areas" (USGS, 2015k, Communities, para. 10). “Have substitute vehicles available for emergency use by police and other essential public personnel” (USGS, 2015k, Communities, para. 11). It is suggested that cars and trucks drive at a speed of 35 mph on ash covered roadways so as not to obscure other driver’s visibility (USGS, 2015m). Privately owned cars and trucks will likely suffer clogged engine air filters and quit running while on community roads and cause possible blocked access to First Responder vehicles on 911 dispatch calls (USGS, 2015k). During traffic patrols and law enforcement operations, many Washington State Troopers’ vehicles were rendered inoperable due to engine damage from ash ingestion (Mayer, 1984). Stranded motorists will have to be picked up and taken to temporary shelters until they can be returned home (USGS, 2015k). Should a heavy rain fall on ash covered roads, the wet ash will become extremely slippery (Mayer, 1984). Ambulance BLS and ALS response times will undoubtedly increase due to poor visibility and ash slickened roads. This situation appears to favor air operations to transport injured patients to save time due to the speed of the helicopters rather than drive a patient to hospital in an ambulance.

Aviation Assets and their Vulnerability to Airborne Ash Hazards

Authorities must however, be aware of the limitations and shortfalls of utilizing jet turbine powered aircraft not only for Medevac of patients to hospital, but also to transport lifesaving commodities to assist communities exposed to volcanic eruption. Drifting or suspended clouds of ash can cause significant damage to aircraft passing through them (Guffanti, Casadevall, & Budding, 2010). Of the 129 reported incidents from 1953 to 2009, nine aircraft that flew through ash clouds experienced engine shutdown during flight (Guffanti, Casadevall, & Budding, 2010). Of these nine incidents, three involved shut down of all engines (Guffanti, Casadevall, & Budding, 2010). Should authorities plan on utilizing airports near the eruption area, winds aloft must be researched to determine if any ash clouds remain, most ash clouds were encountered at an altitude of 25,000 feet where aircraft normally cruise (Guffanti, Casadevall, & Budding, 2010).

Dangerous and numerous instances of aircraft engines ingesting volcanic ash particles cannot be dismissed by Emergency Services personnel and government authorities. A jetliner flying to Narita Airport in Japan, in 2000, passed through an ash cloud from the Miyake-jima Volcano which had erupted only an hour before (Guffanti, Casadevall, & Budding, 2010). Though the engines continued to operate, the flight control system computer as well as the electric powered engine controls stopped working (Guffanti, Casadevall, & Budding, 2010). The windscreen was blasted by the abrasive ash particles, reducing the pilot's vision to a very small undamaged portion of the canopy (Guffanti, Casadevall, & Budding, 2010). This occurred approximately 200km from the Narita airport, where the crew managed to safely land the aircraft. Another jet passenger aircraft in Bariloche, Argentina, passed through an ash cloud and landed without incident. Upon its ensuing take off, the aircraft lost power and had to abort take off. Once the engines where examined, they were found to be heavily damaged by ash (Guffanti, Casadevall, & Budding, 2010).

On 23 to 24 November of 2002, two aircraft experienced damaged after flying through an ash cloud from a volcanic eruption from the Reventador Volcano in Ecuador, twenty days prior to these incidents (Guffanti, Casadevall, & Budding, 2010). Pitot tubes, used to provide air speed and other data to aircraft systems, were found to have ash accumulations. This provided inaccurate flight information to pilots of both aircraft (Guffanti, Casadevall, & Budding, 2010). As such, the coordination of jet powered aircraft and any remaining or continuing airborne ash hazards during recovery, must be considered by air operations personnel as paramount.

Guffanti, Casadevall, and Budding, (2010), explain the informational network that must take place when aircraft are operating in proximity of volcanic eruptions which are expelling ash clouds:

> Preventing encounters that affect the safety and efficiency of flight, whether by strict avoidance of ash contaminated airspace or by defining zones of tolerably low ash concentrations that can be transited with minimal harm, requires rapid, reliable communication of information about the occurrence of explosive eruptions and the locations of ash clouds world-wide to dispatchers, pilots and air traffic controllers (p. 9).

Ash negatively impacts all facets of transportation, Emergency Responders, commuters, and transport of food goods to grocery stores. All of these utilize surface transportation to make the economy work.

The Negative Effects of Ash on Surface Transportation

Currently, there is little scientific data available on the effects of ash on surface-based transportation resources according to Blake, Deligne, Wilson & Wilson, (2017). How officials respond to ash on roadways vary. Ash contamination caused the shutdown of 185 miles of roads and 15 miles of rail after the Mount Saint Helens eruption of 1980 (USGS, 2015f). Cars and trucks experienced clogged engine air filters which resulted in overheating (USGS, 2015f). So significant was the ash on roadways that 165 State Trooper cars were left inoperative due to ash particles clogging engine air filters, of those 50 were damaged beyond repair and scrapped (Volcanic Ashfall Impacts Working Group, 2017). This information is of critical importance to any Police force operating in an ash contaminated environment.

New Zealand transportation officials chose to shut down one of the country's major roadways in 2012 following a volcanic eruption from Mount Tongario even though there was less than 3mm of ash accumulation on the road. After the eruption of Mount Cordon Caulle in Argentina, officials chose to keep roadways open despite an accumulation of 50mm of ash (Blake, Deligne, Wilson & Wilson, 2017). Other factors to consider are duration of the ash, perhaps continually over a period of days as opposed to one ash fall event. Officials in different regions will make decisions based upon their unique needs and situation.

Factors to be considered are ash obscuring lane markings, poor traction and driving visibility as well as the potential for engine damage should the air filter become clogged with ash particles. Airfields should consider closing once 1mm of ash accumulates on runways (Blake, Deligne, Wilson & Wilson, 2017). Ash clouds in the area could potentially close air space and airfields without ash directly accumulated on runways (Blake, Deligne, Wilson & Wilson, 2017). A study published in the Journal of Applied Volcanology entitled, "Improving Volcanic Ash Fragility Functions Through Laboratory Studies: Example of Surface Transportation Networks" found that ash spread over large population centers with extensive road networks can be negatively impacted by as little as ~0.1mm accumulation of ash (Blake, Deligne, Wilson & Wilson, 2017, p. 1). "Disruption to surface transportation can affect commuter travel, access for emergency services, distribution and provision of goods and services, other infrastructure (e.g. electricity systems, water and fuel) and the economy (Blake, Deligne, Wilson & Wilson, 2017, p. 1). Should a community have Police and Fire Department vessels for river, port authority or ocean water patrol, ash causes problems for boats of all sizes. Ash accumulation on navigable waterways tends to clump together in large masses and float on the water's surface. Ships which rely on the intake of waters, albeit ocean, lake or river, to cool internal mechanical systems may experience cooling pump component failures (USGS, 2015h).

Removal of Ash by Public Works Officials from the Community

Public works officials have numerous decisions to make when deciding how to remove volcanic ash, also known as tephra falls, in a manner that best aids the community recovery effort. "…global experience suggests clean-up operations are one of the most challenging aspects of responding to and recovering from tephra falls in urban environments" (Hayes, Wilson, Deligne, Cole, & Hughes, 2017, pg.1). Although small amounts of ash can slicken roadways and cover pavement markings, an accumulation of 10mm of ash is generally looked upon as a starting point for clean-up efforts (Hayes, Wilson, Deligne, Cole, & Hughes, 2017).

The Director of the Street Department for Spokane, Washington, experienced a fine ashfall from Mount Saint Helens in 1980. "Street sweepers had a great difficulty with the fine ash and the sweeper only served to blow the ash rather than vacuuming it up" (USGS, 2015b, Mt. St. Helens, 18 May, 1980; Spokane, Washington, para. 1). Spraying water on the ash did not help (USGS, 2015b). The fine ash quickly absorbed the water intended to clean the ash off the streets (USGS, 2015b). Spokane had received a fine ash, unlike other cities which experienced a heavier coarse ash that could be bladed up with road graders and then hauled off (USGS, 2015b).

The fine ash was not coming up, despite repeated passes with street sweepers (USGS, 2015b). Public Works employees experimented with different methods and discovered an inexpensive solution (USGS, 2015b). Utilizing damp sawdust as a binding agent, the employees spread the material with sander trucks over the fine ash in the streets (USGS, 2015b). The fine ash adhered to the sawdust, which the street sweepers easily vacuumed up (USGS, 2015b). Other cleanup operations where copious amounts of water were applied to heavy ash, found the mixture extremely difficult to manage. Of note is the fact that one cubic foot of water-soaked ash weighs about 80 pounds (Mayer, 1984).

During the 1980 Mount Saint Helens eruption, the Army Corps of Engineers worked with a variety of sealant materials to create a crust or surface barrier on windrowed and stockpiled ash gathered from clean-up efforts to mitigate the resuspension of ash into the air. Options of sealant materials presented to Public Works officials consisted of: agricultural lime, lignin sulfonate, lion prime, Coherex, emulsified asphalt, and slow cure oils (Mount St. Helens Technical Information Network, 1980). Each material has its own merits and limitations, Public Works officials should locate nearby retailers and products available to their community. Private land owners will likely be tasked to clean-up ash on their property.

The resistance of abrasive ash sliding off of a pitched roof is unlikely (Blong et al., 2017). "Recent experiments suggest that dry ash is unlikely to slide off roof pitches less than 35 degrees, and that wet ash will adhere to the roof covering at even higher pitches" (Blong et al., 2017, pg. 5). Should enough ash fall, Public Works officials would likely resort to having citizens clean their property and take their ash to collection points. Environmentalists should be consulted during collection site selection to assure that, "the disposal site has low susceptibility to erosion and leaching into groundwater" (Hayes, Wilson, Deligne, Cole, & Hughes, 2017, p. 6). Public Works officials must ensure these sites are not located near storm drains, as ash will clog storm sewers (Hayes, Wilson, Deligne, Cole, & Hughes, 2017).

Past examples of final dumpsites for ash have been, old quarries, solid waste disposal site/landfill and large vacant field areas (Hayes, Wilson, Deligne, Cole, & Hughes, 2017). "Ideally, potential disposal sites are identified before a volcanic eruption on a regional basis as part of a contingency planning process" (USGS, 2015, Disposal, para. 2). Ash however, can be combined with soil as it has good load bearing qualities for structures and will promote the growth of vegetables when mixed with soil that is fertilized (USGS, 2015).

Removing Ash from Facility and Residential Roofing

Additionally, recovery of ash accumulation from roofs of facilities of all types is another surface that must be cleaned off to avoid structural damage. Roofs of all residential homes and facilities must be cleaned off before the ash is removed from driveways, sidewalks and parking lots (Mayer, 1984). Cleaning of roof areas is a precursor to resume operation of facility HVAC systems (Mayer, 1984). Roofs should be cleared of ash with very small amounts of water sprayed on the dry ash to prevent remobilization. Should excessive amounts of water be sprayed on roofs, collapse could result as ash can absorb nearly twice its weight in water (Mayer, 1984). Spraying high pressure water from fire hoses can physically damage the roof surface (Mayer, 1984).

All of these methods will require coordination by Public Works officials to orchestrate an effective ash clean-up. Clean-up of roadways and airfields will require a large amount of heavy equipment and skilled operators. In order to successfully execute clean-up efforts, the department of Public Works will need to execute a contract to hire private construction companies to help (Hayes, Wilson, Deligne, Cole, & Hughes, 2017). Officials found that more time was needed to clean-up roadways than they anticipated, repeated street sweeping to remove fine ash is one example (Hayes, Wilson, Deligne, Cole, & Hughes, 2017). Performing periodic maintenance on heavy equipment will increase in frequency and duration as ash is highly abrasive and clogs engine air filters as well (Hayes, Wilson, Deligne, Cole, & Hughes, 2017).

