HAZARD + EXPOSURE FACTORS

VOLCANO THREAT ASSESSMENT

VOLCANO RISK WORKSHOP

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Cascades Volcano Observatory, 1300 S.E. Cardinal Ct, Vancouver, Washington

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HAZARD FACTORS

The hazards-ranking schema relies on the Smithsonian's Global Volcanism Program (GVP) volcano reference file as the principal source of the volcano coordinate, volcano type, eruption frequency, and eruption magnitude data.

VOLCANO TYPE (0,1)

Type 0 volcanoes are cinder cones, basaltic volcanic fields, shields, tuff rings, and fissure vents.

Type 1 volcanoes are the generally more explosive stratovolcanoes, lava domes, complex volcanoes, maars, or calderas.

MAXIMUM VEI (SCORED 0-3)

The Volcano Explosivity Index (VEI), defined by Newhall and Self (1982), is a simple 0-8 index of increasing eruptive explosivity, each interval representing an increase of approximately a factor of 10. Owing to uncertainties in assigning VEI estimates to prehistoric or early historic eruptions, and the gradational transition from one VEI level to the next, this system codes VEI designations into 4 scoring categories based mainly on the GVP catalog listings.

- VEI Score 0: VEI ≤ 2 (based on Newhall and Self 1982) receive a 0 because they tend to be short lived and/or not particularly dangerous except in areas close to the vent.
- VEI Score 1: VEI 3-4 (based on Newhall and Self 1982) receive a 1
- VEI Score 2: VEI 5-6 (based on Newhall and Self 1982) receive a score of 2
- VEI Score 3: VEI 7-8 (based on Newhall and Self 1982) receive a score of 3.

If no eruption magnitudes are reported in the literature, Volcano type is used to assign a default score of 0 (for Type 0 volcanoes) or 1 (for Type 1 volcanoes).

EXPLOSIVE ACTIVITY AND MAJOR EXPLOSIVE ACTIVITY (0-1)

These two factors are meant to emphasize particularly active, explosive systems, and de-emphasize systems that may have had major explosive activity at some point in the Holocene, but have changed their eruptive style or have quieted down since (e.g., Crater Lake, Oregon).

ERUPTION RECURRENCE (0,1)

This factor is meant to capture the average time between eruptions, irrespective of explosivity. Eruption recurrence intervals are often bimodal, with clusters of frequent eruptions separated by longer times of quiet (Nathenson, 2001). Because only a limited number of volcanoes have had extensive radiometric dating of eruption products, only 4 broad groupings of recurrence intervals are employed. Although volcanoes with longer eruption recurrence intervals tend to produce more powerful eruptions, this behavior is accounted for in the Explosive activity codes. Large Pleistocene-age silicic caldera systems receive a score of 1 for this factor only if they have demonstrable seismic, deformation and fumarolic unrest.

HOLOCENE PYROCLASTIC FLOWS (0,1)

Pyroclastic flows are one of the most destructive and lethal of volcano hazards. If a system has generated pyroclastic flows in past eruptions, it is deemed capable of producing them again.

HOLOCENE LAHAR (0,1)

This factor is meant to account for large lahars (volcanic debris flows), that traveled beyond the immediate eruption site, beyond the volcanic edifice, and reached now- populated, or potentially-populated areas. As with pyroclastic flows, if a system has generated lahars in past eruptions, it is deemed capable of producing them again.

HOLOCENE LAVA FLOWS (0,1)

This factor flags volcanoes that have produced a lava flow that traveled to populated or potentially populated areas, i.e. some distance beyond the immediate vicinity of the vent.

HOLOCENE TSUNAMI (0,1)

Volcanogenic tsunamis can be generated by several causes. If a tsunami was generated by a sector collapse, and collapses are no longer a factor, then a score of 0 is given. Otherwise, if the tsunami was caused by factors such as explosions through water, dome collapse, or pyroclastic flows, then more may be deemed possible, and a score of 1 is given.

HYDROTHERMAL EXPLOSION POTENTIAL (0,1)

This factor is meant to capture those systems that have evidence of significant Holocene phreatic explosive activity, and/or those systems whose thermal features are extensive enough to pose a potential for explosive activity.

