# Appendix B – Region 12

## Country and regional profiles of volcanic hazard and risk:

## Canada and Western U.S.A.

**S.K. Brown[1], R.S.J. Sparks[1], K. Mee[2], C. Vye-Brown[2], E.Ilyinskaya[2], S.F. Jenkins[1], S.C. Loughlin[2*]**

[1]University of Bristol, UK; [2]British Geological Survey, UK, * Full contributor list available in Appendix B Full Download

This download comprises the profiles for Region 12: Canada and Western U.S.A. only. For the full report and all regions see Appendix B Full Download. Page numbers reflect position in the full report. The following countries are profiled here:



Brown, S.K., Sparks, R.S.J., Mee, K., Vye-Brown, C., Ilyinskaya, E., Jenkins, S.F., and Loughlin, S.C. (2015) Country and regional profiles of volcanic hazard and risk. In: S.C. Loughlin, R.S.J. Sparks, S.K. Brown, S.F. Jenkins & C. Vye-Brown (eds) *Global Volcanic Hazards and Risk,* Cambridge: Cambridge University Press.

## Region 12: Canada and Western USA

***Description***

Region 12: Canada and Western USA comprises volcanoes throughout Canada and the contiguous states of the USA.

| Country | Number of volcanoes |
|---|---|
| Canada | 22 |
| USA | 48 |

*Table 12.1 The countries represented in this region and the number of volcanoes. Volcanoes located on the borders between countries are included in the profiles of all countries involved. Note that countries may be represented in more than one region, as overseas territories may be widespread.*

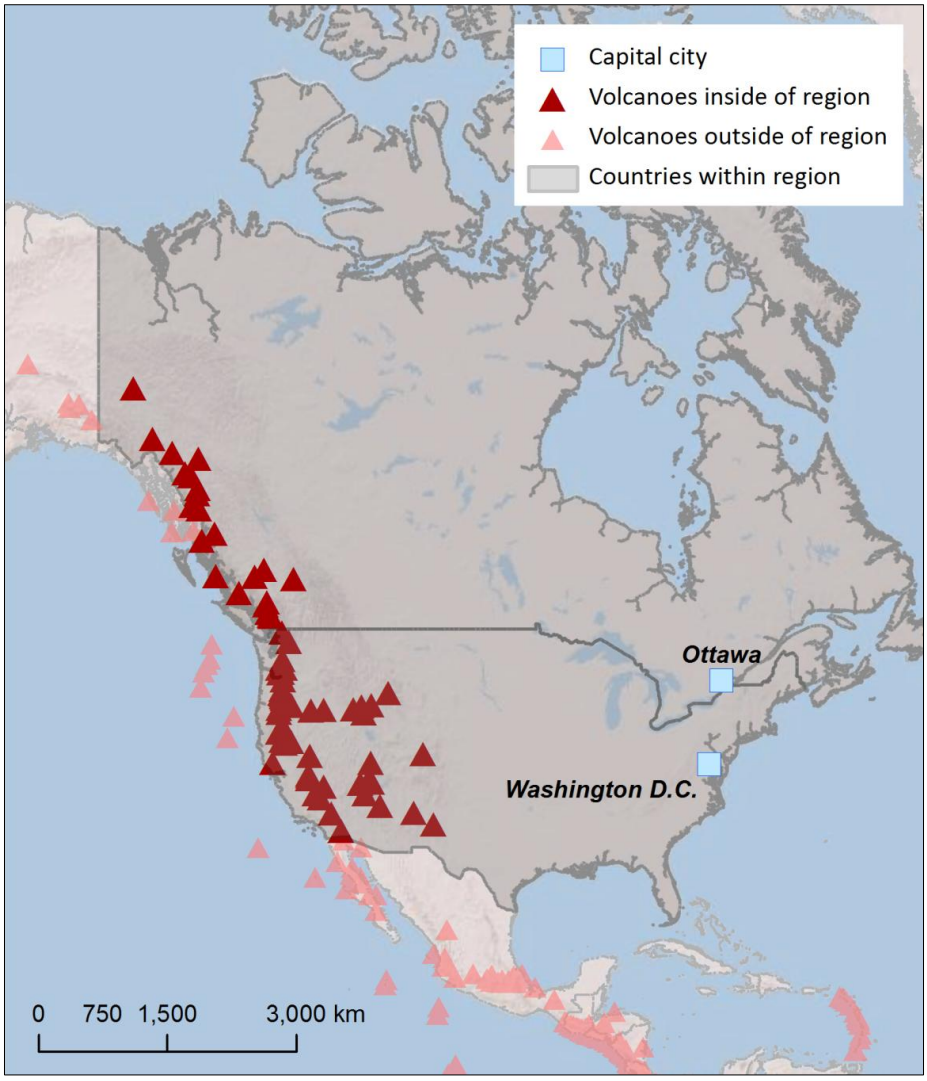


*Figure 12.1 The distribution of Holocene volcanoes through the Canada and Western USA region. The capital cities of the constituent countries are shown.*

Seventy Holocene volcanoes are located in Canada and the Western USA. Most of these volcanoes are in Washington, Oregon and California in the USA. Volcanism here is largely related to the

subduction of the Juan de Fuca Plate beneath the North American Plate. Further north a range of tectonic environments give rise to volcanism, including subduction, rifting and intra-plate processes. Much of the volcanism of the western interior is due to extensional tectonics.

Volcanoes in this region adopt a variety of forms, with volcanic fields and cinder cones being most common (41 such volcanoes). Large cones are also common, with 16 stratovolcanoes and complex volcanoes, primarily found in the USA. Shields, lava domes, calderas and subglacial volcanoes are also located here. The rock type through this region is dominantly basaltic and andesitic, though a range of compositions is present, including silicic rhyolites, chiefly restricted to the western interior of the USA.

Along with volcano morphology and composition, a range of activity styles and eruption magnitudes are recorded through the Holocene, with eruptions of VEI 0 to 7. About 66% of eruptions here have been small, at VEI 0 to 2, however 23 eruptions (about 18%) have been large explosive VEI ≥4 events. All but one of these VEI ≥4 eruptions are recorded from volcanoes in the USA. The largest Holocene eruption recorded in this region was the VEI 7 eruption of Crater Lake in about 5677 BC, which produced ash fall into Canada and pyroclastic flows that travelled 40 km.

Eleven volcanoes have historical records of 40 eruptions, about 70% of which were recorded through direct observations. The record of over 200 eruptions before 1500 AD indicates a reasonable geological record, reflecting geological studies here. 23% of historical eruptions have records of producing pyroclastic flows, one of the highest proportions in any region. Similarly, about 30% resulted in lahars. Lava flows are also recorded in 23% of eruptions, though many regions have a greater proportion.

8% of historical eruptions resulted in loss of life. Most volcanoes here have low proximal populations, and as such are considered relatively low risk. However, the hazard is unclassified at about 85% of volcanoes.

In the USA the U.S. Geological Survey runs a series of Volcano Observatories monitoring the activity here, undertaking scientific research and providing advice and alerts. In Canada, Natural Resources Canada is responsible for the volcanic hazard, however no volcanoes here have dedicated monitoring systems, though plans and resources are available if unrest occurs.

***Volcano Facts***

| | |
|---|---|
| Number of Holocene volcanoes | 70 |
| Number of Pleistocene volcanoes with M≥4 eruptions | 14 |
| Number of volcanoes generating pyroclastic flows | 14 (65 eruptions) |
| Number of volcanoes generating lahars | 12 (59 eruptions) |
| Number of volcanoes generating lava flows | 45 (117 eruptions) |
| Number of eruptions with fatalities | 4 |
| Number of fatalities attributed to eruptions | 84 |

| | |
|---|---|
| Largest recorded Pleistocene eruption | The largest Quaternary eruption recorded was the M8.4 Lava Creek Tephra eruption at Yellowstone at 639 ka. |
| Largest recorded Holocene eruption | The largest recorded Holocene eruption in LaMEVE in this region is the O (Caldera) formation at Crater Lake, at M6.8 in 7627 BP. |
| Number of Holocene eruptions | 245 confirmed Holocene eruptions |
| Recorded Holocene VEI range | 0 – 7 and unknown |
| Number of historically active volcanoes | 11 |
| Number of historical eruptions | 40 |

| Number of volcanoes | Primary volcano type | Dominant rock type |
|---|---|---|
| 3 | Caldera(s) | Andesitic (1), Dacitic (1), Rhyolitic (1) |
| 15 | Large cone(s) | Andesitic (10), Dacitic (4), Trachytic / Andesitic (1) |
| 5 | Lava dome(s) | Rhyolitic (4), Trachytic / Andesitic (1) |
| 10 | Shield(s) | Andesitic (2), Basaltic (6), Rhyolitic (1), Trachytic / Andesitic (1) |
| 36 | Small cone(s) | Andesitic (3), Basaltic (31), Dacitic (2) |
| 1 | Subglacial | Phonolitic (1) |

*Table 12.2 The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.*

***Eruption Frequency***

| VEI | Recurrence Interval (Years) |
|---|---|
| Small (< VEI 4) | 10 |
| Large (> VEI 3) | 170 |

*Table 12.3 Average recurrence interval (years between eruptions) for small and large eruptions in Canada and Western USA.*

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about 10 years, whilst the ARI for large eruptions is longer, at about 170 years.