Prioritization of roadway clean-up may follow along the lines of a snow removal plan. Other considerations by Public Works officials would be whether or not further ash fall was expected before the decision to clean-up is made (Hayes, Wilson, Deligne, Cole, & Hughes, 2017). Preplanning should include the number of Public Works heavy equipment loaders, dump trucks and street sweepers and the respective number of these machines within the community owned by private construction companies (Hayes, Wilson, Deligne, Cole, & Hughes, 2017).

Maintenance of Vehicles in Ash Contaminated Environments

Vehicles operating during ashfall and in ash contaminated environments such as First Responders and Public Works heavy equipment must be prepared to execute a more robust maintenance schedule. Brakes should be cleaned and serviced through the use of compressed air every 100 miles in extreme ash conditions measured in inches while lighter ash accumulation requires the brakes be cleaned every 500 miles (Horwell, 2007). Vehicle alternators should also be cleaned with compressed air during these maintenance intervals (Horwell, 2007). Daily maintenance of vehicles operating in these ash environments requires cleaning of the engine compartment, specifically, radiator and engine air filter (Horwell, 2007). Engine air filters should be replaced when a reduction of engine performance is noted by the vehicle operator (Horwell, 2007).

An expedient cleaning of the engine air filter can be accomplished by using a very low volume of compressed air from the inside of the filter towards the outside in order to dislodge impacted ash particles in the filter media (Horwell, 2007). Engine oil and oil filter should be changed with greater frequency during extreme ash conditions at the 100 mile mark, while lesser ash environments would dictate a change every 1000 miles (Horwell, 2007). Vehicle operators should be instructed not to use windshield wipers on dry ash, as the windshield could be scratched and visibility reduced (Horwell, 2007). Water bottles are suggested as a substitute should wiper-washer reservoir be empty (Horwell, 2007). Vehicle operators are encouraged to operate with lights on, even during daylight hours (Horwell, 2007). First Responders, Public Works officials and other persons working in ash environments should be discouraged from wearing contact lenses in fine ash situations as eye irritation will result (Horwell, 2007). These employees should have glasses as a substitute or be provided with appropriate goggles to protect their eyes (Horwell, 2007). Of critical safety importance is the wear of respirators by these employees. N95 respirators are recommended by the Center for Disease Control and Prevention and should be stocked for employee use during ash operations (Center for Disease Control and Prevention, 2012).

Public Works and electrical utility company employees must be prepared to begin cleaning ash off electrical powerlines and transformers to avoid losing electrical service to Emergency Services, hospitals and the community. Ash falling on electrical power lines, substations and electrical power generation stations can be quite problematic. Should rain fall on ash covered electrical infrastructure components, one or more or all systems could fail. Moist or wet ash can cause, "insulator flashover, breakage of transmission lines, abrasion of turbines and cooling systems at generation sites and disruption of service at the substations" (Wilson, Wilson, Deligne, Blake, & Cole, 2017, p. 24). Heavy ash accumulation on trees may cause them to fall onto electrical powerlines, electrical utility workers will have to survey heavily wooded areas which powerlines transit (Mayer, 1984). During Mount Saint Helens, low voltage distribution facilities and residential circuits seemed more susceptible to outages due to moisture induced flashover than high voltage lines (Mayers, 1984).

The eruption of the Chaiten volcano in Chile, 2008, found winds blowing ash onto electrical powerlines transmission infrastructure, even after the ashfall had stopped (USGS, 2015l). Utility workers had to clean power transmission lines at 10-day increments for a period of many months in order to ensure uninterrupted electrical service to communities (USGS, 2015l). Options for electrical providers can be a preemptive shut down of power. Public Works, Emergency Managers and power station operators must communicate frequently during ashfall. Choosing to shut down power in order to save the electrical infrastructure may result in no electrical power to area airports.

This would negatively impact relief commodities to be flown into the area, forcing ground transportation to be used instead, adding further time to delivery of these lifesaving goods. Without electrical power, First Responders would face challenges responding to emergencies while negotiating uncontrolled traffic intersections. Residents dependent upon electrical powered home health care devices such as infant apnea monitors, would have to make provisions for a portable generator. This hazard must be fully communicated to the public through a robust community preparedness program, designed to educate residents on mitigation options.

Reducing Ash Intrusion of Critical Facilities

Facility interiors are also susceptible to ash intrusion. Emergency Services, Hospitals, and Emergency Operations Center facilities must be aware of ash hazards inside the building. Though a less apparent challenge, practices must be undertaken to minimize ash introduction inside of critical facilities. A single point of entry to the facility must be configured to reduce ash particles tracked in on employee shoes and clothing (USGS, 2015i). Tape up all other facility doors and windows not actively in use (USGS, 2015i). An entryway with secondary doorway nearby should serve as an area to trap ash particles from shoes and exterior clothing. A sheet of plastic is taped to the ceiling before the secondary doorway to limit airborne ash entering the rest of the facility (USGS, 2015i). A wet towel can be placed on the entryway floor or if the facility is highly trafficked, a container of suitable dimension can be placed on the floor and filled with enough water to submerge the soles of footwear (USGS, 2015i). Place brushes or a vacuum, in the entryway so that employees can dislodge gross contamination of ash particles on their exterior clothing (USGS, 2015i).

Protecting priority facility HVAC systems can be expediently accomplished by placing generic 'blue filter media', over the system air intake, which is sold in bulk as a roll in most hardware stores (USGS, 2016). Horizontal air manifolds draw less ash than a vertical air intake manifold (USGS, 2016). A vertical intake manifold could be mitigated by maintenance staff constructing an expedient hood converting the intake to a horizontal one would hold a section of 'blue filter media' to act as a pre-filter for the HVAC system (USGS, 2016). If a pre-filter is not established on priority facilities, the HVAC system is at risk of stalling, overheating or both (USGS, 2016). These pre-filters will require periodic cleaning, a dry method such as a shop vacuum is suggested as any method involving a wet cleaning of the pre-filter or intake manifold will cause blockage of cooling fins and wet ash is able to conduct electricity quite easily (USGS,2016).

During heavy ashfall, this periodic cleaning could take place in as little as once every 30 minutes to keep HVAC units in service (USGS, 2016). Having rolls of 'blue filter media', tape, plastic, brushes and vacuums pre-positioned inside of priority facilities will ensure minimal disruption of key computer systems due to ash contamination. A schematic drawing of the facility's 'ash lock' layout should be readily available and briefed to facility managers and employees. These actions are key in minimizing the exposure of computers inside the facility to ash, which carries its own static charge (USGS, 2016).

The use of laptop computers in an ash contaminated environment by Law Enforcement and other First Responders, will require a protective cover to protect the computer. Today, laptops fulfill all types of roles in maintaining incident command and control functions. Wilson,

Wilson, Cole, & Oze, (2012) found that, “To retain full functionality of critical electronic equipment, we recommend a precautionary approach that all essential electronic equipment should be protected by either placing a physical barrier between the equipment and the ash or gas source, such as sealing the laptop inside a plastic bag” (p. 731). Cleaning off a laptop that had been used in an ash environment, but had not been placed inside a protective covering during operation, was estimated at approximately 30 minutes (Wilson, Wilson, Cole, & Oze, 2012). Caution must be observed as operating the laptop inside of a plastic bag may cause overheating problems. Fine ash was found to cause the most difficulties to laptops operating unprotected in ash contaminated environments (Wilson, Wilson, Cole, & Oze, 2012).

This practice can be applied to other types of electronic devices exposed to ash (Wilson, Wilson, Cole, & Oze, 2012). Especially vulnerable to ash intrusion is the laptop’s CD drive. Fine ash can migrate its way into the CD drive while larger ash particles enter upon opening of the player drive panel. “Ash will cover the lens, preventing the laser underneath from reading the disk” (Wilson, Wilson, Cole, & Oze, 2012, p.731). Use of the CD drive for software or the storage of data during ashfall could result in a loss of functionality (Wilson, Wilson, Cole, & Oze, 2012). The CD itself could be damaged from the highly abrasive ash particles (Wilson, Wilson, Cole, & Oze, 2012). The laptop fan will also accumulate ash particles when operated unprotected, in ashfall. (Wilson, Wilson, Cole, & Oze, 2012). External ports for USB related items were reported to be very susceptible to ash particle intrusion (Wilson, Wilson, Cole, & Oze, 2012). Upon return from the field, laptops should be vacuumed and blown out with canned air (Wilson, Wilson, Cole, & Oze, 2012). The canned air was found to be a most effective field expedient method.

Airport Clean Up and Operation in Ash Contaminated Environments

Just as communities must coordinate ash removal operations, so too must airfield managers. The timely recovery of an ash contaminated airfield will facilitate federal assistance and logistical commodities, providing relief and sustenance for community residents. Airfield managers must develop protocols to "launch-to-survive" aircraft parked on the aprons or to hangar those undergoing maintenance which are unable to fly (Guffanti, Mayberry, Casadevall, & Wunderman, 2009). Aircraft generation equipment can be moved into back shops or in other covered storage areas. The cleaning of ash must begin as soon as ashfall has stopped to clear airfield operating pavements. "An important aspect of mitigation efforts to reduce airport vulnerability to volcanic hazards is preparedness, especially by formulation of an airport-specific operational plan" (Guffanti, Mayberry, Casadevall, & Wunderman, 2009).

These contingency ashfall plans apply to Department of Defense resources as well. Mount Spurr erupted on the 18th of August 1992, prompting the Alaska Volcano Observatory to warn Elmendorf Air Force Base in Anchorage. Alaska Volcano Observatory personnel were able to give a two-hour warning prior to ashfall arriving at the air base. The Installation Commander was able to launch, shelter or seal 104 aircraft and send non-mission-essential personnel home to care for their families (Guffanti, Mayberry, Casadevall, & Wunderman, 2009). The warning of impending ashfall hazard to regional airports can divert inbound aircraft if necessary, while taking steps to prepare heavy equipment and airfield sweepers to begin ash removal operations. The airfield manager must maintain close contact with the servicing Volcano Observatory and address ash clean-up in the emergency operations plan for the airfield.

Should the airport choose to remain open under ash conditions, provisions for continued clearing of ash from runway surfaces must be taken (Casadevall, 1994). Airport maintenance teams and managers must explore ash clean-up techniques and discuss the pros and cons of wet or dry removal. Those involved in past ash clean-up of airfields expressed the preference of wetting the ash with water to minimize resuspension during the operation (Casadevall, 1994). Others felt that adding water to fallen ash on runways only served to turn it into a form like slurry (Casadevall, 1994). If the slurry could not be immediately removed, heavy equipment operators reported that the mixture began to harden (Casadevall, 1994). Some airports reported using a combination of these methods for recovery of ash from airfield pavements (Casadevall, 1994).

Emergency Operations Plans will identify the task of ashfall recovery to affected agencies and as a result, functions such as airports must in turn, develop their own plan of how these tasks will be executed. Airfield managers and airfield pavements maintenance crews should examine and discuss tactics, techniques and procedures on how they would accomplish ashfall clean-up.

Public Works officials and Emergency Managers must plan on dealing with resuspension of fallen ash during clean-up operations in a post-volcanic eruption environment. As the clean-up of ash from urban, infrastructure and transportation resources will undoubtedly take time. Ash dispersion modeling software is now being programed to recognize, plot and predict this hazard (Liu, et al., 2014). Researchers have found that ash from eruptions years ago can be driven by winds from areas outside the areas cleaned-up by officials. Of course, ash driven by strong winds is generally expected to occur most often in the weeks and months after an eruption. This phenomena was experienced with eruption events at Mount Saint Helens, in the United States, Mount Hudson, in Chile, Mount Etna, in Sicily, and Puyehue-Cordon Caulle, in Chile (Liu, et al., 2014). Distances in the tens of thousands of kilometers have been recorded of wind driven ash movement (Liu, et al., 2014). A 2011 eruption from Puyehue-Cordon Caulle in

Argentina, had officials pointing out the need for “remobilization forecasts that can be run in an operational capacity” (Liu, et al., 2014, p. 9463). “Although potential damage to aircraft by ash ingestion is the most widely publicized of the indirect hazards, volcanic ash fall can also severely impact on critical infrastructure, vehicle safety, and agriculture” (Liu, et al., 2014, p. 9464).