SECTOR COLLAPSE POTENTIAL (0,1)

This factor is probably the most ambiguous in its application. It is limited to stratovolcanoes, and large oceanic shield volcanoes (Kilauea and Mauna Loa, Hawaii). In general if the volcano has more than about 1000 m relief, has active fumaroles, or has large altered areas and/or has a permanent snow and ice cover, and appears steep sided, it was scored positively. If a volcano has a history of sector collapses and has rebuilt its edifice it also received a score of 1. The Alaska Volcano Observatory considers all Aleutian stratovolcanoes that form the bulk of islands or are near the coastlines of islands to have significant collapse potential and these were scored accordingly. This factor can be more rigorously evaluated on a case by case basis if detailed geological and topographical data are available, such as was done for Mount Rainier (Reid and others, 2001).

PRIMARY LAHAR SOURCE (0,1)

Not all volcanoes have been mapped well enough to determine whether or not lahars are part of their history, so this factor considers the key ingredient, water in the form of lakes, rivers and ice on the volcanic edifice. Approximately 106 m3 is the threshold water volume to filter out volcanoes with small lakes and marginal permanent snow cover.

HISTORICAL UNREST FACTORS

Unrest is taken to mean abnormal geophysical activity since the last eruption. The unrest factors apply if the unrest occurred since the last eruption and is ongoing or occurs in fits and starts.

Fumarolic activity and the presence of magmatic gas isotopes in cold springs or vents provide the most persistent signal of unrest or latent magmatic activity. Fumarolic or hot spring activity is easily observed and these phenomena have been widely catalogued through time providing greater confidence that this form of unrest is accurately captured in this study. Seismic and deformation unrest nearly always require instrumental detection, and thus, the number of volcanoes scoring positively for this factor is small because the sample time frame is short.

Globally, there are exceptions where long historical records include reports of persistent felt seismicity near volcanoes in the Mediterranean, Latin America, and Asia, and where deformation that can be tracked by evidence left by apparent changes in sea level on natural and man-made features, but these are rare. Owing to the short time (approximately 30 years) over which we have instrumental observations in the U.S., seismic and deformation unrest at numerous volcanoes is scored as 'not determined' (nd).

SEISMIC UNREST (0,1)

The criterion for scoring this factor is any seismic activity within about 20 km of a volcano. Some volcanoes are larger than 40 km in diameter so some flexibility in the distance is necessary. The only type of seismicity excluded from this code comprises tectonic earthquakes that occur on regional faults not directly related to the volcanic system.

DEFORMATION UNREST (0,1)

This factor is meant to capture those systems that are deforming in response to magma intrusion or that exhibit gross changes in the existing hydrothermal system. Not included are those systems that are only subsiding (e.g., Medicine Lake). Most of the examples of deformation come from either USGS leveling campaigns or InSar surveys, and more systems are likely to be found actively deforming as InSAR data become more extensive and more instruments are deployed globally. Lu and others (2003, and references therein) was the principal source of information for Alaskan volcanoes.

FUMAROLIC OR OTHER MAGMATIC DEGASSING (0,1)

Any fumaroles or thermal features associated with a volcanic system result in a score. Cold degassing of magmatic gases is also included as a positive factor (e.g. carbon dioxide at Long Valley, sulfur/chloride anomalies at South Sister).

EXPOSURE FACTORS

Population potentially at risk on the ground can now be easily estimated through the use of the LandScan population database (Ewert and Harpel, 2004). Infrastructure potentially at risk was coded using map data at various scales (e.g., Federal lands at 1:2M, http://nationalatlas.gov/atlasftp.html), and Heiken and others (1995) for power generation/transmission. A volcano's proximity to airports was determined using a U.S. Department of Transportation Master Coordinate Table for airports (http://www.transtats.bts.gov). Regional aviation risk is based primarily on passenger counts and does not take into account the significant amount of freight traffic flying the North Pacific or other air routes. Much more work needs to be done to better quantify the number of planes and passengers traversing volcanic regions and the aviation numbers reported here are minimums.

Exposure to tephra fall hazards beyond the immediate vicinity of the volcano are not considered here though more people are adversely affected by airfall tephra than any other volcanic phenomena. Where tephra falls beyond the immediate vicinity of the volcanic edifice is determined by the vicissitudes of wind velocity and direction, and estimating the numbers of persons that would be potentially affected by this phenomena is beyond the scope of this study.