***Eruption Size***

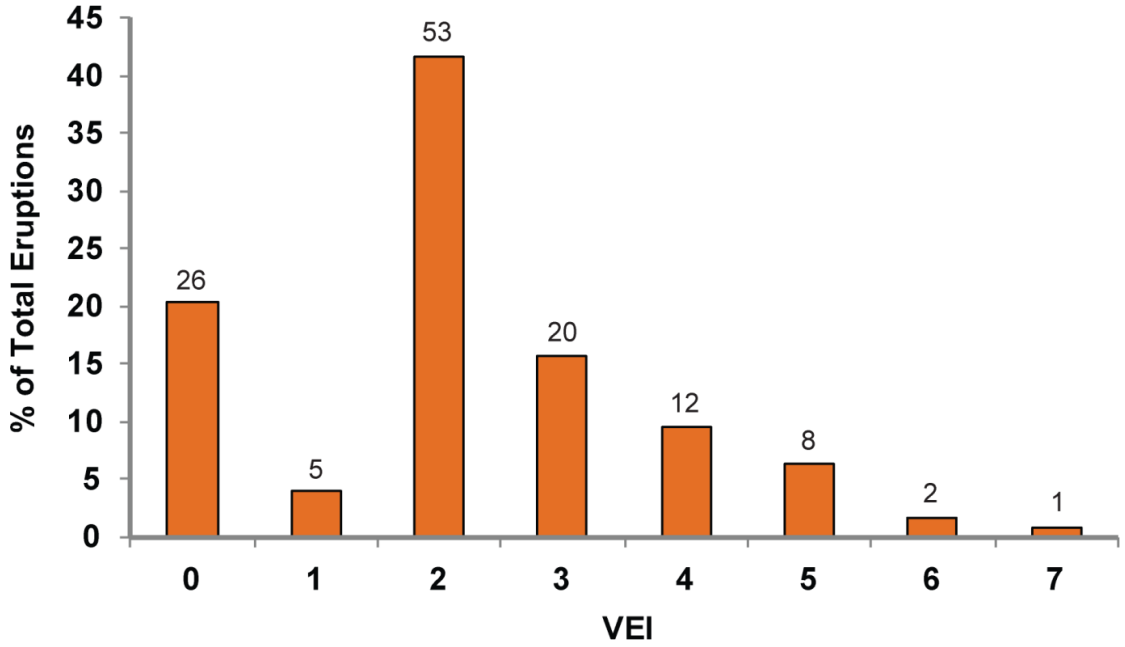


*Figure 12.2 Percentage of eruptions in this region recorded at each VEI level; the number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 118 eruptions were recorded with unknown VEI.*

Eruptions are recorded through the Canada and Western USA region of VEI 0 to 7, representing a range of eruption styles from gentle effusive events to very large explosive eruptions. VEI 2 events dominate the record, with nearly 45% of all Holocene eruptions classed as such. Over 18% of eruptions here are explosive at VEI ≥4.

***Socio-Economic Facts***

| | |
|---|---|
| Gross Domestic Product (GDP) per capita (2005 PPP $) | 35,716 – 42,486 (Mean 39,101) |
| Gross National Income (GNI) per capita (2005 PPP $) | 35,369 – 43,480 (Mean 39,425) |
| Human Development Index (HDI) (2012) | 0.911 – 0.937 (Very High) |

***Population Exposure***

| | |
|---|---|
| Number (percentage) of people living within 10 km of a Holocene volcano | 24,610 (0.01 %) |
| Number (percentage) of people living within 30 km of a Holocene volcano | 375,305 (0.11 %) |
| Number (percentage) of people living within 100 km of a Holocene volcano | 4,187,725 (1.22 %) |

***Infrastructure Exposure***

| | |
|---|---|
| Number of airports within 100 km of a volcano | 102 |
| Number of ports within 100 km of a volcano | 49 |
| Total length of roads within 100 km of a volcano (km) | 29,259 |
| Total length of railroads within 100 km of a volcano (km) | 8,443 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **CLASSIFIED** | **Hazard III** | | Shasta | Rainier; St. Helens | | | | |
| | **Hazard II** | | | Baker | | | | |
| | **Hazard I** | | Adams; Sand Mountain Field; Three Sisters; Newberry; Medicine Lake; Craters of the Moon | | | | | |
| | | | | | | | | |
| **UNCLASSIFIED** | **U – HHR** | | **Lassen Volcanic Center;** Mono Lake Volcanic Field; Iskut-Unuk River Cones; Tseax River Cone; Wells Gray-Clearwater | Glacier Peak; **Hood** | | | | |
| | **U- HR** | | Jefferson; Blue Lake Crater; Belknap; Bachelor; Davis Lake; Crater Lake; Diamond Craters; Jordan Craters; Mono Craters; Ubehebe Craters; Golden Trout Creek; Shoshone Lava Field; Wapi Lava Field; Hell's Half Acre; **Yellowstone**; Markagunt Plateau; Carrizozo; Zuni-Bandera; Uinkaret Field; Edziza; Hoodoo Mountain; Nazko; Meager | West Crater; Indian Heaven; Inyo Craters; **Mammoth Mountain;** Salton Buttes; Black Rock Desert; Dotsero; Garibaldi | San Francisco Volcanic Field | | | |
| | **U- NHHR** | **Cayley Volcanic Field** | Devils Garden; Cinnamon Butte; Silver Lake; **Coso Volcanic Field;** Fort Selkirk; Alligator Lake; Atlin Volcanic Field; Tuya Volcanic Field; Heart Peaks; Level Mountain; Spectrum Range; Crow Lagoon; Milbanke Sound Group; Satah Mountain; Silverthrone; Bridge River Cones | Lavic Lake | Soda Lakes; Garibaldi Lake | Clear Lake | | |
| | | **PEI 1** | **PEI 2** | **PEI 3** | **PEI 4** | **PEI 5** | **PEI 6** | **PEI 7** |

*Table 12.4 Identity of the volcanoes in this region in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

***Population Exposure Index***

| Number of Volcanoes | Population Exposure Index |
|---|---|
| 0 | 7 |
| 0 | 6 |
| 1 | 5 |
| 3 | 4 |
| 14 | 3 |
| 51 | 2 |
| 1 | 1 |

*Table 12.5 The number of volcanoes in Canada and Western USA classed in each PEI category.*

***Risk Levels***

| Number of Volcanoes | Risk Level |
|---|---|
| 0 | III |
| 4 | II |
| 6 | I |
| 60 | Unclassified |

*Table 12.6 The number of volcanoes in the Canada and Western USA region classified at each Risk Level.*