Agriculture, Preparing and Recovering the Whole Community

Agriculture also suffers damages and degraded operations due to ash contaminating water supplies and if ashfall is significant enough, crops can be ruined, or ash must be removed from fields prior to use (Wilson, Stewart, Cole, Johnston, & Cronin, 2010). Farming consumes 80% of water uses throughout the world (Wilson, Stewart, Cole, Johnston, & Cronin, 2010). Irrigation ditches used to provide water to crops, often clog with ash sediment and must be manually or mechanically removed to restore flow. Communities generally experience an increase in water use of two to three times the normal usage rate. Public Works officials and Emergency Management personnel must be cognizant of the strain an ashfall event places on this critical utility. Water for removal and cleaning of surfaces after ashfall, historically have led to unusually high consumption rates for affected communities (Wilson, Stewart, Cole, Johnston, & Cronin, 2010).

Newly fallen ash is quite corrosive and acidic from mineral acids and can be harmful to humans and livestock (Wilson, Stewart, Cole, Johnston, & Cronin, 2010). Should falling ash become wet or once down, receive a rainfall, the ash is able to pass a static charge when exposed to electrical equipment (Wilson, Stewart, Cole, Johnston, & Cronin, 2010). Ash may contaminate open air water storage catchments. Farmer’s electrical irrigation pumps and sprinklers are also damaged by volcanic ash. The static charge and highly abrasive ash particles short-out irrigation pump electrical panels, damage moving pump motor parts and industrial grade sprinkler heads, causing a lack of water to crops and livestock (Wilson, Stewart, Cole, Johnston, & Cronin, 2010). Water resources that are of a surface type are much more susceptible to ash contamination than sub-surface water resources, such as experienced during the Mount Saint Helens eruption of 1980 (Wilson, Stewart, Cole, Johnston, & Cronin, 2010).

Ash Hazards to Air Operations and Commercial Air Corridor Traffic

"One of the greatest and least appreciated volcanic hazards is the threat that ash clouds pose to aircraft" (National Research Council, 2000, pg. 34). The Eyjafjallajokull volcanic eruption in April and May of 2012, resulted in ash dispersed upwards of 30,000 feet, causing "…unprecedented disruption to aviation across Europe and the Atlantic, leading to considerable economic losses in the aviation industry. About 100,000 commercial flights were cancelled, the majority occurring during the first five days of the eruption" (Gudmundsson, Pedersen, Vogfjörd, Thorbjarnardóttir, Jakobsdóttir, & Roberts, 2010, p. 13). On April 15th of 2012, ash was blown over such a vast area that the countries of Norway, Sweden, Northern Ireland and Great Britain grounded all commercial aviation flights (Gudmundsson, Pedersen, Vogfjörd, Thorbjarnardóttir, Jakobsdóttir, & Roberts, 2010). To resume flight schedules, European aviation administrators had to re-evaluate airborne ash concentration, which re-opened air commerce in Europe (Gudmundsson, Pedersen, Vogfjörd, Thorbjarnardóttir, Jakobsdóttir, & Roberts, 2010).

Not only are ash clouds a hazard to flying aircraft, "The primary hazard to airports is ashfall, which can cause loss of visibility, create slippery runways, infiltrate communication and electrical systems, interrupt ground services, and damage buildings and parked airplanes" (Guffanti, Mayberry, Casadevall, & Wunderman, 2009, p. 289). Of airports that experienced ash events, 75 percent were within a distance of 300km of the volcano (Ewert, Guffanti, & Murray, 2005). The following international airports are within 300km of one or more volcanoes, Seattle-Tacoma, San Francisco, Las Vegas, Honolulu, Kona, Saipan, Portland, Anchorage and Fairbanks (Ewert, Guffanti, & Murray, 2005). Alaska airports, Anchorage and Fairbanks experience 11,000 passengers a day transported (Ewert, Guffanti, & Murray, 2005). Flights that transit the Anchorage and Fairbanks airspace and do not stop are thought to be approximately 200 flights and 20,000 passengers a day (Ewert, Guffanti, & Murray, 2005).

Generally, ash accumulations of centimeter or less can shut down airfield operations for a period of several days (Guffanti, Mayberry, Casadevall, & Wunderman, 2009). The airport in Quito, Ecuador, was closed after approximately two to three centimeters of ash fell from the 1999 eruption of Guagua Pichincha, located 15 kilometers from the airport for 3 days (Guffanti, Mayberry, Casadevall, & Wunderman, 2009). The Quito airport again suffered a closure from ashfall, this time for an 8 day period in 2002, from the Reventador volcano some 90km to the east (Guffanti, Mayberry, Casadevall, & Wunderman, 2009). Any ash amount over a trace immediately requires action on the part of the Airfield Manager to initiate clean-up efforts. Ash does not weather away, if not collected and removed, it can be re-suspended by gusting winds and begin the problem for airfield operations all over again (Guffanti, Mayberry, Casadevall, & Wunderman, 2009).

An example of this at an airport would be the 1991 eruption of Hudson volcano in Chile. Besides ash accumulating from the primary eruption, "In addition to the initial ashfall, strong surface winds in Argentina's arid Patagonia region then re-suspended ash for months after the eruption, causing reduced visibility and flight cancellations on several occasions" (Guffanti, Mayberry, Casadevall, & Wunderman, 2009, p. 292). Here in the United States, the Grant

County Airport was closed due to ash for a period of 15 days after Mount Saint Helens erupted (Guffanti, Mayberry, Casadevall, & Wunderman, 2009).

Ted Stevens International Airport in Anchorage, neighboring Elmendorf Air Force Base and Merrill Field are all within 250 miles of four active volcanoes (Guffanti, Mayberry, Casadevall, & Wunderman, 2009). Operations at each of these airfields is advised by the Alaska Volcano Observatory located in downtown Anchorage. Wind direction has everything to do with the ash hazard, should one of the four Alaskan volcanos erupt. During Mount Saint Helens 1980 eruption, the Portland International Airport in Oregon, 75 km away to the southwest, received no ash accumulation (Guffanti, Mayberry, Casadevall, & Wunderman, 2009). A few months after the Mount Saint Helens' eruption, ash was blown out of subsequent activity and the winds had changed direction, so Portland International Airport did experience interruptions in flight operations.

Should a volcano continue to erupt through a period of weeks or months, prevailing winds could carry recurring ashfall over airports in the region. This would severely restrict the movement by air of life saving commodities to effected communities. Not all eruptions have to be as violent as Mount Saint Helens was in 1980. From 1944 to 2006, medium volcanic eruptions were responsible for 68% of 171 volcanic events (Guffanti, Mayberry, Casadevall, & Wunderman, 2009). Medium eruptive events also carried ash to airports as far away as 1,000km (Guffanti, Mayberry, Casadevall, & Wunderman, 2009). Loss of airport usage due to ash contamination can result in significant financial losses for the aviation industry and associated businesses within the community. Anchorage's Ted Steven's International Airport in Anchorage, Alaska, lost $21 million U.S. dollars during the eruption of Mount Redoubt from 1989 to 1990 (Guffanti, Mayberry, Casadevall, & Wunderman, 2009). This is of significance because the Ted Steven's International Airport leads the United States aviation industry in cargo weight-landed, handling 26% of all air cargo moved by United States flagged carriers (Guffanti, Mayberry, Casadevall, & Wunderman, 2009).

Ewert, Guffanti, & Murray (2005) emphasized three key points when looking at the volcanic hazards faced in the United States. Areas around Mount Rainer, Mount Baker, which are in close proximity to Seattle-Tacoma, Washington and Mount Hood which is near Portland, Oregon, have seen a continued migration of people and families moving into the shadow of these volcanoes. The Ring of Fire, a grouping of volcanic chain that is directly below heavily travelled air corridors carrying passengers and cargo, facilitating international economic commerce (Ewert, Guffanti, & Murray, 2005). At risk are passenger airliners which could inadvertently fly through an ash cloud causing engine failure at high altitude (National Research Council, 2000). Should an airborne ash threat occur, the National Oceanic and Atmospheric Administration's Office of the Federal Coordinator for Meteorology, would convene the Volcanic Ash Working Group (Ewert, Guffanti, & Murray, 2005). Member agencies of the working group are, the United States Geological Survey Office, National Oceanic and Atmospheric Administration, Federal Aviation Administration, National Aeronautics and Space Administration, Department of Defense and the Smithsonian Institution (Ewert, Guffanti, & Murray, 2005).

Airborne ash can be so fine that it is invisible to pilots and unable to be picked up by aircraft radar (National Research Council, 2000). Air traffic routes from the United States, Canada and Asia, fly above Alaskan and Russian volcanoes. "On average, approximately four volcanoes per year erupt ash clouds of sufficient height and volume to endanger aircraft in the heavily traveled North Pacific air corridor" (National Research Council, 2000, pg. 40). Ash carried by winds aloft can be transported great distances. When Mount Pinatubo, located in the

Philippines erupted on June 15th of 1991, ash was recorded as far away as 5000 miles east (National Research Council, 2000). Twenty planes in the air over 600 miles away required extensive maintenance upon landing as they inadvertently passed through the ash cloud (National Research Council, 2000). Passengers and millions of dollars' worth of cargo is transported each day. Being denied access to these mapped out and approved routes would negatively impact United States' based companies that provide logistical cargo services.

The National Research Council (2000) report, "Review of the United States Geological Survey's Volcano Hazards Program" conveyed an incident which began monitoring of airborne ash by the Alaska Volcano Observatory located in Anchorage, Alaska:

> On December 15, 1989, KLM flight 867, carrying 231 passengers bound for Anchorage, inadvertently entered an ash cloud from the erupting Redoubt Volcano, 150 miles away. All four engines on the 747 failed when they ingested ash. The jet fell at a rate of 1,500 feet per minute from an altitude of 27,900 feet to 13,000 feet. After 11 tries, the pilot was able to restart the engines and land the plane safely. The incident occurred over the snow-covered Talkeetna Mountains, which have an elevation of 7,000 to 11,000 feet. The plane required $80 million in repairs, including replacement of all four engines (p. 53).

The United States Geological Hazards Survey Volcano Hazards Program serves to, "assess volcanic hazards based upon past history, monitor for early warning signals that that can indicate eruptions and design of crisis response strategies when large eruptions take place" (National Research Council, 2000, p. 2). Currently high risk volcanoes with real-time monitoring telemetry in place, can notify a controller at the respective volcano observatory, who in turn notifies the Federal Aviation Administration within approximately five minutes (Ewert, Guffanti, & Murray, 2005). The Anatanhan volcano, in the Mariana Islands, had no monitoring telemetry installed when it erupted in 2003 (Ewert, Guffanti, & Murray, 2005). Due to the lack of monitoring instruments, the eruption was not known for a period of many hours which prevented notification to aircraft flying in the area (Ewert, Guffanti, & Murray, 2005). The National Oceanic and Atmospheric Administration controls two Volcanic Ash Advisory Centers, located in Washington, D.C. and Anchorage, Alaska to monitor ash clouds and deliver advisories to the aviation community (Ewert, Guffanti, & Murray, 2005).

Currently the United States Geological Survey identified the Aleutian volcanoes posing the greatest hazard to the aviation industry (National Research Council, 2000). The Cascade Range, though largely inactive, pose the greatest risk to heavily populated cities and commercial industry in close proximity to these volcanoes (National Research Council, 2000). The Alaska Volcano Observatory, Cascades Volcano Observatory, National Aeronautics and Space Administration's Jet Propulsion Laboratory and Goddard Space Flight Center currently partner with the Volcanic Hazards Program to provide additional scientific and technical support as required (National Research Council, 2000).