VPI30 (0 TO X)

This code is the log10 of the population within 30 km radius circle of a volcano. The LandScan 2002 database (http://www.ornl.gov/sci/gist/landscan/) produced by the Oak Ridge National Laboratory is used in conjunction with coordinate data from the GVP reference file to calculate the number of people within 30 km. The 30 km distance was chosen for several reasons: 1) population distributions near volcanoes vary greatly with latitude and 30 km appears to catch proximal population in all regions, 2) data in Newhall and Hoblitt (2002) show that for VEI 4-5 (for many systems the likely worst case) eruptions, a pyroclastic flow has a small but significant (approximately 5 percent) chance of exceeding 30 km distance from the vent, 3) data from Newhall and Hoblitt (2002) also indicate an that the probability of tephra accumulations exceeding 10 cm at 30 km downwind are about 10 percent for a VEI 3 eruption, and about 80% for VEI ≥4. Pyroclastic flows are a lethal hazard, and accumulation of several centimeters of tephra has adverse effects on surface transportation, electric power distribution, surface water supplies, etc. A 10 cm accumulation volcanic ash, particularly if it is wet, is the threshold beyond which structural damage to buildings begins. Thus, this index estimates how many persons on the ground may be subject to serious (life-threatening) effects.

In volcanic fields which consist of numerous vents dispersed over large areas, the VPI30 estimate is taken from the single GVP coordinate for the field, which approximates the geometric center of the entire field (Simkin and Siebert, 1994).

LOG10 OF APPROXIMATE POPULATION DOWNSTREAM OR DOWNSLOPE, OUTSIDE THE 30 KM VPI CIRCLE (0-X)

This factor is used only with volcanoes that have a primary lahar hazard (e.g., Cascade or Alaskan stratovolcanoes) or significant lava flow hazard (e.g., Mauna Loa) that extends farther than 30 km from vent areas. Where digital volcano hazards maps exist as Geographic Information System (GIS) layers, the flowage hazard zones outside the 30 km VPI circle were overlain on the LandScan 2002 to estimate this factor. These calculations were made for Kilauea, Mauna Loa, Mauna Kea, Hualalai, Mount Baker, Glacier Peak, Mount Rainer, Mount St. Helens, Mount Adams, Mount Hood, South Sister, Crater Lake, and Newberry Volcano.

Estimates were made for Mount Shasta and Lassen Peak by USGS volcanologists familiar with the hazards and geography of these areas (Michael A. Clynne, oral communication, 2004). This methodology has not yet been applied to Alaskan volcanoes, though given the generally sparse population in the volcanic regions of Alaska, this factor will probably not change the overall threat rankings significantly.

HISTORICAL FATALITIES (0,1)

If there were fatalities at a volcano in the past and a permanent, population is still present, chances are good that fatalities may happen again.

HISTORICAL EVACUATIONS (0,1)

If there were evacuations at a volcano in the past and a permanent, population is still present, chances are good that evacuations may be imposed again.

LOCAL AVIATION EXPOSURE (0-2)

Local threats to aviation by volcanoes are principally to airports. The authors reviewed a database on effects of volcanic activity on airports (Guffanti and others, 2003) and found that 75 percent of airports adversely affected by volcanic activity were all within 300 km of the erupting volcano, while those affected solely by basaltic-type eruptions were generally within 50 km. To quantify airport exposure the following scoring criteria are used: If any type volcano is within 50 km of a jet-service airport it gets a score of 1; if a Type 1 volcano (generally explosive potential) is within 300 km of a jet-service airport it gets a score of 1; if a Type 1 volcano is within 300 km of a major international airport it gets a score of 2; if none of these criteria are met the volcano gets a score of 0. Jet service airports used were: Adak, Cold Bay, Sitka, Petersburg/Wrangel, Ketchikan, Sun Valley, Idaho Falls, Jackson Hole, Reno, Mammoth, Albuquerque, Klamath Falls, Medford, Bend-Redmond, Salt Lake City, Phoenix, Sacramento, and Aspen. All Type 1 volcanoes in the conterminous U.S. are within 300 km of a jet service airport. Major international airports used were: Anchorage, Fairbanks, Seattle/Tacoma, Portland.