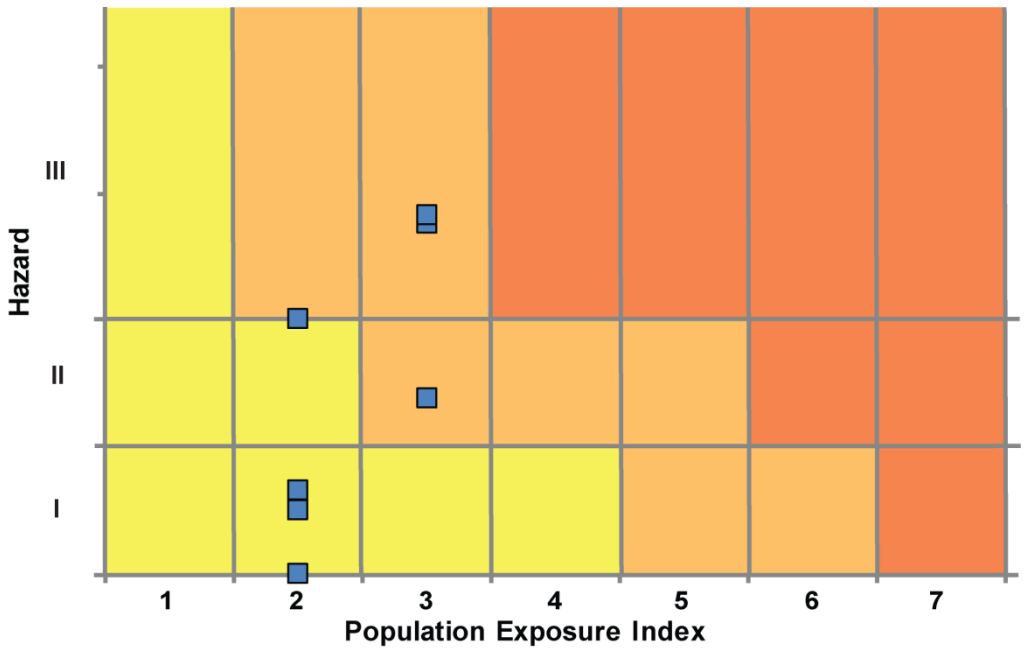


*Figure 12.3 Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.*

***Regional monitoring capacity***

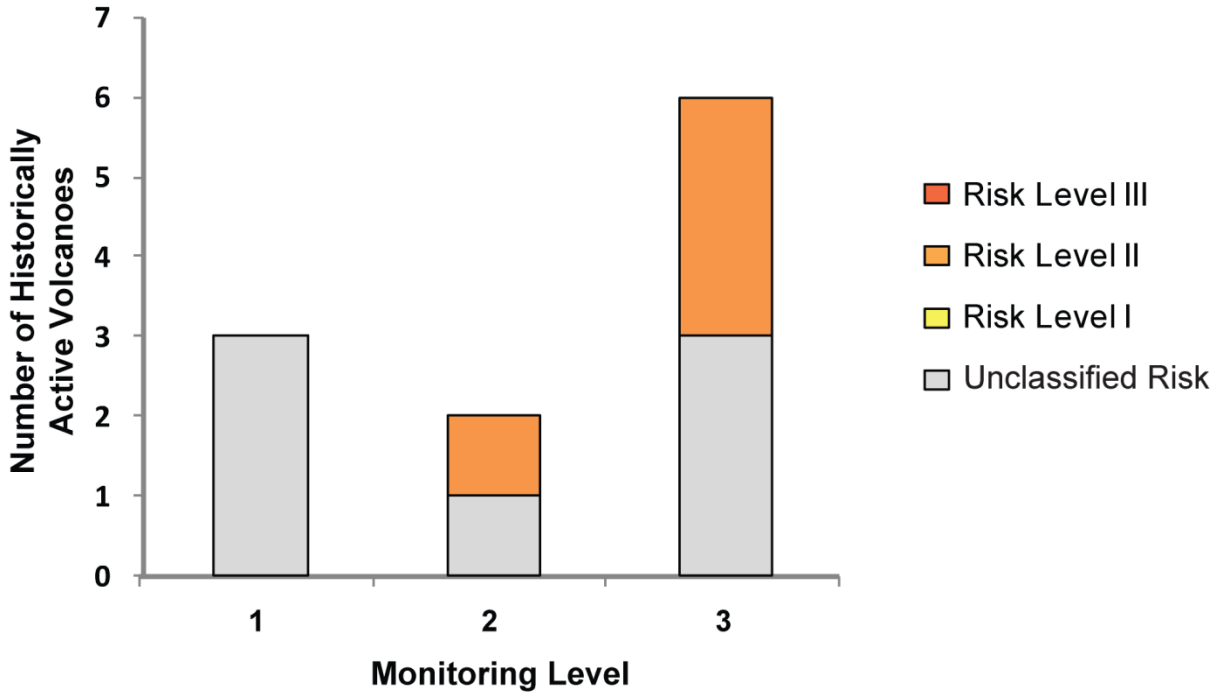


*Figure 12.4 The monitoring and risk levels of the historically active volcanoes in Canada and the Western USA. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.*

# Canada

***Description***

Twenty-two volcanoes of Holocene age are listed by the GVP in western Canada, all in British Columbia and the Yukon Territory, from the border with Washington State (USA) in the south to Alaska (USA) in the north. Many of these volcanoes are volcanic fields comprising dozens of vents over thousands of square kilometres. Volcanism in Canada arises through compressional, subduction zone processes between the North American Plate and the Juan de Fuca Plate, and crustal extension within the North American Plate; intra-plate hotspot volcanism may also play a role. The range of origins for volcanism here results in a correspondingly large range of volcano morphologies and magma compositions. Although a number of stratovolcanoes are located in Canada, volcanic fields comprising many small discrete centres are the most common form of volcanism in Canada.

During the Holocene nineteen eruptions are recorded from eight volcanoes in VOTW4.22, however if eruptions from individual vents are considered then this number is far greater. It is highly probable that many more Canadian volcanoes have had Holocene activity, but this has not been confirmed quantitatively. Recorded activity ranges from VEI 0 to 5, indicating a range from small effusive activity to large explosive activity, however the size of most eruptions is unknown.

The largest Holocene eruption of VEI 5 occurred at the stratovolcano Mount Meager in 410 BC. This large explosive eruption generated pyroclastic flows, lahars, and lava domes, and the formation and failure of a dam made of welded pyroclastic material, with an accompanying flood. Ash was distributed across British Columbia and neighbouring Alberta. Hot springs are active at Mount Meager, indicative of an ongoing heat source. A debris avalanche, not of volcanic origin, occurred at this volcano in 2010, with debris extending to nearly 13 km, damming rivers and leading to the evacuation of 1500 residents, resulting in about costs of about $10m CAD (Guthrie et al., 2011).

Historical activity has occurred at only one volcano, Tseax Cone, and is recorded in the oral histories of the Nisga'a people. The ~ AD 1700 eruption of Tseax River cone produced lavas which inundated a village. Evacuations, property damage, and fatalities occurred. Several other eruptions have occurred in the last few centuries and are documented geologically but not historically, probably due to the isolation of the volcanoes.

Despite the number of volcanoes in Canada, the exposed population is relatively small with much of the population, and therefore infrastructure, concentrated in the south of Canada, towards the border with the United States. Much of the Greater Vancouver Regional District lies within 100 km of Mount Baker (Washington State, USA) and the southernmost Canadian volcano, Garibaldi, however most volcanoes in Canada have a very low proximal population within 30 km. No detailed risk assessments have been undertaken for any Canadian volcanoes by the Geological Survey of Canada. All Canadian volcanoes have considerable uncertainty associated with the assessment of hazard, and research is needed to better understand the eruptive history.

Natural Resources Canada (NRCan) is the agency responsible for the provision of technical and scientific information regarding volcanic unrest, hazard and eruptions affecting Canada. The

Geological Survey of Canada (GSC) is part of NRCan, and is funded by the federal government. There is currently no dedicated ground-based monitoring at any of the Canadian volcanoes, however a national seismic network is in place, monitored by NRCan. A seismologist is always on-call, and would be alerted to earthquakes of M≥3 detected through the continuous and automatic monitoring network. Small earthquakes and swarms near volcanoes might not be noticed by the seismologist on-call until the visual inspection of all data the next working day. Should seismic unrest be detected via this network, NRCan would respond by augmenting monitoring, as the resources are available to respond to developing situtations.

The most recent eruption in Canada took place around 1800 at the Lava Fork volcano in the Iskut-Unuk River cones. As such, no current employees at NRCan have experience in responding to an eruption. However, in 2007 an earthquake swarm occurred in the Nazko region, near Nazko cone. NRCan responded with additional monitoring and provided advice regarding the probable activity styles were an eruption to occur, and a preliminary volcanic hazard map was produced from existing data. Many of the personnel involved in the response to this swarm are still at NRCan.

NRCan has set protocols and plans in place to respond to increasing unrest and eruptions. The Interagency Volcanic Event Notification Plan (IVENP) would be activated at the onset of an eruption in Canada. IVENP is a short-term communications plan that outlines the rapid notification procedures among the key Canadian agencies that would be involved in the response to a volcanic eruption within or near Canada; it is a communications plan, not a response plan. IVENP's primary objective is to ensure that volcanic ash information for Canada is rapidly and appropriately communicated to aviation agencies. Natural Resources Canada's Standard Operating Procedure: Volcanic Situations details the NRCan protocols for volcanic unrest and eruptions. During volcanic unrest or eruption, Natural Resources Canada would communicate with numerous agencies involved in public safety and scientific research. This would include (but would not be limited to) the agencies involved in Canada's Interagency Volcanic Event Notification Plan (IVENP): Environment Canada (which includes the Volcanic Ash Advisory Centre in Montréal), Public Safety Canada, Emergency Management British Columbia, the Airline Pilots Association, Nav Canada, the Royal Canadian Mounted Police (RCMP), Transport Canada, and the Yukon Emergency Measures Organization. There would also likely be extensive communications with specific organizations or stakeholders in the region of unrest.

No specific Alert Level system has been developed for use in Canada due to the absence of recent activity. NRCan plans to use the U.S. Geological Survey's Volcano Alert Levels and Aviation Colour Codes in the event of unrest.

The public is exposed to hazard education in volcanic regions provided by Public Safety Canada, Emergency Preparedness British Columbia, and the Yukon Emergency Measures Organization, who work closely with NRCan in dealing with potential volcanic hazards. NRCan provides hazard information to the public through research publications, fact sheets, books, maps, brochures, etc. In addition, NRCan engages with the public through school visits, meetings, and conferences, and the Geological Survey of Canada includes publicly-accessible libraries and bookstores.