Ashfall Community Preparedness and Educational Materials

The United States Geological Survey's Volcano Hazards Program develops community preparedness educational materials for communities with volcanic hazards nearby (National Research Council, 2000). The program works with officials and local Emergency Management offices to create a dialog of technical information. Informational briefings, talks, seminars, and office visits are just a part of the program's community preparedness and education effort. The Volcano Hazards Program has produced volcanic educational materials in the form of brochures, talking papers, rudimentary maps, videos, exhibitions and preparedness talks with community residents (National Research Council, 2000). Officials in Iceland conducted a public preparedness education program on volcanic hazards. All citizens participated in the 2006 exercise which served them very well during the April and May 2012 eruption of the Eyjafjallajokull volcano (Gudmundsson, Pedersen, Vogfjörd, Thorbjarnardóttir, Jakobsdóttir, & Roberts, 2010).

Traditional community preparedness literature, often in the form of brochures, tends to deal with having the all the contents of a disaster supply kit on hand and having a family communications plan. The addition of specific items to mitigate ash fall would be a disposable respirator and additional engine air filters for each vehicle the family owns. This literature, while critical in urban areas, does not bridge the gap for rural areas where farmers, ranchers and others raise crops and livestock.

Farming Preparedness Tips and Techniques During Ashfall

Farmers and growers should, while of course having a plan for their families, develop a plan for their farming operation as well (Wilson, Stewart, Cole, Johnston, & Cronin, 2010). Wilson, Stewart, Cole, Johnston, & Cronin, (2005) compiled the experiences of farmers, growers and ranchers in post-eruptive ash environments. As water is a key resource to these operations, an increase of acidity, accumulation of ash settling in irrigation ditches, damage to electrical pumps, and clogging of industrial caliber sprinkler heads were commonalities despite the geographic differences (Wilson, Stewart, Cole, Johnston, & Cronin, 2010). As part of an agricultural preparedness program, farmers should be encouraged to have on hand power-take-off drive water pumps, should their electrical irrigation pumps fail. Portable fuel driven generators would provide direct electric power to these water pumps, should the electrical grid fail due to ash damage (Wilson, Stewart, Cole, Johnston, & Cronin, 2010). Other provisions for agricultural water shortages could be mitigated to some degree by the use of portable stored water containers (Wilson, Stewart, Cole, Johnston, & Cronin, 2010).

A preparedness educational material brochure could easily be created and distributed by Emergency Management officials to area farmers. Suggested topics would be daily operational steps that would posture the farming operation to mitigate a volcanic eruption with minimal to little notice. A rain water collector from the roof(s) of the home or outbuildings should be fitted with a valve which would shut to protect the water collected in the storage tank (Wilson, Stewart, Cole, Johnston, & Cronin, 2010). Suggest that farmers have a five to seven day supply of stored water on site, use would be rotated and replenished so as not to cause stagnation (Wilson, Stewart, Cole, Johnston, & Cronin, 2010). Maintain and repair irrigation systems, consider placing overhead cover above the pumps to prevent direct ash accumulation (Wilson, Stewart, Cole, Johnston, & Cronin, 2010). The use of deeper livestock watering troughs would help dilute any acidic properties of ash that would fall, protecting livestock (Wilson, Stewart, Cole, Johnston, & Cronin, 2010). If supplied by surface water source, contact neighbors with subsurface water source that would share their clean water, should ash contaminate surface sources (Wilson, Stewart, Cole, Johnston, & Cronin, 2010). Place livestock in shelter buildings if possible and equip with a portable water supply (Wilson, Stewart, Cole, Johnston, & Cronin, 2010). When Volcano Observatories issue eruption warnings, consider not watering, if soil moisture content is favorable, as watered crops would readily attract ash and cause extensive damage to crops (Wilson, Stewart, Cole, Johnston, & Cronin, 2010).

Upon ashfall, make periodic checks of irrigation ditches and pumping equipment systems (Wilson, Stewart, Cole, Johnston, & Cronin, 2010). When removing accumulated ash, lightly wet with water, if enough is available, prior to handling to prevent resuspension (Wilson, Stewart, Cole, Johnston, & Cronin, 2010). Should ash accumulation be of such consequence or last so long as to cause consumption of drinking water supplies, ash laden water can be allowed to sit and settle. Though bitter to taste, “It is likely to be unpalatable due to a bitter metallic taste, but it is unlikely to pose a risk to human health if drunk on a short-term basis” (Wilson, Stewart, Cole, Johnston, & Cronin, 2010, p. 687). Categorize farming chores as, vital, required, obligatory, and optional should conditions become severe (Wilson, Stewart, Cole, Johnston, & Cronin, 2010, p. 687)

Electrical Power Grid Vulnerabilities to Ashfall Community Awareness

Citizens must be made aware of how susceptible the community’s electrical infrastructure is to ash deposition. Ready.gov encourages the public to maintain a Disaster Supply Kit to sustain themselves for three days without electrical power (National Response Framework, 2016). Fallen ash on electrical systems when exposed to rain or other source of moisture could cause power outages in the effected ashfall area. The electric company provider may choose to shutdown the effected grid until the ash can be removed, thus a serious emphasis must be communicated to residents of effected communities.

Ashfall Preparedness and Recovery Educational Subjects and Materials

Local Emergency Management officials would be best served by creating an education brochure on how best to mitigate the effects that ash hazards pose to residents. As an example of commercial disaster education products, the Quick Series, Disaster Response flip booklet, is well known in the Emergency Management field. Used by many local, state and federal agencies’ as a handout during community preparedness programs. However, volcanoes are not even listed as a natural disaster, though earthquake, and tsunamis are (QuickSeries, 2017).

Educating those living in the shadow of a volcano of its hazards is quite difficult as the volcano has likely shown no activity in many years. When asked about the high numbers of causalities from volcano eruptions, Nuhfer, Proctor, & Moser, reasoned, “Because volcanoes lie dormant for centuries between eruptions, and long periods of inactivity bring a false sense of security to residents who often fail to evacuate the area in time” (Nuhfer, Proctor, & Moser, 1993, p. 56). Winds will push ashfall towards the leeward, or protected, side of the volcano, often called the shield side. These areas may accumulate ash several tens of feet thick (Nuhfer, Proctor, & Moser, 1993).

Emergency Management educational preparedness materials tend to be of a citizen-centric nature. However, ash preparedness materials for Public Works personnel, recounting lessons learned from other ash recovery and clean-up efforts could easily be created. Outside of technical reports and case studies, a common educational product for Public Works was not discovered during this research. The case study of Mount Saint Helens is a perfect example as it reveals difficulties experienced by area communities and should be included in the creation of this Public Works educational product. Unusual and unforeseen circumstances such as the demand on water caused some communities to ration use to keep hydrant pressures up should a fire break out (USGS, 2015n). One community, Ellensburg, Washington, experienced peak water usage more than 2.5 times the normal rate during the first four days after eruption. Clean-up of ash with water in Anchorage, Alaska after Mount Spurr erupted in 1992, saw a 70 percent increase on city water demand (USGS, 2015n). Another community, Yakima, Washington, saw a solid waste formal rate 15 times higher than normal at their waste water treatment plant. This is the type of information water and waste utility Public Works personnel would benefit from, as the demand for water and solid waste removal was quite unexpected by officials. Two days later the Yakima waste water facility machinery broke down as the grit classifier and gear mechanisms to operate the cleaning bar were overwhelmed with a mixture of ash and sludge (Volcanic Ashfall Impacts Working Group, 2017). The ash became clogged in the pipes and ash passing through the trickling filter rock media damaged it. This was due to the abrasiveness of the ash as it stripped minute fragments of the filtering rock causing an even further build up, clogging this critical water filtration component (Volcanic Ashfall Impacts Working Group, 2017). All these utility-centric problems should be presented in lessons learned format so that Cascade Range Public Works can know specific vulnerabilities of their utility operating systems.

Airport Preparedness for Ashfall and Protective Actions for Aircraft

Airport managers and the aviation community would be well served to have a volcanic ash preparedness primer or guide, specifically addressing the vulnerabilities of aircraft operations. Airfield managers must develop a launch-to-survive protocol whereby aircraft leave their home airport to avoid an impending ash cloud. Winds aloft would have to be consulted to determine an airfield outside of the ash plume. This would put these aircraft in a position to render transport of aid commodities, additional responders and transport of patients.

Aircraft left behind should be hangered if at all possible as ash contamination can accumulate around hatches and doors on aircraft that require pressurization could pose difficulties while in flight (Casadevall, 1994). Should an aircraft hangars be full and aircraft cannot be evacuated from the area, extensive preventative actions must be taken to minimize ash intrusion into the cabin and other aircraft systems, both interior and exterior. Should suitable materials be available and in enough quantity, aircraft could be expediently covered to minimize ash intrusion, of course this may not be feasible due to aircraft size. “Sealing an aircraft would take 4 to 5 hours, and removing all seals and tape would take 1 to 2 hours…” on an average sized commuter jet (Casadevall, 1994, p. 126). Each aircraft is equipped with a variety of "ports, vents, seams and joints" which can be unique to each aircraft manufacturer. These procedures are very labor intensive, which must be considered when aircraft operations in an ash environment are to be undertaken (Casadevall, 1994, p. 126). Casadevall (1999), noted aircraft fueling operations require fully operating tank vents to be successful:

> Fuel tank vents must be open during loading, unloading, and transfer of fuel. If vents are plugged with ash, or if sealed, the tank could collapse. A 4 to 5 pounds per square inch vacuum is sufficient to cause collapse. (p. 126).

An exposed, unprotected aircraft on a parking ramp in a post-ashfall environment will require extensive and time consuming tasks for maintenance personnel to prepare the aircraft for service. Vacuuming or using forced air to remove ash from aircraft exterior surfaces is recommended (Casadevall, 1994). These actions are accomplished to minimize ash intrusion into control surface mechanisms as well as ports and vents. Sweeping is not recommended, nor is scrubbing of aircraft surfaces recommended (Casadevall, 1994). Washing the aircraft with water is recommended, should water utility lines be rendered inoperative, crash-fire apparatus must be considered and coordinated with Fire Department personnel for its use. The landing gear, air conditioning inlets, underside and engines are areas to be washed (Casadevall, 1994). It is recommended to check the pH of the aircraft surface to determine the level of acidity of the ash. If the acidic level is high, the acidity can be neutralized by combining a petroleum-based solvent during the aircraft washing process (Casadevall, 1994).

Airfield Managers and operators must be educated on steps they can take to increase the preparedness posture of their contingency plans. If the situation requires operation of the airfield in an ash environment, the runways and taxiways must be cleaned as if snow was falling. Should there be limited equipment to conduct these operations, case studies have shown that aircraft were towed to the cleared runway and launched from there (Casadevall, 1994). Aircraft generation equipment must be operational in order to support the launching of the airplane, if they are not operational, large frame aircraft cannot be launched. (Casadevall, 1994). These equipment items should be sheltered inside of a hangar to ensure their readiness Casadevall (1994), pointed out, ash must be removed from any airfield pavement surface where auxiliary equipment is to be operated:

> Gas turbines, air compressors, and air conditioners operate by ingesting large volumes of air. This equipment has only coarse filtration (or none at all), and extra filtration cannot be added without impacting operation. Using air conditioners to pressurize aircraft compartments [in order to keep out ash] would only blow ash into the aircraft and ruin the air conditioners in the process. (p. 127).

Electrical power interruption must be considered as air traffic control towers must have a serviceable backup generator. Backup generators must also be checked regularly by maintenance personnel to ensure they have not been damaged by ash particles (Casadevall, 1994). Of special note to Air Traffic Control tower operators and Airfield Managers is that communication antennas should be equipped with ceramic insulators. Ash is very difficult to successfully remove Teflon insulators as it will cause electrical shorting (Casadevall, 1994). Airfield landing systems are very critical and must be protected from ash intrusion. Relay boxes must be sealed, ash vacuumed and contacts cleaned with contact cleaner (Casadevall, 1994). Exposed rotating radar antennae bearings should be washed with high pressure water and re-lubricated to maintain service life (Casadevall, 1994).