REGIONAL AVIATION EXPOSURE = LOG10 OF DAILY PASSENGER COUNT (0-X)

This is one of the more difficult exposure factors to quantify. Information on how many jet aircraft and passengers traverse a volcanic area in a given time period are not easily available. As a starting point, the authors used the airport statistics available from the US D.O.T. (2001) for the principal airports located in or near volcanic areas (Anchorage, Fairbanks, Seattle-Tacoma, Portland, Sacramento, San Francisco, Honolulu, Hilo, Kona, Maui, Guam, and Saipan). These statistics give the number of enplaned (departing) passengers per year. Checking statistics in individual port annual reports generally confirms the DOT statistics and indicates that the approximate numbers of departing and arriving passengers can be obtained by multiplying the enplaned passengers by two. Air cargo flights are not included in this factor, though for the North Pacific routes these are an important part of the aviation exposure.

Passengers per day for US volcanic regions were estimated in the following manner: For the Washington and Oregon Cascades, the daily number of passengers reported for Seattle-Tacoma and Portland airports were added. In all cases the log10 of the daily passenger counts was used as the regional aviation risk code. The regional code is applied only to Type 1 volcanoes and those Type 0 volcanoes that have a history of producing explosive eruptions. The numbers are minimums, but the relative scores appear appropriate relative to one another.

POWER INFRASTRUCTURE (0,1)

Power generation, transmission, or distribution within 30 km or within flowage hazard zone (e.g., power generation/transmission for electricity, oil, or gas), or a generation facility in the area typically downwind of the volcano get a score of 1 for this factor. Heiken and others (1995) are the main data source for this factor. Small distribution lines to a few cabins were not counted as "infrastructure", but distribution lines within a town or city downwind were.

TRANSPORTATION INFRASTRUCTURE (0,1)

Port facilities, rail lines, and major roads are included, and for this study state highways and interstate highways were considered major roads. In addition, as civil aviation is a critical mode of transportation in Alaska, Type 1 volcanoes near heavily used air traffic corridors received a point. Alaskan volcanoes that received this score were Mount Spurr, Mount Redoubt, and Augustine Volcano.

MAJOR DEVELOPMENT OR SENSITIVE AREA (0,1)

This factor is meant to cover economically and symbolically important places, things, and activities. If a volcano is within a developed national park, it got a point. A volcano in a national park may also threaten developed areas outside park boundaries. Other examples that were counted as positives for this factor are ski areas on Cascade volcanoes and the fish packing plant at Akutan in the Aleutians.

VOLCANIC ISLAND (0,1)

Experience with eruptions on small populated islands over the past 100 years demonstrates the particular difficulty in mitigating volcano hazards in such situations. A volcano making up a significant portion of an island poses higher risk because islands are difficult to evacuate. This factor is only applied to islands with a permanent population.

LEVEL OF MONITORING

These guidelines are used to characterize both current and future (desired) monitoring levels. For each volcano, the main monitoring methods (seismic, deformation, gas, hydrologic, remote- sensing) are rated on a scale of 0-4. Then an overall rating is given, also using a 0-4 scale.

Seismic pertains to real-time stations. Remote sensing pertains to airborne, satellite, and/or ground based instruments that are independent of airborne gas measurements and satellite- based InSAR. The seismic rating strongly influences the overall rating; for any volcano, the overall rating cannot be higher than its seismic rating. For each volcano, six numbers are assigned (see Appendix 5): a number for the level of each of the five monitoring techniques (seismic, deformation, gas, hydrologic, and remote-sensing) and a number for the overall level of monitoring.

LEVEL 0: NO GROUND-BASED MONITORING

No real-time data from ground-based sensors are available. Eruption confirmation (up to hours after the fact) is provided only by remote-sensing data or from people observing the event.

LEVEL 1: MINIMAL MONITORING

Monitoring provides the ability to detect that an eruption is occurring or that gross changes are occurring/have occurred near a volcano. Data are not collected systematically or at very long intervals (e.g., >5 years).

Seismic
Volcano lies within a regional network; no near-field stations are in place but at least one station is within 50 km of the volcano. (Example: Crater Lake). Or, a single near-field station is present, but no regional network exists. (Example, Sarigan).

Deformation
Geodetic benchmarks and baseline measurements exist for detection of deformation via repeated surveys at multiple-year intervals. (Example: Shasta). Or, coherent InSAR interferogram(s) exist(s).

Gas
Airborne or campaign gas measurements are done rarely as an infrequent reconnaissance check for anomalous degassing.

Hydrologic
Inventory exists of temperature and major chemistry of fumaroles, thermal, and slightly thermal springs and wells. Where lahar potential exists, study of past lahars and debris flows has been conducted, including as appropriate, estimation of extent of hydrothermal alteration and estimates of slope stability.