**See also:**

Guthrie, R.H., Friele, P., Allstadt, K., Roberts, N., Evans, S.G., Delaney, K.B., Roche, D., Clague, J.J., and Jakob, M. (2011). The 6 August 2010 Mount Meager rock slide-debris flow, Coast Mountains, British Columbia: characteristics, dynamics, and implications for hazard and risk assessment. *Natural Hazards and Earth System Sciences*, 12, 1277-1294.

Natural Resources Canada website: [www.nrcan.gc.ca/home](www.nrcan.gc.ca/home)

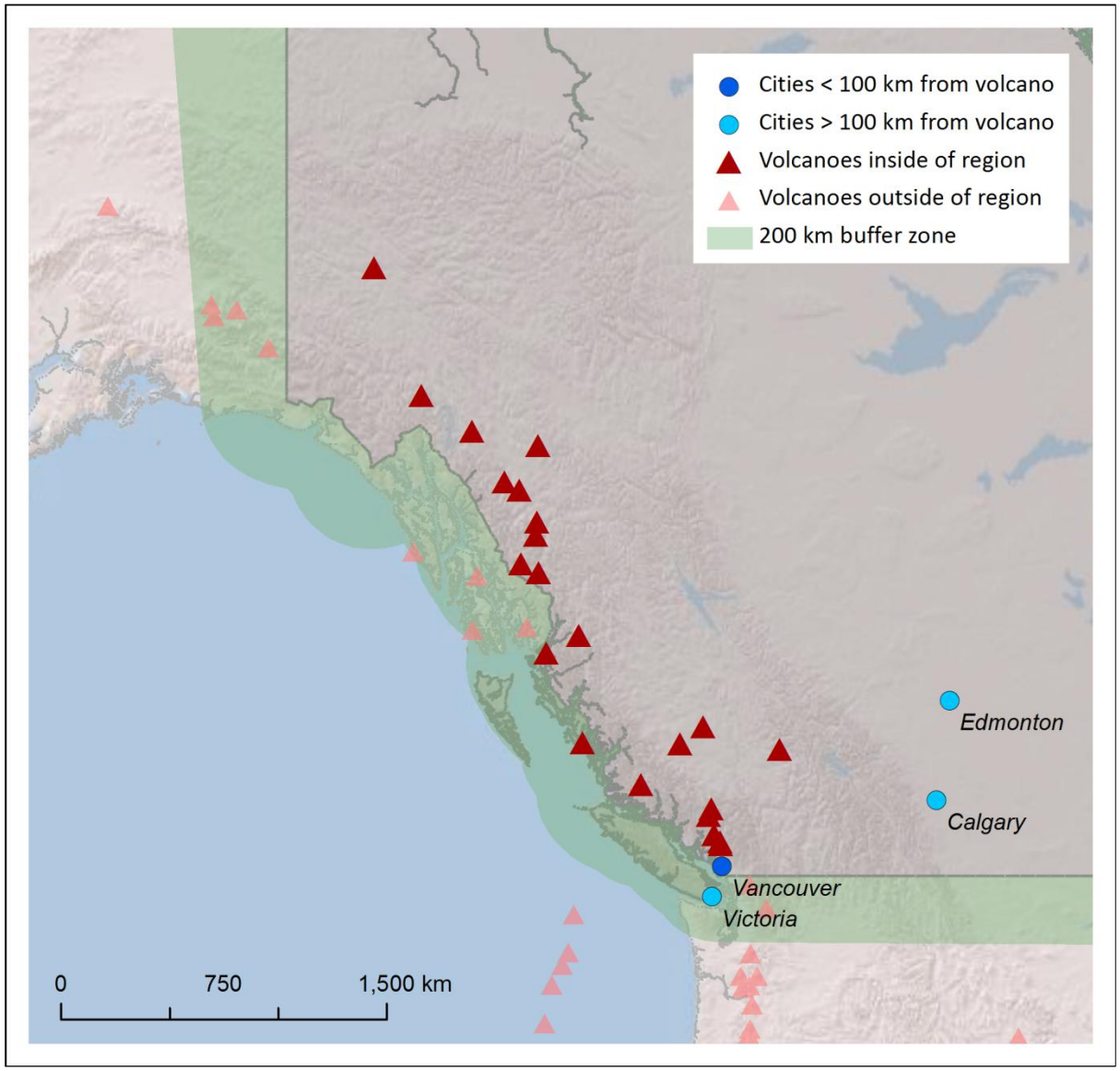


*Figure 12.5Location of Canada's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Canada.*

***Volcano Facts***

| | |
|---|---|
| Number of Holocene volcanoes | 22 |
| Number of Pleistocene volcanoes with M≥4 eruptions | - |

| | |
|---|---|
| Number of volcanoes generating pyroclastic flows | 1 |
| Number of volcanoes generating lahars | 1 |
| Number of volcanoes generating lava flows | 8, with many monogenetic vents |
| Number of fatalities caused by volcanic eruptions | Oral histories suggest ~2000 people, however the precise number is unknown. |
| Tectonic setting | 16 intra-plate, 6 Subduction zone |
| Largest recorded Pleistocene eruption | - |
| Largest recorded Holocene eruption | The M5.0 Bridge River Tephra/Pebble Creek Formation of Mount Meager in 2360 BP. |
| Number of Holocene eruptions | 19 confirmed eruptions. 2 uncertain eruptions. |
| Recorded Holocene VEI range | 0 – 5 and unknown |
| Number of historically active volcanoes | 3 |
| Number of historical eruptions | 4 |

| Number of volcanoes | Primary volcano type | Dominant rock type |
|---|---|---|
| 1 | Caldera(s) | Andesitic (1) |
| 4 | Large cone(s) | Andesitic (1), Dacitic (2), Trachytic / Andesitic (1) |
| 3 | Shield(s) | Basaltic (1), Rhyolitic (1), Trachytic / Andesitic (1) |
| 13 | Small cone(s) | Andesitic (1), Basaltic (12) |
| 1 | Subglacial | Phonolitic (1) |

*Table 12.7 The number of volcanoes in Canada, their volcano type classification and dominant rock type according to VOTW4.0.*

Silverthrone is the only caldera listed in Canada, however the age of the most recent activity at this volcano is uncertain as although the textures and degree of dissection suggests the lavas here are less than 10,000 years old this has not been confirmed with radiometric dating.

Hoodoo Mountain is classed in VOTW4.0 as a subglacial volcano. This is a complex, long-lived centre with both subaerial and subglacial deposits, and volcano-ice interaction has played a large role in its history. Many more volcanic centres in Canada have evidence for subglacial or ice-contact eruptions. Three monogenetic basaltic centres of Edziza are subglacial, and numerous further vents of Edziza could be classed as small cones, however Edziza itself is classed as a stratovolcano.

The age of the shield volcano Level Mountain is uncertain.

***Socio-Economic Facts***

| | |
|---|---|
| Total population (2012) | 34,828,000 |
| Gross Domestic Product (GDP) per capita (2005 PPP $) | 35,716 |
| Gross National Income (GNI) per capita (2005 PPP $) | 35,369 |
| Human Development Index (HDI) (2012) | 0.911 (Very High) |

***Population Exposure***

| | |
|---|---|
| Capital city | Ottawa |
| Distance from capital city to nearest Holocene volcano | 3299.6 km |
| Total population (2011) | 34,030,589 |
| Number (percentage) of people living within 10 km of a Holocene volcano | 14 (<1%) |
| Number (percentage) of people living within 30 km of a Holocene volcano | 2,703 (<1%) |
| Number (percentage) of people living within 100 km of a Holocene volcano | >2 million (<10%) |

Ten largest cities, as measured by population and their population size:

| | |
|---|---|
| Toronto | 4,612,191 |
| Montreal | 3,268,513 |
| Vancouver | 1,837,969 |
| Calgary | 1,019,942 |
| Ottawa | 812,129 |
| Edmonton | 712,391 |
| Winnipeg | 632,063 |
| Quebec | 528,595 |
| Victoria | 289,625 |
| Saskatoon | 198,958 |

***Infrastructure Exposure***

| | |
|---|---|
| Number of airports within 100 km of a volcano | 7 |
| Number of ports within 100 km of a volcano | 21 |
| Total length of roads within 100 km of a volcano (km) | 8,634 |
| Total length of railroads within 100 km of a volcano (km) | 1,127 |

The volcanoes in Canada are located in the west through the provinces of British Colombia and the Yukon. Many of these volcanoes are located near the coast, and as such 21 ports are situated within 100 km. Despite the number of volcanoes in Canada, the exposed population is relatively small with much of the population, and therefore infrastructure concentrated in the south of Canada, towards the border with the United States. The southernmost volcano in Canada, Garibaldi, lies just within 100 km of the USA, meaning the 100 km radius for this volcano extends into the US. And indeed, Mt Baker in the USA lies within 100 km of Canada, placing much of the Greater Vancouver Regional District within the 100 km radius of this Holocene volcano. Seven airports lie within 100 km of a volcano in Canada, as does an extensive road and rail network.