Operating an airfield in an ash contaminated environment requires Airfield Managers to not only clear airfield pavement surfaces from ash, but to repeat cleaning of these surfaces as landing aircraft re-suspend ash which in turn deposits itself again on airfield pavements (Casadevall, 1994). Even airfield support vehicular equipment can re-suspend residual ash. Steps can be taken to try to suppress ash on the airport infield surfaces, most important are the grass areas at the edge of runways and taxiways. Materials such as Coherex or liquid lignin are binding and sealing agents sprayed on windrows. Windrows are elongated piles of ash similar to snow piled after a snow plow passes. Aircraft take offs generate jet engine blast and landings cause wing-tip vortices that can re-suspend ash that has been piled in windrows. Water sprinklers have been used in place of sealing agents to wet down ash and minimize re-suspension due to aircraft flights (Casadevall, 1994).

Educate pilots to steer clear of eruptions. If other air traffic control systems can provide radar coverage to the airfield, shutting down the radar could prove to be a viable option (Casadevall, 1994). Facilities that are considered non-essential to flight operations should be shut down, as this will minimize ash intrusion. Covering shut down computers with plastic can further mitigate the corrosive and static potential of ash interfering with computer functions. If repeated eruptions and subsequent ashfall occur, provisions for these procedures to be carried out 24/7 must be planned for.

Casadevall (1994) reported, light aircraft entering the ash cloud for research purposes experienced the following situations:

> Zero to limited visibility. Heat and slight turbulence, which caused a bump with each entry into the cloud. Copious quantities of ash entering the cabin through fresh air vents. The fuel-air ratio was upset, engines sputtered, and manifold

> pressure fell off rapidly. Once through the cloud, engine performance improved... (p. 142).

Pilots flying search and rescue missions must be aware of the hazards ash clouds possess and that the ash plume may shift as winds aloft change. Scientist performing this research found that cockpit windscreen damage occurred to the point that the windscreen was literally sandblasted, reducing the pilot's view. An expedient solution found was a 0.007-inch film of clear Mylar with tape to the windshield to protect it. The mylar was replaced after each flight. The mylar application has great potential as a best practice to mitigate physical damage to small aircraft windscreens. Upon inspection of the aircraft engines spark plugs, a "black, glassy, obsidian-like deposits completely covered the electrodes" (Casadevall, 1994, p. 142). Casadevall (1994), wrote about conditions while operating small aircraft in ash contaminated environments, research scientist found the following while repeatedly operating in ash environments:

> Judging from the increase of metallic elements shown by the oil analysis, it is obvious that the ingestion of volcanic ash is detrimental to aircraft powerplants. Ash will shorten the operating life of reciprocating engines and may, under sustained, severe volcanic-ash ingestion, cause engine failure (p. 142).

Any air operations conducted such as search and rescue or Medevac flights, must take these hazards into consideration. Casadevall (1994) warned that pilots and air crew operating in areas where volcanoes are present and or supporting aerial deliver of FEMA commodities to communities which has suffered a volcanic eruption must be aware of indicators that they have flown into or through and ash cloud:

> Recognition of an ash encounter may be accomplished by observing one or more of the following: heavy static discharges, glow in engine inlets, ash appearing in

> the cockpit and cabin with an acrid odor, multiple engine malfunctions or flameouts, and a decrease in air speed (p. 151).

There are comprehensive resources of information which delve into specific and technical aspects of aircraft flight and corrective actions to engine throttle settings and other measures to be taken when aircraft are caught in an ash cloud. Casadevall, (1994) outlines explicit instructions to pilots and air crew on flying maneuvers, expected system malfunctions and mid-air engine restart protocols (Casadevall, 1994, p.151-155). This paper serves to make local, state and federal emergency management personnel aware of the dangers of operating aircraft in an ash environment. Aerial transport of life sustaining commodities may very well depend upon prevailing winds and utilization of airports outside of the ash plume. Study of prevailing winds throughout the calendar year must be incorporated into planning and will reflect the most likely path of an ash plume based upon historical wind patterns.

A product which has already been created is, "The Health Hazards of Volcanic Ash-A Guide for the Public" and commissioned by the International Volcanic Health Hazard Network, GNS Science, and the United States Geological Survey by Horwell & Baxter, in 2007 (Horwell, & Baxter, 2007). This 15 page guide is an ideal community preparedness tool for those living near volcanoes. Horwell and Baxter (2007), created a guide highlighting health problems expected due to ash exposure and explains the effects in layperson's terms:

> Common acute (short term) symptoms include: Nasal irritation and discharge (runny nose). Throat irritation and sore throat, sometimes accompanied by dry coughing. People with pre-existing chest complaints may develop severe bronchitic symptoms which last some days beyond exposure to ash (for example, hacking cough, production of sputum, wheezing, or shortness of breath). Airway

> irritation for people with asthma include shortness of breath, wheezing and coughing. Breathing becomes uncomfortable (p. 4).

A companion booklet on the subject of ash and actions for civilians to take is, “Guidelines On Preparedness Before, During and After an Ashfall” which describes protective actions for citizens to take when faced with an ash scenario. This was commissioned by the International Volcanic Health Hazard Network, Cities and Volcanoes Commission, GNS Science and the United States Geological Survey and written by Horwell in 2007. (Horwell, 2007). Advice on disaster supply kit contents, caring for the family automobile in ash environments and directions on how to clean ash up from the outside and inside of the home are presented in an easily explained fashion (Horwell, 2007). Guidance on the proper type of N95 respirator is given as well as directions for creating an expedient respirator from a dampened piece of cloth and other protective actions, make these two guide books at the forefront of research material explicitly for citizens (Horwell, 2007).

Summary of Literature Review

A web portal would be a one source for Emergency Managers, First Responders, Police, Emergency Medical Services, medical facility treatment Healthcare Professionals, Public Works officials and Airport Managers who wish to write, review, or update their community’s Emergency Operations Plan. The web portal managing staff would then update and continue to locate and bring new research material to the site. Another, and perhaps the most perplexing problem is that the continental United States has not experienced an ash incident since the eruption of Mount Saint Helen in 1980 (Wagner, 1980).

Additionally, the limitations of this data not being in one repository can also slow research and studies by scientific communities without a geological background as well as those scientists who research volcanoes outside of the Volcano Hazards Program (National Research Council, 2000). The USGS is the clear leader on ash hazard information and is the obvious choice for reference and lessons learned. The difficulty lies in taking time to research information on ashfall during the actual event. Short, operational quick reaction checklists could easily be created and personalized to each agency and department. These checklist would then become the basis for a new subject on the training calendar, familiarizing employees and officials so that additional engine air filters, dust masks and googles could be programed for and funded. Safety briefings would include that contact lenses are not recommended for wear in an ash environment. Personnel would be encouraged to have a spare set of prescription glasses at work. No one has time to go home and get these things while an eruption is occurring.

Should a community require evacuation, Emergency Managers must be aware of the limited speed vehicles can travel on ash slickened roads. Further, there may be abandon vehicles blocking the roadway due to engine failure from ash contamination. Community traffic evacuation from a volcanic eruption should have multiple route options as ash degrades traction, limits visibility and clogs engine air filters. Lesser and reduced speeds would greatly slow vehicle egress speed and the progress of the evacuation. Winds aloft at the time of eruption will dictate where the ash falls.

The International Volcanic Health Hazard Network has two very informative and layperson friendly guides on communities exposed to volcanic ash. These two documents could be locally modified for communities living near volcanoes in the Cascade Mountain Range. Offering advice on ash removal from a private residence, the guide warns of trying to wash ash accumulation from a roof due to the increased weight of wet ash and its danger of roof collapse (Horwell, 2007).

Ash loading of roofs was a leading cause of facility and residential damage to structures during the 1991 eruption of Mount Pinatubo, in the Philippines. Clark Air Force Base, located 12 miles from the volcano received ashfall rates from 2 to 4 inches (USGS, 2015d). The town of Castillejos, 17 miles away from the eruption experienced ash accumulation of 6 to 8 inches (USGS, 2015d). During the eruption, the Philippines experienced Typhoon Yunna which wet the ash and created roof loads of 94 to 125 pounds per cubic foot, resulting in 847 deaths (USGS, 2015d). Once an eruption occurs, area forecasts must be closely watched for precipitation which would negatively complicate ash loading of residential and facility roofs.

Residents and facility managers would have to be advised of the importance of clearing these surfaces of ash accumulation. The handbook, “Guidelines on Preparedness Before, During and After an Ashfall” caution that numerous citizens have died from slipping off an ash-slickened roof while trying to clean-up their residence (Horwell, 2007). Not only does the guide highlight ash hazards, but it lists basic preparedness reminders that would apply during an eruption such as having cash on hand as ash may cause power failures, rendering Automatic Teller Machines inoperable (Horwell, 2007). The guide also urges to have prescription medications on hand during an ashfall situation when electrical power failure would render a pharmacy ineffective to dispense medicines (Horwell, 2007). The guide further recommends contact lens wearers use their eye glasses instead of contacts or find goggles to protect eyes from fine ash (Horwell, 2007). Outdoor and indoor ash clean-up procedures and ash waste collection procedures are outlined for the home owner and those living in urban environments as well (Horwell, 2007).

The companion document is, “The Health Hazards of Volcanic Ash-A Guide for the Public” which is a comprehensive guide to the negative health effects of ash for citizens. This guide provides guidance on children and ash exposure. The guide cautions that children may not heed warnings to stay inside and run the risk of lung and eye irritation (Horwell, & Baxter, 2007). Fresh ash is acidic, which further exacerbates irritation of the lungs and eyes (Horwell, & Baxter, 2007). The guide explains that ashfall, "generates much anxiety" (Horwell, & Baxter, 2007, p. 3). A suggestion within this guide is for communities to organize day-care activities to allow parents time to clean-up ash while the children are entertained in a school gymnasium for example (Horwell, & Baxter, 2007). Medical facilities and health care professionals are instructed to expect persons to report with eye and lung irritation, this is above other trauma such as slip and fall injuries due to ash accumulation (Horwell, & Baxter, 2007).

Shortfalls of Literature

Thirty-seven years have transpired since Mount Saint Helens erupted, and it is doubtful that any official working at the time of the eruption would still be in the same serving capacity to pass on any corporate knowledge learned firsthand during ash clean up. This research hopes to identify this knowledge gap and leverage case studies, technical report research, and locate these materials in a central repository web page. This site would contain information about ash hazards on the web and identify a predominate source for such materials, with USGS agency concurrence, these documents would reside there. This would then become an authoritative source of ash hazard information for local, tribal, state and government officials to utilize. The Volcanic Ashfall Impacts Working Group web page contains a significant collection of ash related information. Other sources of information on ash are available in various forms, textbooks, technical reports, YouTube, newspaper, after action reports and educational preparedness materials. Discovering materials is difficult as they are located in a variety of vastly different sources. The collection and consolidation of these materials should reside on the

Volcanic Ashfall Impacts Working Group web page. Trying to locate such sources during an eruption would prove to be quite problematic while determining a selection of particular courses of action without the benefit of knowing the problem had been dealt with previously, yet located in an unfamiliar and obscure report.

METHODOLOGY

Research Design

The Research Design involved mixed methods of qualitative and quantitative data (van Thiel, 2014). Quantitative research techniques were utilized to review a sampling of Cascade Mountain Range area community Emergency Operations Plans for a provision on ash clean up. Qualitative research looked at a variety of sources, case studies, written technical reports, documented firsthand accounts of experiences during ash fall, and cleanup methods best practices as well as those that failed to work and why. Desk research was used to examine the historic effect of volcanic eruptions and ash fall on communities that experienced such phenomenon. Desk research described how each community was impacted, how authorities responded to emergencies and what methods were utilized to clean up and dispose of the ash. The damage by ash to communities First Responder vehicular resources and critical infrastructure, was researched to document second and third fiscal effects to replace these resources. The mixed method of research was utilized as the collected data may not fit neatly into a tiered fashion (van Thiel, 2014).