Remote sensing
Baseline inventory exists of Landsat-class (15-30 m resolution) satellite images. Routine scans for eruption clouds are conducted by meteorological agencies.

LEVEL 2: LIMITED MONITORING FOR CHANGE DETECTION

Monitoring provides the ability to detect and track activity frequently enough in near-real time to recognize that something anomalous is occurring.

Seismic

Volcano lies within a regional network and 1-2 near-field (within ~10 km of volcano) stations are in place. (Examples: Hood, Lassen).

Deformation

Geodetic network exists, with baseline established by two or more surveys. InSAR observations are possible on a summer-to-summer basis. At least three continuous stations (GPS or tiltmeters are operating in the vicinity of the volcano. The combination of techniques enables tracking of geodetic unrest in space and time at a minimal level. (Example: Three Sisters).

Gas

Repeated airborne or campaign gas measurements have been conducted to establish a baseline of carbon dioxide emission rate (or other gas as appropriate to the volcano) for identification of significant changes in degassing.

Hydrologic

Comprehensive temperature, chemical, and isotopic database exists on gases and waters, with scheduled re-sampling of selected features. Scheduled measurements are taken of stream discharge, sediment transport, if appropriate, along with annual max-min estimates of snow and ice cover. Water levels in wells that respond to strain events are recorded.

Remote sensing

Regular processing and review of near-real-time meteorological satellite images (AVHRR, GOES), and/or review of non-real-time research satellite images (e.g., MODIS) is done by an observatory. Baseline inventory exists of air photos and/or satellite images with high spatial resolution (1 m).

LEVEL 3: BASIC REAL-TIME MONITORING

Monitoring provides the ability detect and track pre-eruptive and eruptive changes in real-time, with a basic understanding of what is occurring.

Seismic

Volcano network includes 3-4 near-field stations and a total of at least six within 20 km of vent. The volcano may or may not be within regional network. Network may or may not have a single three-component instrument. (Examples: Rainier, Redoubt)

Deformation

Geodetic network exists, and surveys are routinely repeated. At least six continuous stations (GPS and/or tiltmeters) are operating in the vicinity of the volcano. This enables tracking of geodetic unrest in space and time and source modeling at a basic level. LIDAR-derived images are available for active features. (Example: St. Helens).

Gas

Airborne or campaign measurements of gas emissions are done frequently (annually to monthly, as appropriate), with support of 1-2 telemetered continuous monitoring installations. Less frequent plume measurements are supplemented by ground-based instruments.

Hydrologic
Level-2 coverage is available along with continuous-sensing probes deployed in features of primary interest, including water wells. LIDAR-derived DEMs are available for lahar- runout modeling.

Remote sensing
Level 2 capability plus routine use of multi-channel thermal-infrared data from an ASTER-class satellite. Airborne thermal and/or SAR overflights, are conducted as indicated by other monitoring data. Where practicable, remote video camera is in operation.

LEVEL 4: WELL-MONITORED
Monitoring provides the ability to track detailed changes in real-time and to develop, test, and apply models of ongoing and expected activity.

Seismic
12-20 stations are in place within 20 km of vent; including several near-field sites. Network includes numerous three-component instruments and a mix of other instrument types, including several digital broadband stations, acoustic sensors, and accelerometers. Borehole instruments are used where practicable. (Examples: Long Valley, Kilauea)

Deformation
Geodetic surveys are routine, and sufficient continuous stations (GPS, tiltmeters, and/or dilatometers) are installed to track closely geodetic unrest in space and time and do detailed source modeling to help distinguish among alternative mechanisms. (Examples: Long Valley, Kilauea)

Gas
Airborne or campaign gas measurements done frequently. A continuous monitoring array of several stations and other types of gas measurements (including DOAS) is deployed as appropriate for the volcano to enable quick identification of key geochemical changes.

Hydrologic
Level-3 coverage is available along with real-time monitoring of hill-slope soil moisture, stream discharge, etc. as appropriate. AFM systems are installed, where warranted, and supported by models predicting lahar size and area of impact.

Remote sensing
Level 3 coverage is available along with other data from all pertinent satellite sensors (e.g., daily multi-channel, high-resolution thermal-infrared images and frequent, high resolution, multi-channel visible images). Where practical, continuous ground-based thermal imaging and Doppler radar coverage is available for ash detection and eruption-rate estimates.

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