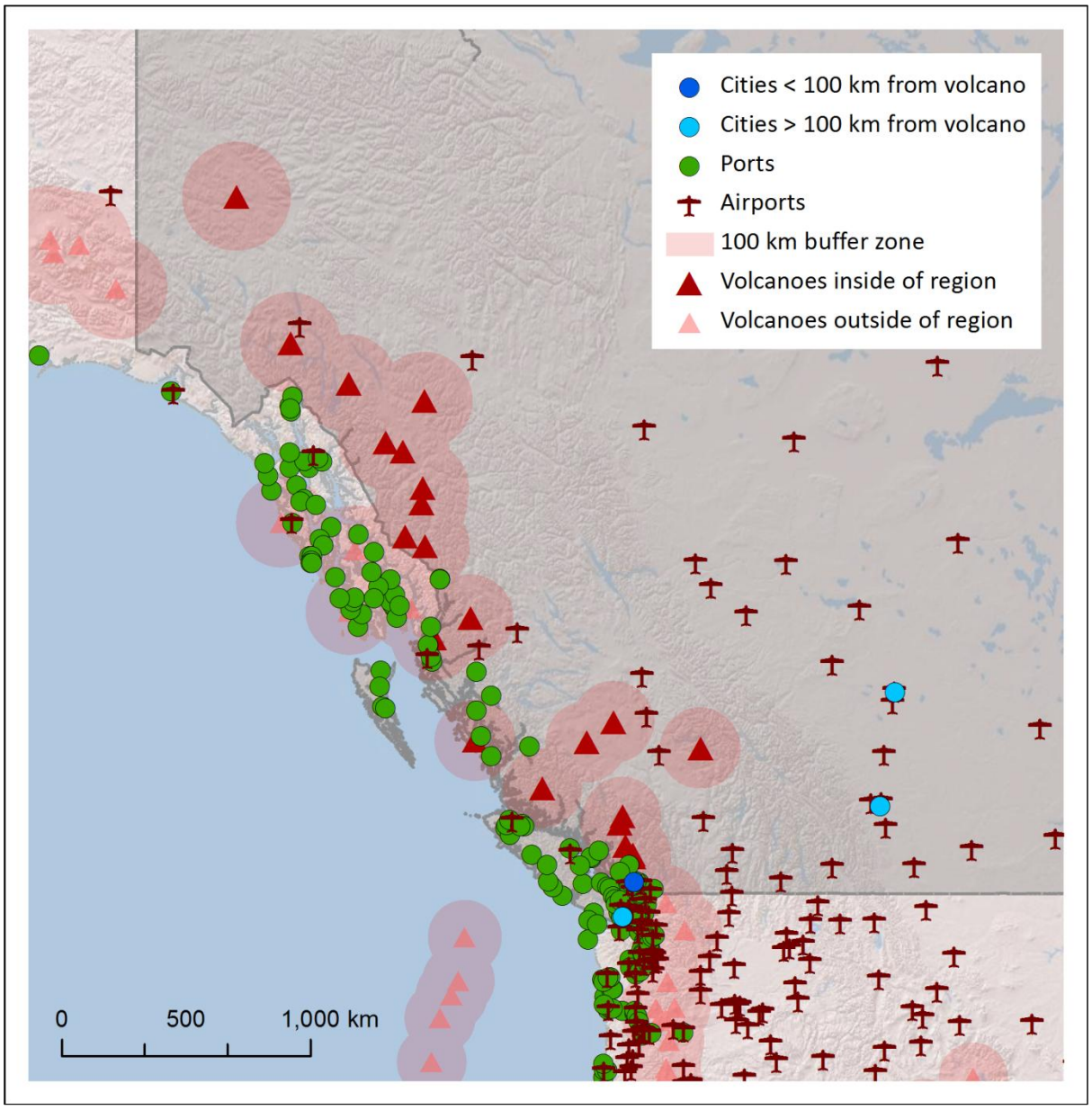


*Figure 12.6 The location of Canada's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.*

***Hazard, Uncertainty and Exposure Assessments***

The eruption records for the volcanoes in Canada are not sufficiently extensive or detailed for determination of the hazard through the calculation of the VHI without large associated uncertainties. All volcanoes here are therefore unclassified. Nineteen Holocene eruptions are confirmed from eight volcanoes or volcanic fields, with the remaining volcanoes having no confirmed Holocene eruptions. The most recent eruption was the 1800 AD eruption of Iskut-Unuk River Cones. Small earthquakes have been recorded in the vicinity of a number of Canada's volcanoes, however these have not been confirmed as volcanogenic.

Most Canadian volcanoes have very small proximal populations within 30 km, increasing substantially at 100 km radius, categorising these with low to moderate PEI of 2 – 4.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **CLASSIFIED** | **Hazard III** | | | | | | | |
| | **Hazard II** | | | | | | | |
| | **Hazard I** | | | | | | | |
| | | | | | | | | |
| **UNCLASSIFIED** | **U – HHR** | | Iskut-Unuk River Cones; Tseax River Cone; Wells Gray-Clearwater | | | | | |
| | **U- HR** | | Edziza; Hoodoo Mountain; Nazko; Meager | Garibaldi | | | | |
| | **U-NHHR** | | Fort Selkirk; Alligator Lake; Atlin Volcanic Field; Tuya Volcanic Field; Heart Peaks; Level Mountain; Spectrum Range; Crow Lagoon; Milbanke Sound Group; Satah Mountain; Silverthrone; Bridge River Cones; | Cayley Volcanic Field | Garibaldi Lake | | | |
| | | **PEI 1** | **PEI 2** | **PEI 3** | **PEI 4** | **PEI 5** | **PEI 6** | **PEI 7** |

*Table 12.8 Identity of Canada's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

***National Capacity for Coping with Volcanic Risk***

The volcanoes of Canada do not currently have dedicated ground-based monitoring systems in place. Only three Canadian volcanoes have been active since AD 1500, and these are unclassified for risk with a low PEI. Natural Resources Canada monitors a regional network of seismometers, which may provide indication of unrest at these volcanoes.

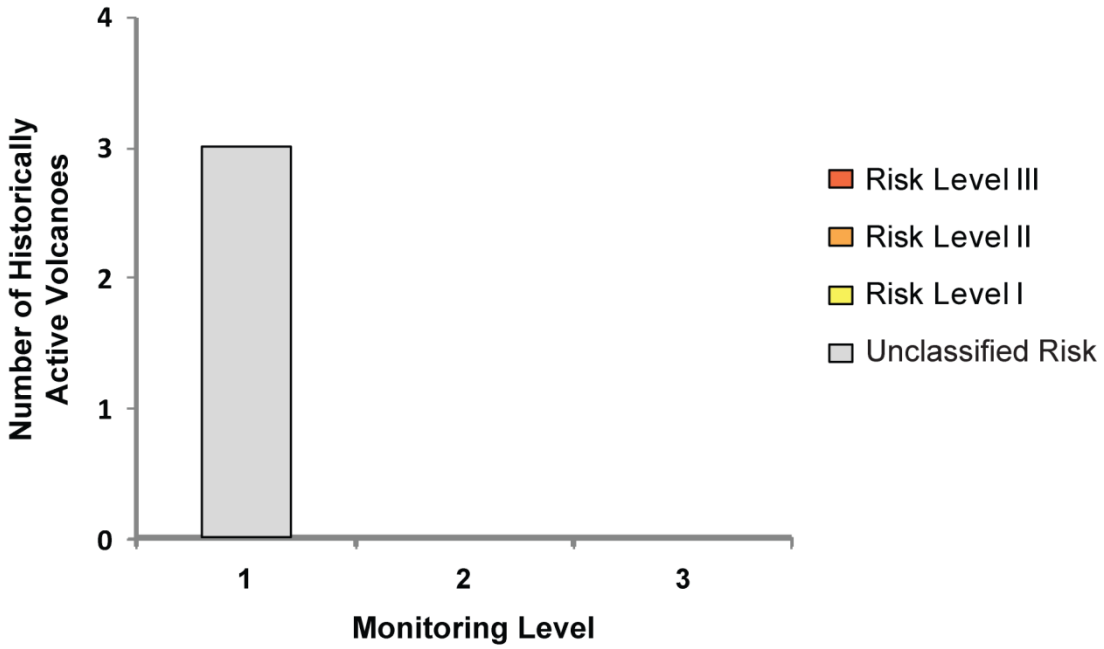


*Figure 12.7 The monitoring and risk levels of the historically active (with eruptions since 1500 AD) volcanoes in Canada. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.*

## U.S.A. (contiguous states)

See Region 4 for American Samoa, Region 8 for the Marianas, Region 11 for Alaska, Region 13 for Hawaii.