Data Collection

Data Collection drew from case studies, first hand and previously recorded Public Works after action reports and documentaries. Desk research described how each community was impacted, how authorities responded to emergencies and what methods were utilized to clean up and dispose of the ash. A quantitative method identified the number of communities who have provisions for ash clean-up in their Emergency Operations Plan. These results were then compared with the number of communities in the Cascade Mountain Range whose Emergency Operations Plans address ash hazards. The Emergency Operations Plan research provided a picture of the level of preparedness and establish a baseline regarding the hazard posed by volcanic ash. This would then represent a value of how many communities have an operational plan developed to remove ash. Another baseline was established by checking Cascade Mountain Range communities' preparedness webpages to see if citizens are advised by emergency management officials of how to survive and operate in an ash contaminated environment. This will identify the level of community preparedness.

Data Analysis

Data Analysis Plan detailed successful cleanup approaches and those efforts which were not successful. These were documented and annotated as positive or negative and why the method failed. This data was compiled into an ash fall lessons learned clean-up. Positive and negative clean-up experiences were recorded. Presenting the information in this fashion allows Emergency Managers, Public Works officials and Airfield Managers to compare their Emergency Operations Planning actions to those applied in the practical application of a historic ash fall incident. The number of communities on a regional level was compared on their readiness to recover from an ash incident. This in turn could be utilized for outside response agencies such as the Federal Emergency Management Agency. Planning for the transportation of life saving commodities whether by air, roadway, or railway, directly into the affected region or community will depend upon how quickly ash can be cleaned-up by the community.

Further analysis of this data identified shortfalls in community planning. Specifically, where logistical resources such as additional engine air filters for fire apparatus, police cars, ambulances, as well as airport and public works heavy equipment have not been warehoused in quantities required to operate in an ash contaminated. Having additional numbers of filters on hand will allow continued operation in an ash environment while conducting response and recovery operations. Data did not accurately reflect First Responders, Airport Workers and Public Works officials having multiple dust masks issued to these personnel. These are required when employees and responders are working outdoors and exposed in the ash environment. Emergency Operations Plans do not typically list personal protective equipment items. County standard operating procedures were not available on county public web pages for research. Communities were evaluated as to whether Emergency Management officials have levied a requirement for residents to have an extra car engine air filter or if families have a dust mask for each member. This was not observed during web research. Emergency Management web page and plan searches did not identify agencies with and without engine air filters and dust masks. The research could not determine if such logistical commodities exist to enable operating in an ash environment. This research was conducted as an aid to help assist with increasing the level of preparedness throughout the Cascade Mountain Range against volcanic ash hazards.

RESULTS

The research conducted showed that the Volcanic Ashfall Impacts Working Group webpage is the most comprehensive central repository for Cascade Mountain Range volcanic information. A joint response effort does exist in the form of a Mount Saint Helens – Mount Adams Volcanic Regional Coordination Plan. The plan is an agreement between all county, tribal, public, private, state and federal governments, responding agencies and organizations (Washington Military Department, 2014). Though Mount Saint Helens erupted in May of 1980, for two months prior the volcano experienced increased seismic activity, yet procedures operating in an ash contaminated environment were developed in an impromptu manner (USGS, 2015c).

RQ1 explored community Emergency Operation Plans having provisions addressing a coordinated clean up, removal, and disposal of ash. The ash clean up effort is critical to open airports, roadways, railways, and waterways for the delivery of FEMA lifesaving commodities to the affected communities. A review of 131 county Emergency Operations Plan or their equivalent was conducted for California, Oregon and Washington. There were 18 counties whose plan was not readily accessible from a public webpage search criterion of Office of Emergency Management. California has 58 counties, of those 49 were available for public viewing, 16 of those 49, mentioned volcano as a hazard, representing a figure of 32 percent. Oregon has 35 counties, 7 could not be accessed, and 28 did mention volcanic activity as a hazard for a figure of 67 percent. Washington State has 38 counties, 2 plans could not be accessed for review, leaving 23 counties where volcano hazard was addressed, for a figure of 63 percent. Each state, California, Oregon and Washington had robust volcanic hazard planning identified in their respective state level Emergency Operation Plan.

RQ2 addressed the problem of citizens fearing that ashfall represents some type of toxic inhalation health hazard. During the Mount Saint Helens eruption, an inaccurate report identified the free silica content of the ash as 60 percent. This led to speculation that silicosis could be contracted by breathing ash contaminated air. The Center for Disease Control and Prevention was requested to send a team of physicians and a team from the National Institute for Occupational Safety and Health (NIOSH) to quantify the free silica ash content. The NIOSH team found the silica content of ash to range from 3 to 7 percent, thus allaying community fears. The CDC was also monitoring 21 Washington State area hospitals, 15 in Idaho, 7 in Montana, 6 in Oregon and two clinics, one in Yakima Valley and the other in Othello, Washington (Federal Coordinating Office, 1980). Though patients did check in for respiratory problems, the increase was not to the level expected by the CDC (Federal Coordinating Office, 1980). Educational materials on the health affects of ash were not seen or were not readily available during the research of the 131 counties of the Cascade Mountain Region in the United States.

RQ3 explores operating in an ash contaminated environment while performing an Emergency Services missions. Specific operating restriction in an ash contaminated environment are documented in lessons learned located on the Volcanic Ashfall Impacts Working Group. While Emergency Operations Plans identify and task agencies to perform response and recovery tasks, there were few if any county plans that addressed the reduced speed due to poor traction that emergency vehicles will experience. Operation of vehicle engines, aircraft turbine engines, locomotive train engines, water vessels and emergency generators require extra engine air filter replacement to avoid overheating and engine failure due to ash ingestion. The degradation of internal combustion powered vehicles, and the restriction ash contamination places on airport operational status is not acknowledged in Emergency Operations

Plans. Extra engine air filters must be carried as bench stock for Emergency Services agencies as these air filters will be in high demand by citizens who are facing the same conditions. Operating a Base Support Installation to move life saving commodities must be located outside the ash contaminated area until such time as transportation infrastructure in the affected community can be cleaned up and recovered.

RQ4 dealt with aviation and ash clouds on the dangers to flying operations. The aviation flying industry was found to be extremely informed and have explicit notification protocols in place to warn flights traveling around the world which could encounter ash when there is an eruption in the flight path. This repeated exposure has the aviation industry dealing with ash on a nearly routine basis. The advisory group, International Civil Aviation Organization, (ICAO), chartered by the United Nations, produces Standards and Recommended Practices through accord with other countries' aviation agencies throughout the world (ICAO, 2018). Airborne ash clouds are tracked by the Washington Volcanic Ash Advisory Center, (WVAAC), and falls under National Oceanic and Atmospheric Administration (WVAAC, 2018). The WVAAC produces Significant Meteorological Information (SIGMET) reports on ash and weather phenomena in their assigned area of responsibility (WVAAC, 2018). Numerous historic reports of damage to aircraft from ash are documented on the USGS.gov website and other sources such as Volcanic Ash and Aviation Safety: Proceedings of the First International Symposium on Volcanic Ash and Aviation Safety, a textbook compilation of aviation ash-centric technical reports (Casadevall, 1994). There are technical reports contained in this work which address the clean-up of ash contaminated airports. The clean-up of ash technique, whether wet or dry or a combination of both, will be decided by the Airfield Manager of the airdrome. Clean-up techniques employed by previous Airfield Managers are presented in a lessons learned format (Casadevall, 1994).

RQ5 looked at community preparedness educational materials readily available on county Office of Emergency Management or equivalent agency webpages in the Cascade Mountain Range states. Disaster Supply Kit contents were listed and or links provided to sites such as Ready.gov. Where volcanic activity was mention in county's Emergency Operations Plan, there was not a direct correlation of ash hazards to educational community preparedness materials. The United States Geological Survey webpage maintains a list of volcanic eruption preparedness gear (USGS, 2016b). Various links to USGS, Ready.gov, and American Red Cross, were observed on California, Oregon and Washington State and county Office of Emergency Management webpages. A noteworthy educational product on ashfall hazards is the USGS Factsheet 027-00, Volcanic Ash Fall- A "Hard Rain" of Abrasive Particles (USGS, 2000). A very suitable ash hazard educational pamphlet is, "Guidelines on Preparedness Before, During and After an Ashfall" (Horwell, 2007). This publication is accompanied by "The Health Hazards of Volcanic Ash-A guide for the public" (Horwell & Baxter, 2007). Both products are available through the USGS Publications Warehouse.

DISCUSSION

There are 13 volcanoes in the Cascade Mountain Range of west coast of the United States (Washington State Hazard Mitigation Plan, 2014). The number of persons effected in any future eruption requires comprehensive community preparedness. The USGS (2014), emphasized that cities in proximity of the Cascades continue to grow. A basic awareness education level of volcanic hazards faced by those should be communicated to citizens in communities along the Cascade Mountain Range:

> In Cascade Range vicinity, the number of people at immediate risk during eruptions is greater than at any other volcanic area within the United States. The 2010 census notes that more than 10 million people live in Washington and Oregon alone, and populations are increasing in areas at risk for volcanic hazards. Additionally, aviation air space between the Canadian border and Mount Shasta (California) accommodates almost 2,000 flights daily. The next eruption near a Cascade volcano could upset the lives of hundreds of thousands of people and disrupt many others (Volcano Hazards in the Cascade Range, para. 1).

"Hazardous volcanic activity will continue to occur, and, because of increasing population, increasing development, and expanding national and international air traffic over volcanic regions, the exposure of human life and enterprise to volcano hazards is increasing" (Ewert, Guffanti, & Murray, 2005, p. 3).

The ash cloud from the May 18, 1980, eruption of Mount Saint Helens left 500 million tons of ash particles on areas in Washington, Idaho and Montana (USGS, 2000). Over 10,000 persons were stranded as roads became slick, travelers drove cars at speeds of 5 mph as the visibility was so poor, and many vehicle engines were damaged by ash ingestion (USGS, 2000). Fiscally, losses from the eruption cost $1 billion in economic and property loss mostly due to ashfall (USGS, 2000). Ash from a Cascade Mountain Range volcanic eruption has the potential to negatively impact numerous communities, disrupt air travel and other manners of surface transportation. Operating vehicles in an ash contaminated environment can lead to engine overheating and failure if air filters are clogged with ash particles. Regarding First Responders operating vehicles in ash contaminated environments, Washington State Troopers documented that, of the 165 patrol vehicles driven in the ash, 50 were damaged beyond repair and the other 115 were temporarily unavailable as mechanics had to change engine air filters and blow ash particles out of the radiators, alternators and brakes (Volcanic Ashfall Impacts Working Group, 2017).

Technology has increased dramatically since Mount Saint Helens erupted in 1980. HVAC systems for buildings with critical computer technology will need expedient pre-filters constructed out of some type of filter media which can capture ash particles. Buildings housing server farms will likely require hourly HVAC filter inspection and cleaning. Critical facilities must be outfitted first with contingency pre-filter filter media, before less critical facilities receive these important resources. Accidents on ash slicked roadways are highly probable as drivers will likely crash into one another. Med-Evac flights may not be able to operate in an active ash cloud drifting over the community. Authorities will be challenged with calls from stranded drivers on the roads as citizens concerned about the air quality will likely inundate authorities with calls.

REFERENCES

Blake, D. M., Deligne, N. I., Wilson, T. M., & Wilson, G. (2017). Improving volcanic ash fragility functions through laboratory studies: example of surface transportation networks. Journal of Applied Volcanology, 6(1), 16. doi.org/10.1186/s13617-017-0066-5

Blake, D. M., Wilson, T. M., Cole, J. W., Deligne, N. I., & Lindsay, J. M. (2017). Impact of volcanic ash on road and airfield surface skid resistance. Sustainability, 9(8), 1389.