***Description***

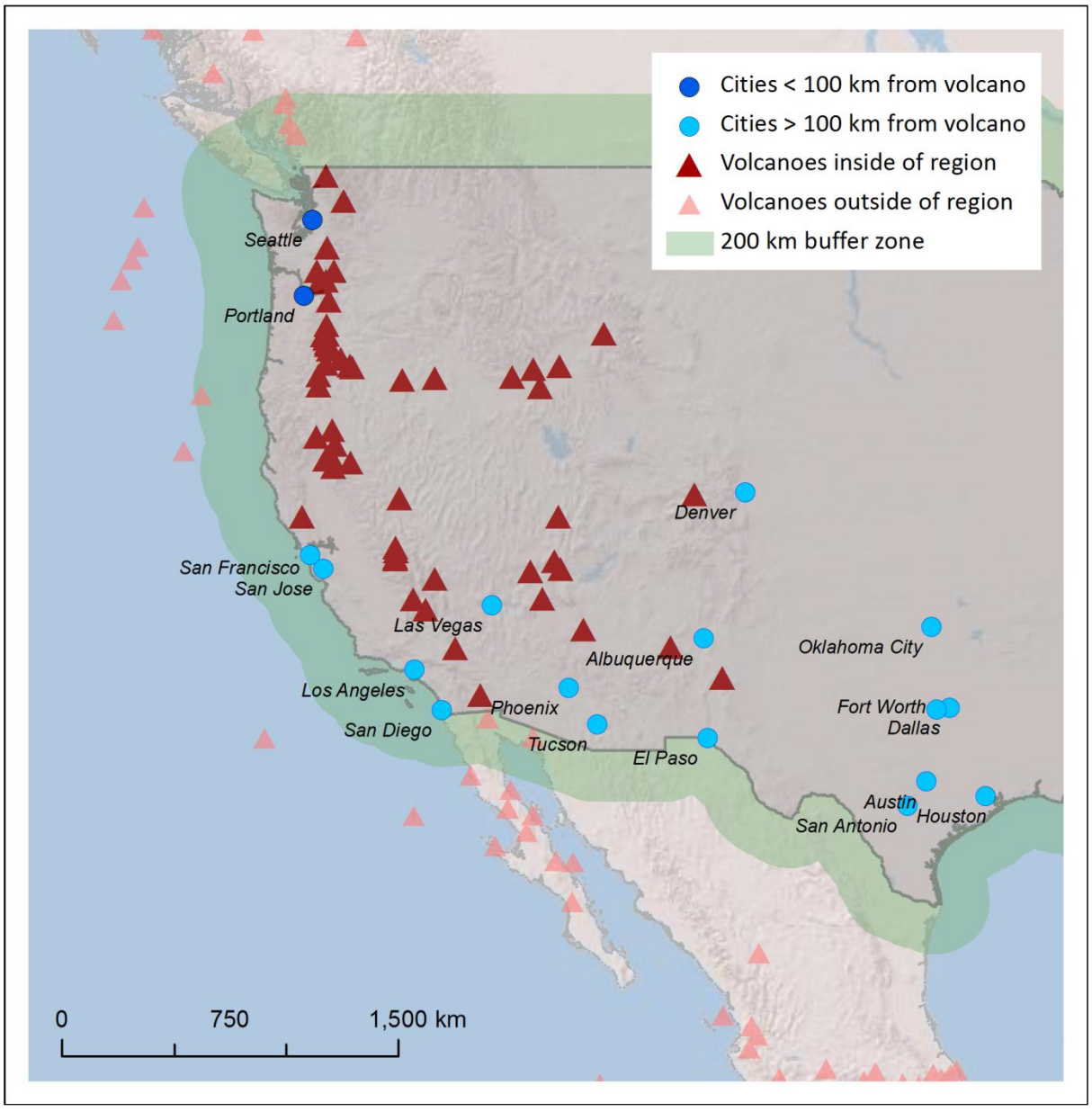


*Figure 12.8 Location of the volcanoes in the contiguous United States, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect these states.*

Forty-eight Holocene volcanoes are located in the contiguous 48 States of the U.S.A. (referred to from here as the U.S., excluding Alaska, Hawaii, Samoa and Marianas). Volcanism here is largely due to the subduction of the Pacific and Juan de Fuca Plates beneath the North American Plate and

extensional tectonics inland. This has given rise to the formation of dominantly andesitic volcanic centres dominated by volcanic fields, cinder cones and stratovolcanoes.

The U.S. has an extensive Pleistocene record of large explosive eruptions, with 14 volcanoes recorded in LaMEVE with eruptions of VEI/M≥4. The largest recorded Pleistocene eruption was the M8.4 eruption of Yellowstone about 639,000 years ago, which ejected the 1000 cubic kilometre Lava Creek Tuff and formed the 45 x 85 km caldera.

Forty-two volcanoes have records of Holocene activity, with the remaining volcanoes having activity of suspected though unconfirmed Holocene age. 226 Holocene eruptions are recorded here, from VEI 0 to 7. This size range demonstrates the range in activity in the U.S., from small events to very large explosive eruptions. About 10% of eruptions here are recorded at VEI ≥4. Pyroclastic flows are recorded in about 28% of Holocene eruptions. The largest Holocene eruption was that of Mt. Mazama, about 7700 years ago, at the present day site of Crater Lake in Oregon. This VEI 7 eruption is one of the World's largest known Holocene eruptions, producing pyroclastic flows that extended to about 40 km, extensive ash fall into Canada and the 8 - 10 km caldera. Most commonly small eruptions of VEI 0 - 2 are recorded.

Of the Holocene record, about 16% of the eruptions have been recorded since 1500 AD, with 36 historic eruptions of VEI 1 to 5 from 8 volcanoes. Just 2 eruptions of VEI ≥4 (VEI 5) are recorded in 1800 and 1980 at Mt. St. Helens. The latter eruption produced a debris avalanche, lahars, pyroclastic flows and resulted in evacuations and loss of life.

In total, throughout the United States, less than 2% of the population live within 100 km of one or more Holocene volcano. The size of the local population varies at each volcano, however over 60% are classed here with a low PEI on the basis of a small local population.

The U.S. Geological Survey (USGS) Volcano Hazards Program (VHP) runs monitoring and research institutions with five volcano observatories, three of which are active in the contiguous U.S. The California Volcano Observatory (CalVO) monitors volcanoes in California and Nevada. The volcanoes of Washington, Oregon and Idaho are monitored by the Cascades Volcano Observatory (CVO). The Yellowstone Volcano Observatory (YVO) monitors the Yellowstone volcano.

Dedicated ground-based monitoring is operated at many volcanoes in the U.S. The USGS VHP and the Consortium of U.S. Volcano Observatories (CUSVO) have developed the National Volcano Early Warning System (NVEWS). This is designed to ensure that all volcanoes of the U.S.A. are monitored at appropriate levels based on their relative threat. This relative threat is determined using hazard and exposure indicators. Scores are assigned for these factors (including, but not limited to: volcano type, maximum eruption size, recurrence rates, occurrence of various hazardous phenomena, population size and infrastructure location). The hazard and exposure scores are multiplied to give an overall threat score. These scores are divided into five categories: Very High, High, Moderate, Low and Very Low.

Those volcanoes currently classed by the USGS with a High to Very High Threat potential are:

| | |
|---|---|
| CalVO | Clear Lake |
| | Lassen Volcanic Center |
| | Long Valley Caldera |

| | |
|---|---|
| | Medicine Lake |
| | Mono-Inyo Chain |
| | Shasta |
| | Salton Buttes |
| CVO | Crater Lake |
| | Glacier Peak |
| | Mount Adams |
| | Mount Baker |
| | Mount Hood |
| | Mount Rainier |
| | Mount St. Helens |
| | Newberry |
| | Three Sisters |
| YVO | Yellowstone |

Many volcanoes, particularly those that have not had historical activity, are insufficiently monitored for detection of early volcanic unrest. NVEWS would ensure that the most hazardous volcanoes are properly monitored to allow forecasts of activity to be made and risk reduced.