Blong, R. J., Grasso, P., Jenkins, S. F., Magill, C. R., Wilson, T. M., McMullan, K., & Kandlbauer, J. (2017). Estimating building vulnerability to volcanic ash fall for insurance and other purposes. Journal of Applied Volcanology, 6(1), 2.

Casadevall, T. J. (Ed.). (1994). Volcanic ash and aviation safety: proceedings of the first international symposium on volcanic ash and aviation safety (Vol. 2047). US Government Printing Office.

Center for Disease Control and Prevention. (28 September, 2012). Key facts about protecting yourself after a volcanic eruption. Retrieved from: https://www.cdc.gov/disasters/volcanoes/after.html

Ewert, J. W., Guffanti, M., & Murray, T. L. (2005). An assessment of volcanic threat and monitoring capabilities in the United States: framework for a National Volcano Early Warning System (No. 2005-1164).

Federal Coordinating Office. (1980). Mount St. Helens Technical Information Network Bulletins 1 – 33. National Technical Information Service. Accession number PB81-138950. Springfield, Virginia.

Gudmundsson, M. T., Pedersen, R., Vogfjörd, K., Thorbjarnardóttir, B., Jakobsdóttir, S., & Roberts, M. J. (2010). Eruptions of Eyjafjallajökull Volcano, Iceland. Eos, Transactions American Geophysical Union, 91(21), 190-191.

Guffanti, M., Casadevall, T. J., & Budding, K. E. (2010). Encounters of aircraft with volcanic ash clouds: a compilation of known incidents, 1953-2009. US Department of Interior, US Geological Survey.

Guffanti, M., Mayberry, G. C., Casadevall, T. J., & Wunderman, R. (2008;2009;). Volcanic hazards to airports. *Natural Hazards, 51*(2), 287. doi:10.1007/s11069-008-9254-2

Hayes, J., Wilson, T. M., Deligne, N. I., Cole, J., & Hughes, M. (2017). A model to assess tephra clean-up requirements in urban environments. Journal of Applied Volcanology, 6(1), 1-23. doi:http://dx.doi.org.ezproxy1.apus.edu/10.1186/s13617-016-0052-3

Horwell, C. (2007). Guidelines on preparedness before, during, and after an ashfall. Retrieved from: http://www.ivhhn.org/pamphlets.html

Horwell, C., & Baxter, P. (2007). The health hazards of volcanic ash--A guide for the public. Retrieved from: http://www.ivhhn.org/pamphlets.html

International Civil Aviation Organization. (2018). A United Nations Specialized Agency. About ICAO. Retrieved from: https://www.icao.int/about-icao/Pages/default.aspx

Klickitat County. (November, 2012). Support Annex C. Hazard Identification & Vulnerability Analysis. Comprehensive emergency management plan.

Liu, E. J., Cashman, K. V., Beckett, F. M., Witham, C. S., Leadbetter, S. J., Hort, M. C., & Guðmundsson, S. (2014). Ash mists and brown snow: Remobilization of volcanic ash from recent Icelandic eruptions. Journal of Geophysical Research: Atmospheres, 119(15), 9463-9480.

Mayer, W. H. (1984). The Mitigation of Ash Fall Damage to Public Facilities: Lessons Learned from the 1980 Eruption of Mt. St. Helens. Washington Federal Emergency Management Agency, Region X.

Montz, B. E., Tobin, G. A., & Hagelman, R. R. (2017). Natural hazards: explanation and integration. Guilford Publications.

Mount St Helens Technical Information Bulletin. (16 June, 1980). Controlling blowing dust from volcanic ash. Bulletin number 19. Retrieved from: https://volcanoes.usgs.gov/volcanic_ash/mt_st_helens_1980_remobilisation.html

National Volcano Early Warning and Monitoring Systems Act, H.R. 4475, 115th Cong. (2017).

National Research Council. (2000). Review of the US Geological Survey's Volcano Hazards Program. National Academies Press.

National Response Framework, Third Edition, 2016. Department of Homeland Security. Retrieved from https://www.fema.gov/media-library/assets/documents/117791

Nuhfer, E. B., Proctor, R. J., & Moser, P. H. (1993). The citizen’s guide to geologic hazards. The American Institute of Professional Geologists, 134.

Port of Moses Lake. (2012). The Port of Moses Lake. A history. Ross Printing Company. Spokane, Washington.

QuickSeries. (2017). Disaster Response. Retrieved from: http://quickseries.com/products/disaster-preparedness/?query_search=natural+disaster&query=%22natural%2520disaster%22

Stone, F. P. (2007). The" worried well" response to CBRN events: Analysis and solutions. AIR UNIV MAXWELL AFB AL COUNTER PROLIFERATION CENTER.

United States Geological Survey. (2000). Volcanic Ash Fall – A Hard Rain of Abrasive Particles. Fact Sheet. 027-00. Retrieved from: https://pubs.er.usgs.gov/publication/fs02700

United States Geological Survey. (31 March, 2014) Cascades Volcano Observatory. Volcano Hazards Program. Volcano Hazards in the Cascade Range. Expanding populations near volcanoes put more people at risk. Retrieved from: https://volcanoes.usgs.gov/observatories/cvo/hazards.html

United States Geological Survey. (16 December, 2015). Preparing a building for ashfall. Volcanic ash impacts and mitigation. Retrieved from: https://volcanoes.usgs.gov/volcanic_ash/keeping_ash_out.html

United States Geological Survey. (16 December, 2015a). Free crystalline silica in volcanic ash. Health. Mount saint helens. Retrieved from: https://volcanoes.usgs.gov/volcanic_ash/mount_st_helens_health.html

United State Geological Survey. (17 December, 2015b). Infrastructure. Water supply. Mount saint helens 1980. Retrieved from: https://volcanoes.usgs.gov/volcanic_ash/mount_st_helens_infrastructure.html

United States Geological Survey. (17 December, 2015c). Infrastructure. Transportation. Retrieved from: https://volcanoes.usgs.gov/volcanic_ash/mount_st_helens_infrastructure.html

United States Geological Survey. (17 December, 2015d). Infrastructure. Power Network. Retrieved from: https://volcanoes.usgs.gov/volcanic_ash/mount_st_helens_infrastructure.html

United States Geological Survey. (17 December, 2015e). Case study. Mt St Helens 1980. Retrieved from: https://volcanoes.usgs.gov/volcanic_ash/mount_st_helens_emergency_management.html

United States Geological Survey. (17 December, 2015f). Remobilization. Chaiten volcano. Chile. Retrieved from: https://volcanoes.usgs.gov/volcanic_ash/chaiten_2008_remobilisation.html

United States Geological Survey. (17 December, 2015g). Water Supply. Mount Spurr 1992 eruption. Retrieved from: https://volcanoes.usgs.gov/volcanic_ash/spurr_1953_1992.html

United States Geological Survey. (16 December, 2015h). Communities. What can I do? Retrieved from: https://volcanoes.usgs.gov/volcanic_ash/communities.html

United States Geological Survey. (16 December, 2015i). Recommendations for a local preparedness plan. Communities. Local preparedness plan. Retrieved from: https://volcanoes.usgs.gov/volcanic_ash/local_preparedness_plan.html

United States Geological Survey. (16 December, 2015j). Clean-up strategies. Volcanic ash. Retrieved from: https://volcanoes.usgs.gov/volcanic_ash/cleanup_strategies.html

United States Geological Survey. (17 December, 2015k). Ash disposal. Volcanic ash. Retrieved from: https://volcanoes.usgs.gov/volcanic_ash/ash_disposal.html

United States Geological Survey. (14 December, 2015l). Vehicles. Volcanic ash. Retrieved from: https://volcanoes.usgs.gov/volcanic_ash/vehicles.html

United States Geological Survey. (9 December, 2015m). Railways. Volcanic ash. Retrieved from: https://volcanoes.usgs.gov/volcanic_ash/railways.html

United States Geological Survey. (14 December, 2015n). Marine. Transportation. Volcanic ash. Retrieved from: https://volcanoes.usgs.gov/volcanic_ash/marine_transportation.html

United States Geological Survey. (15 March, 2016). Heating, ventilation and air conditioning. HVAC and generators. Retrieved from: https://volcanoes.usgs.gov/volcanic_ash/HVAC_gensets.html

United States Geological Survey. (16 December, 2016a). Pinatubo. Case study. Retrieved from: https://volcanoes.usgs.gov/volcanic_ash/pinatubo_1991.html

United States Geological Survey. (18 March, 2016b). Be ready for the next volcanic event. Preparedness. Retrieved from: https://volcanoes.usgs.gov/vhp/preparedness.html

Volcanic Ashfall Impacts Working Group. (12 September, 2017). Mount Saint Helens Case Study. United States Geological Survey. Retrieved from https://volcanoes.usgs.gov/volcanic_ash/

Wagner. (1980). Volcanic Ash Information 5. Oregon State University Agricultural Experiment Station and Extension Service. Retrieved from Wagner, S. L. (1980). Volcanic ash--health hazards. Corvallis, Oregon. Extension Service, Oregon State University.

Washington State Hazard Mitigation Plan. (2014). Tab 5.10. Volcano profile. Retrieved from: https://mil.wa.gov/other-links/enhanced-hazard-mitigation-plan

Washington Volcanic Ash Advisory Center. (2 February 2018, 2018). Active Volcanoes in Washington VAAC area of responsibility. Retrieved from: http://www.ospo.noaa.gov/Products/atmosphere/vaac/

Wilkinson, S. M., Dunn, S., & Ma, S. (2012). The vulnerability of the European air traffic network to spatial hazards. Natural hazards, 60(3), 1027-1036.

Wilson, T., Stewart, C., Cole, J., Johnston, D., & Cronin, S. (2010). Vulnerability of farm water supply systems to volcanic ash fall. Environmental Earth Sciences, 61(4), 675-688.

Wilson, G., Wilson, T., Cole, J., & Oze, C. (2012). Vulnerability of laptop computers to volcanic ash and gas. Natural hazards, 63(2), 711-736.

Wilson, G., Wilson, T. M., Deligne, N. I., Blake, D. M., & Cole, J. W. (2017). Framework for developing volcanic fragility and vulnerability functions for critical infrastructure. Journal of Applied Volcanology, 6(1), 14.

APPENDICES

Volcanoes of the Cascade Mountain Range, note that this area of the United States is quite heavily populated.