**See also:**

Ewert, J.W., Guffanti, M., and Murray, T.L. (2005) An assessment of volcanic threat and monitoring capabilities in the United States: framework for a National Volcano Early Warning System. USGS Open-File Report, 2005-1164. pubs.usgs.gov/of/2005/1164/

Ewert, J.W. (2007) System for ranking relative threats of U.S. volcanoes, Natural Hazards Review, v8, no.4, p 112-124; dx.doi.org/10.1061/(ASCE)1527-6988(2007)8:4(112)

Guffanti, M., Diefenbach, A.K., Ewert, J.W., Ramsey, D.W., Cervelli, P.F., Schiling, S.P. (2009) Volcano-monitoring instrumentation in the United States, 2008, USGS Open-File Report 2009-1165. pubs.usgs.gov/of/2009/1165/

NVEWS: National Volcano Early Warning System: volcanoes.usgs.gov/publications/2009/nvews.php

USGS Volcanic Hazards Program: volcanoes.usgs.gov/index.php

***Volcano Facts***

| | |
|---|---|
| Number of Holocene volcanoes | 48 |
| Number of Pleistocene volcanoes with M≥4 eruptions | 14 |
| Number of volcanoes generating pyroclastic flows | 13 |
| Number of volcanoes generating lahars | 11 |
| Number of volcanoes generating lava flows | 37 |
| Number of fatalities caused by volcanic eruptions | ?79 |

| | |
|---|---|
| Tectonic setting | 27 Subduction zone, 28 Rift zone |
| Largest recorded Pleistocene eruption | The Yellowstone eruptions of the Lava Creek Tuff 639,000 years ago and the Huckleberry Ridge Tuff about 2,133,000 years ago were both over magnitude 8. |
| Largest recorded Holocene eruption | The M6.8 Crater Lake eruption of Mt. Mazama, Oregon, in about 7627 BP. |
| Number of Holocene eruptions | 226 confirmed eruptions. |
| Recorded Holocene VEI rang | 0 – 7 and unknown |
| Number of historically active volcanoes | 8 |
| Number of historical eruptions | 36 |

| Number of volcanoes | Primary volcano type | Dominant rock type |
|---|---|---|
| 2 | Caldera(s) | Dacitic (1), Rhyolitic (1) |
| 11 | Large cone(s) | Andesitic (9), Dacitic (2) |
| 5 | Lava dome(s) | Rhyolitic (4), Trachytic / Andesitic (1) |
| 7 | Shield(s) | Andesitic (2), Basaltic (5) |
| 23 | Small cone(s) | Andesitic (2), Basaltic (19), Dacitic (2) |

*Table 12.9 The number of Holocene volcanoes in the contiguous states of the USA, their volcano type classification and dominant rock type according to VOTW4.0.*

Note that the calderas here are Yellowstone (rhyolitic) and Crater Lake (dacitic). Long Valley caldera itself is not included as this is Pleistocene in age, however features within the area of Long Valley Caldera, considered distinct from the caldera, are included: Mammoth Mountain is a trachytic lava dome complex; Mono and Inyo Craters are rhyolitic lava domes and explosion craters; and Mono Lake Volcanic Field comprises cinder cones and lava domes.

***Socio-Economic Facts***

| | |
|---|---|
| Total population (2012) | 317,806,000 |
| Gross Domestic Product (GDP) per capita (2005 PPP $) | 42,486 |
| Gross National Income (GNI) per capita (2005 PPP $) | 43,480 |
| Human Development Index (HDI) (2012) | 0.937 (Very High) |

***Population Exposure***

| | |
|---|---|
| Capital city | Washington D.C. |
| Distance from capital city to nearest Holocene volcano | 2709.4 km |
| Total population (USA) (2011) | 311,591,917 |
| Number (percentage) of people living within 10 km of a Holocene volcano | 26,309 (<1%) |
| Number (percentage) of people living within 30 km of a Holocene volcano | 388,808 (<1%) |
| Number (percentage) of people living within 100 km of a Holocene volcano | 4,196,889 (1.4%) |

Ten largest cities, as measured by population and their population size:

| | |
|---|---|
| New York | 8,008,278 |
| Los Angeles | 3,694,820 |
| Chicago | 2,841,952 |
| Houston | 2,027,712 |
| Philadelphia | 1,517,550 |
| Phoenix | 1,321,045 |
| San Antonio | 1,256,810 |
| San Diego | 1,223,400 |
| Detroit | 951,270 |
| San Jose | 894,943 |

***Infrastructure Exposure***

| | |
|---|---|
| Number of airports within 100 km of a volcano | 95 |
| Number of ports within 100 km of a volcano | 28 |
| Total length of roads within 100 km of a volcano (km) | 20,625 |
| Total length of railroads within 100 km of a volcano (km) | 7,316 |

The volcanoes of the contiguous States are located in the western states, with most forming a chain north to south from Mexico to Canada in California, Oregon and Washington. Most volcanoes here are located far enough inland that ports are not located within their 100 km radius, however 28 ports are within this distance. Two of the largest cities in the USA, Seattle and Portland, are located within 100 km of volcanoes in the northern Cascade Range and nearly 100 airports are affected, along with numerous towns and cities. An extensive road and rail network falls within this distance of the volcanoes. The 100 km radius of volcanoes in the north and south extends into Canada and Mexico respectively, and indeed volcanoes in these countries also have 100 km radii extending into the USA.

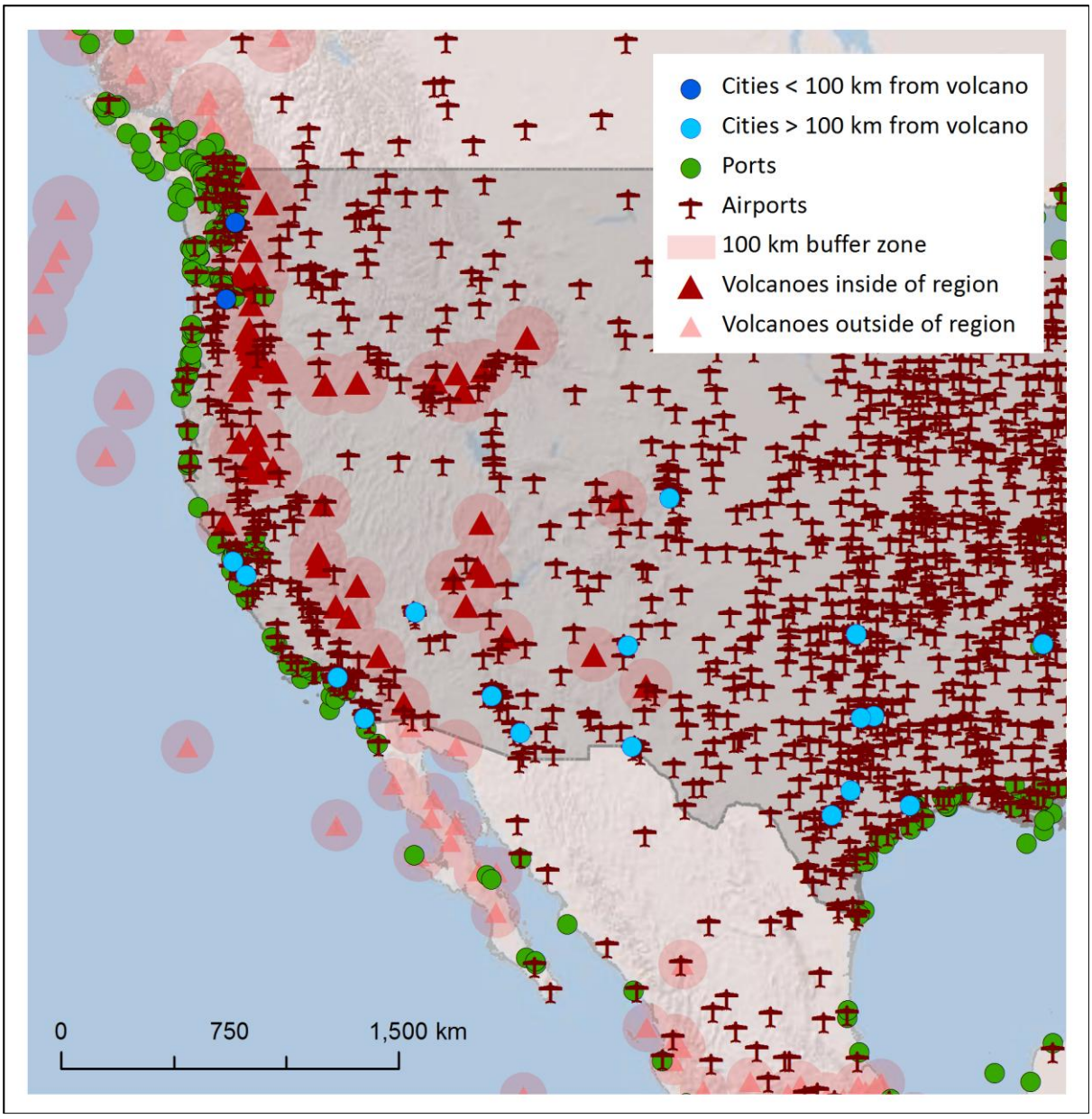


*Figure 12.9 The location of the volcanoes in the contiguous United States and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.*

***Hazard, Uncertainty and Exposure Assessments***

The volcanoes of the contiguous states of the USA have varying levels of data available in their eruption record. About 20% of volcanoes have appropriate eruptive histories to determine a hazard level through calculation of the VHI. These classified volcanoes span all three hazard levels, though most are classed at Hazard Level I. With eruption histories including large explosive events and eruptions commonly producing pyroclastic flows, Shasta, Rainier and St. Helens all are classed at Hazard Level III.