Courtesy of Cascade Volcano Observatory (USGS, 2017)

https://volcanoes.usgs.gov/observatories/cvo/cascade_volcanoes.html

USGS geologist Don Swanson (in red) and his colleague, Jim Moore, view a car filled with ash deposits from the May 18, 1980, eruption of Mount St. Helens.

http://bigislandnow.com/2017/05/11/geologist-recalls-mount-st-helens-eruption-37-years-ago/

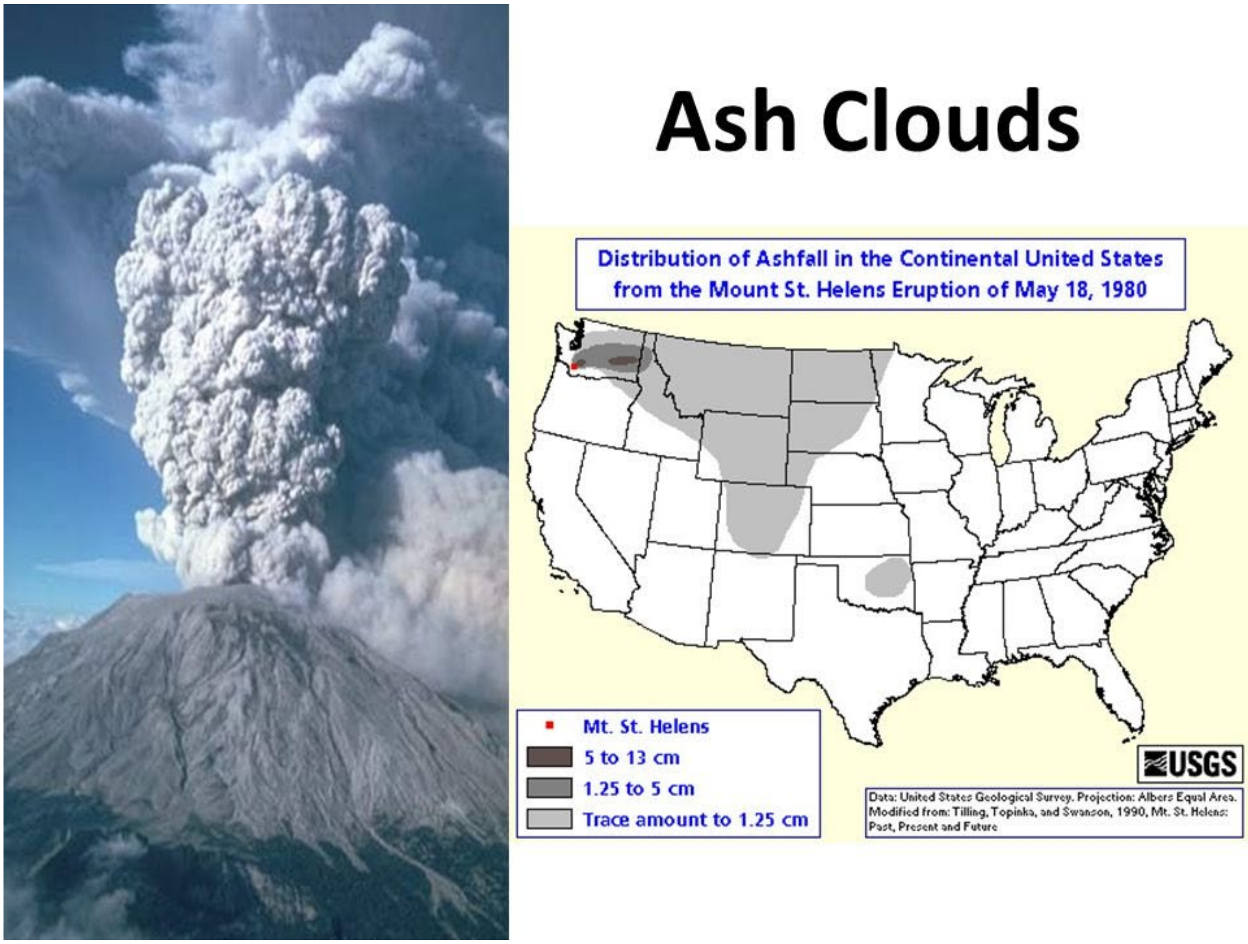
Mike Clinton shovels ash off Yakima sidewalk on May 20, 1980. A thick coating of ash covered the city. Public Works officials must coordinate clean up of commercial and residential areas and schedule times for ash to be hauled away.

Courtesy of the Seattle Times, 20 May, 1980.

A resident of Yakima cleans off his car as ash falls in the background, note dust mask.

Courtesy of Yakima Mission

https://yakimamission.wordpress.com/2016/05/18/mount-saint-helens-day-18-may-1980/



Courtesy of USGS.

Extent of ash carried by winds aloft from Mount Saint Helens 18 May, 1980, eruption.

Visibility is greatly reduced as drivers must reduce speed to avoid resuspension of the ash, creating even more dust.

Downtown Yakima, Washington, 18 May, 1908. Courtesy of Yakima Mission

https://yakimamission.wordpress.com/2016/05/18/mount-saint-helens-day-18-may-1980/

Traveling through the deserted town Chehalis. Courtesy of Seattle Times, taken 18 May, 1980

https://www.seattletimes.com/seattle-news/northwest/how-the-seattle-times-covered-the-mount-st-helens-eruption-36-years-ago/

Figure 412.—Removal of ash from the May 18 eruption, Interstate 90, eastern Washington. Photograph by Washington State Highway Department.

The ash accumulation is so great that it is removed with a snowplow. Operating heavy equipment in ash contaminated environments requires additional engine air filters and daily maintenance checks.

Courtesy of Oil-Electric, newspaper origin unknown

http://www.oil-electric.com/2010/05/may-18-1980-mt-st-helens-bn-connection.html

This airport is clearing its ramp and runway surfaces of ash. Airports will have significant ash piles to be hauled off of the extensive amount of airfield pavements.

Courtesy of the Yakima Herald.

https://www.google.com/search?q=mount+st+helens+ash&source=lnms&tbm=isch&sa=X&ved=0ahUKEwjVl6bxoY3ZAhUmqVQKHXJEASMQ_AUICigB&biw=1366&bih=613#imgrc=Pd9RDFlT0LbkNM:

Because of air filter devices, police cars in Moses Lake, Wash., appear to be from out of this world.

This illustrates the point State Troopers went to prevent patrol cars from ingesting ash into the engine.

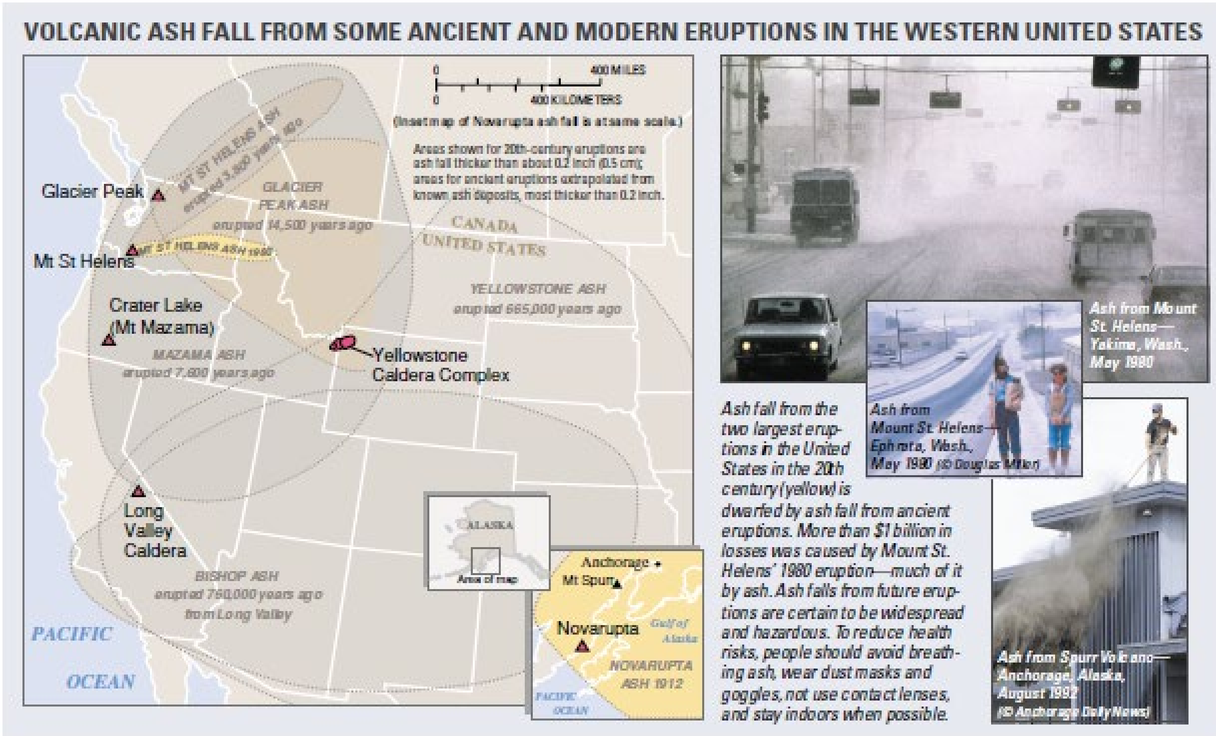
Courtesy of Mount St Helens History.

http://www.mountsthelens.com/history-2.html

Ash dumps will have to be selected prior to ashfall. Areas sited as dumps should be able to hold significant amounts of ash. This motor grader has gathered this amount of ash from one city street.

Courtesy of USGS, 2015

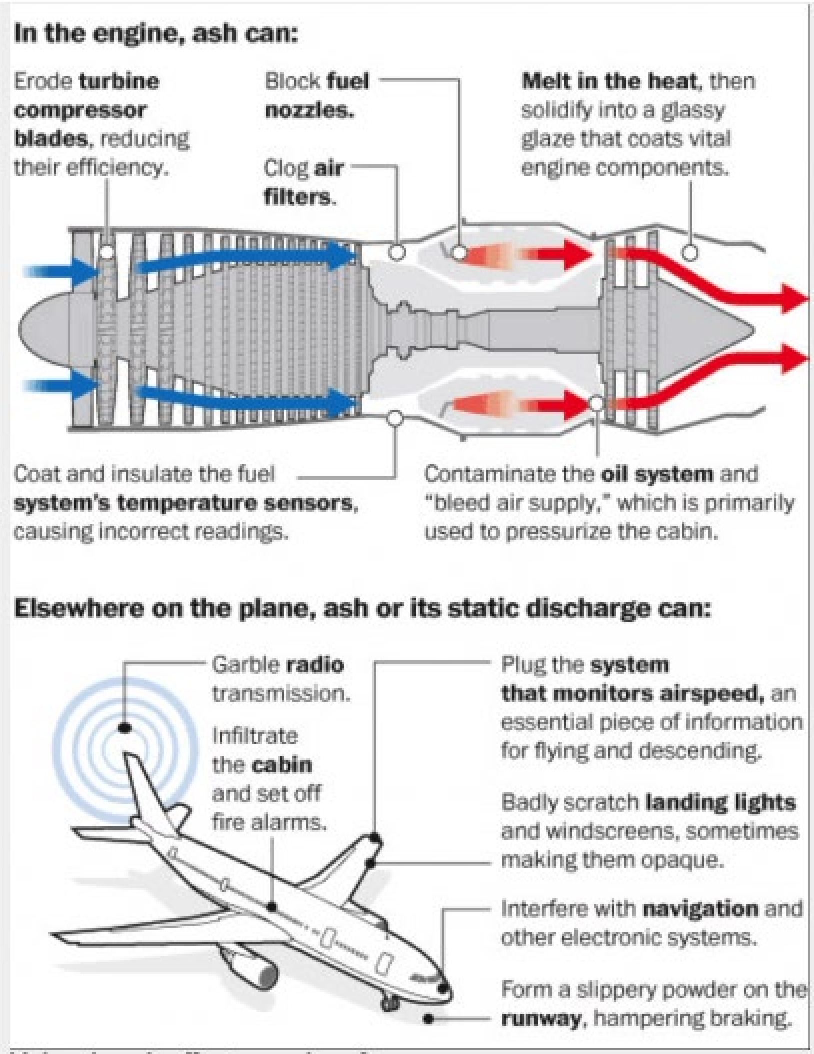
https://volcanoes.usgs.gov/volcanic_ash/ash_removal.html



Should an eruption of this magnitude occur again, the affects would be far reaching, not only to residents in these areas, but all facets of transportation required to move lifesaving FEMA commodities into devastated areas.

Graphic courtesy of United States Geological Survey

https://pubs.usgs.gov/fs/fs027-00/fs027-00.pdf



Volcanic ash effects on aircrafts
Original image can be found at:
http://www.examiner.com/article/mother-nature-one-ups-scientists-no-clear-guidelines-for-air-travel-ash-filled-skies

Abraded windscreen from the Boeing 747 damaged in the December 15, 1989 eruption of Redoubt Volcano. The frosted right side of the glass almost completely obscured the pilots ability to see out; on the left, the clearer, less-abraded side received only glancing blows from ash particles as the plane flew through the ash cloud. This instructive piece of aviation history is housed at the University of Alaska Anchorage in Anchorage.

The danger of flying into airborne ash clouds cannot be understated as pilots risk loss of visibility as ash particles sandblast cockpit windshields.

https://volcanoes.usgs.gov/volcanic_ash/ash_clouds_air_routes_effects_on_aircraft.html