Of the unclassified volcanoes, seven have no confirmed Holocene eruptions. The remaining unclassified volcanoes have a Holocene eruption record, including historic (post-1500 AD) events at

four volcanoes. Only Lassen Volcanic Centre has erupted since 1900 AD, though unrest in this time has been recorded at Hood, Mammoth Mountain, Yellowstone and Coso Volcanic Field. Six unclassified volcanoes have Holocene records of large VEI ≥4 eruptions.

The PEI at these volcanoes ranges from low to high, at PEI 2 to 5. At most volcanoes the proximal population is relatively small, and all classified volcanoes are classed at Risk Levels of I and II.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **CLASSIFIED** | **Hazard III** | | Shasta | Rainier; St. Helens | | | | |
| | **Hazard II** | | | Baker | | | | |
| | **Hazard I** | | Adams; Sand Mountain Field; Three Sisters; Newberry; Medicine Lake; Craters of the Moon | | | | | |
| | | | | | | | | |
| **UNCLASSIFIED** | **U – HHR** | | **Lassen Volcanic Center;** Mono Lake Volcanic Field | Glacier Peak; **Hood** | | | | |
| | **U- HR** | | Jefferson; Blue Lake Crater; Belknap; Bachelor; Davis Lake; Crater Lake; Diamond Craters; Jordan Craters; Mono Craters; Ubehebe Craters; Golden Trout Creek; Shoshone Lava Field; Wapi Lava Field; Hell's Half Acre; **Yellowstone**; Markagunt Plateau; Carrizozo; Zuni-Bandera; Uinkaret Field | West Crater; Indian Heaven; Inyo Craters; **Mammoth Mountain;** Salton Buttes; Black Rock Desert; Dotsero | San Francisco Volcanic Field | | | |
| | **U-NHHR** | | Devils Garden; Cinnamon Butte; Silver Lake; **Coso Volcanic Field** | Lavic Lake | Soda Lakes | Clear Lake | | |
| | | **PEI 1** | **PEI 2** | **PEI 3** | **PEI 4** | **PEI 5** | **PEI 6** | **PEI 7** |

*Table 12.10 Identity of the volcanoes in the contiguous States in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed*

*eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

| Volcano | Population Exposure Index | Risk Level |
|---|---|---|
| Baker | 3 | II |
| Rainier | 3 | II |
| St. Helens | 3 | II |
| Shasta | 2 | II |
| Adams | 2 | I |
| Craters of the Moon | 2 | I |
| Medicine Lake | 2 | I |
| Newberry | 2 | I |
| Three Sisters | 2 | I |
| Sand Mountain Field | 2 | I |

*Table 12.11 Classified volcanoes of the contiguous states of the U.S. ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 6 volcanoes; Risk Level II – 4 volcanoes; Risk Level III – 0 volcanoes.*

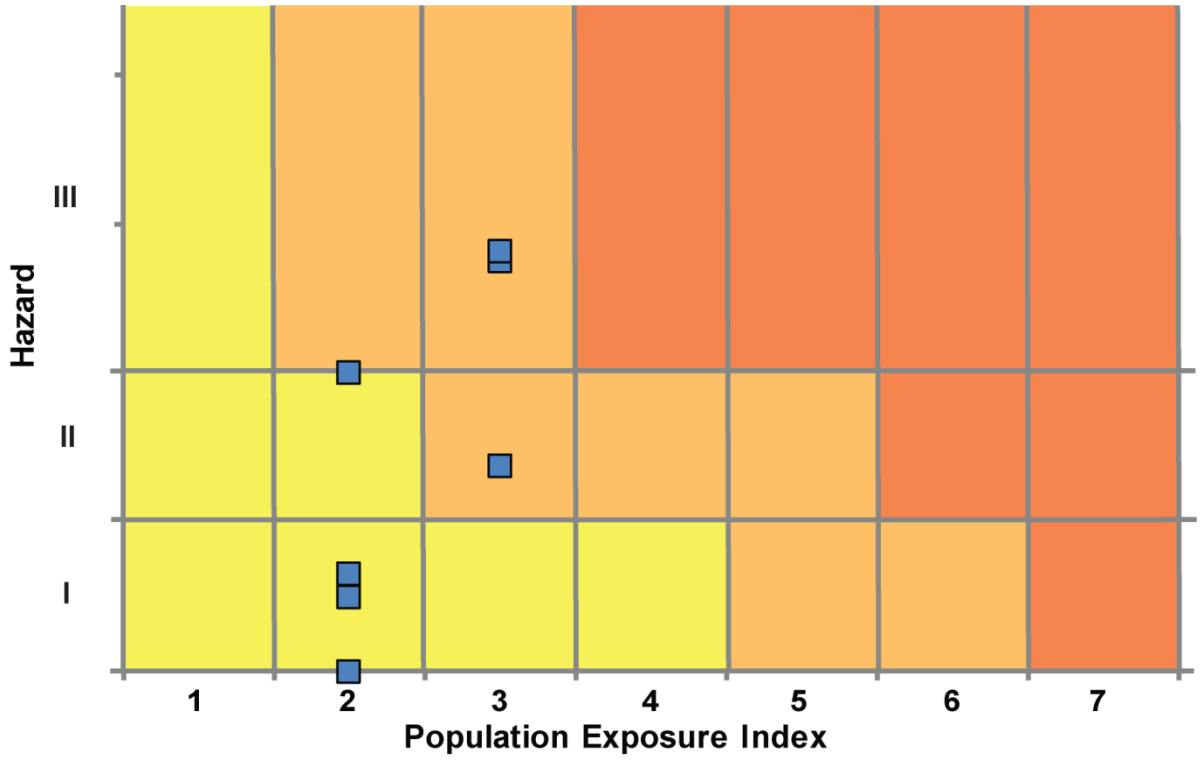


*Figure 12.10 Distribution of the classified volcanoes in the contiguous states of the U.S. across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.*

***National Capacity for Coping with Volcanic Risk***

Eight volcanoes have records of historical activity in the U.S. Baker, Rainier, St. Helens and Shasta are classed at Risk Level II, while Glacier Peak, Hood, Lassen Volcanic Center and Mono Lake Volcanic Field are unclassified. These historically active volcanoes are monitored by the California Volcano Observatory (CalVO) and the Cascades Volcano Observatory (CVO) through seismic and deformation networks.

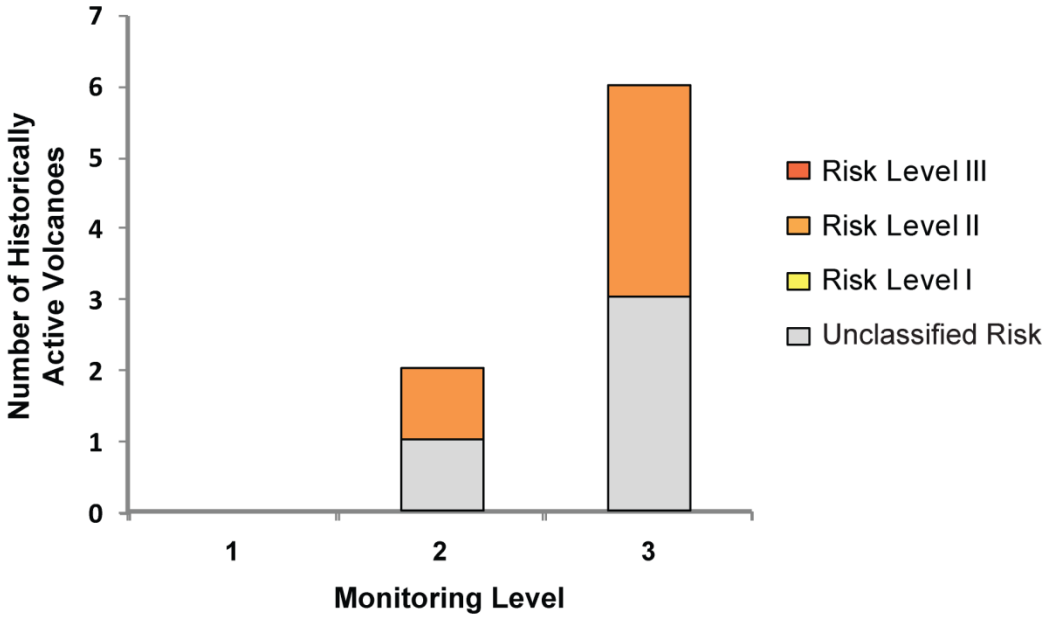


*Figure 12.11 The monitoring and risk levels of the historically active volcanoes in the contiguous states of the U.S. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.*