Volcanic Hazards Vulnerability Assessment of the Enumclaw – Buckley, Washington Community

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Abstract

Geographic Information Systems (GIS) was used to analyze volcanic hazards and risks related to a potential eruption at Mount Rainier, Washington. This project focuses on the Enumclaw – Buckley communities. The possible affects of the hazards on these communities were analyzed by examining critical facilities, social, economic, and environmental factors in relation to potential hazards. Finally mitigation opportunities were assessed to target future problems in planning.

Introduction

At 8:32 a.m. a 5.2 magnitude earthquake caused Mount Saint Helens' summit to slide away, triggering it's first eruption in 123 years. On May 18, 2000, ABC News reported these facts in a special anniversary article. The blast, with a velocity of 300 mph and temperatures reaching 660 degrees Fahrenheit, blew down 4 billion board feet of timber. The lateral blast covered 230 square miles, reaching 17 miles northwest of the crater. Landslides moved at 70 to 150 mph and covered 23 square miles, burying 14 miles of the North Fork of the Toutle River Valley. Lahars or volcanic mudflows, damaged 27 bridges, destroyed 200 homes, and left 31 ships stranded on the Columbia River. 57 lives were lost and countless animals died in the blast zone. Approximately 7,000 big-game animals and nearly 12 million salmon fingerlings died (Dube 2000).

Mount Saint Helens has provided one of the best-documented volcanic eruptions in US history. Scientists have turned the mountain into a living laboratory. By studying the May 18, 1980 eruption, scientists are better prepared for future eruptions.

Scientists are also preparing for future eruptions by assembling lists of high-risk volcanoes. When developing these lists a set of criteria is used. The frequency and type of recorded historic eruptions are considered. They also look at the nature and extent of past eruptive products. Various demographic determinates are evaluated, such as population density and property at risk. The topography, drainage systems, and the amount of glacial ice load are also factors that can contribute to the hazardous risk of a volcanic eruption. Finally, scientists consider current volcanic activity, for example, ground deformation, seismic activity, and gas emissions.

Mount Rainier ranks high in the above criteria, and therefore could be considered a high-risk volcano. With a summit elevation of 14,410 feet, Mount Rainier is the highest peak in the Cascade Range (Hoblitt 1998). The Cascade Range, located in the Pacific Northwest, extends from Mount Garibaldi in British Columbia, Canada, to Lassen Peak in Northern California (Figure 1). The volcanoes of the Cascade Range, along with the Alaskan volcanoes make up the North American portion of the Pacific "Ring of Fire". These volcanoes are known for their recurrent and damaging earthquakes and destructive volcanic activity.

Figure 1. Volcanoes of the Cascade Range.

Mount Rainier is a composite or stratovolcano. Stratovolcanoes often have symmetrical cones, which are comprised of alternating layers of lava flows, ash, and other volcanic debris. These volcanoes pose great risk to nearby populations, because their eruptions are extremely explosive.

An eruption at Mount Rainier poses considerable danger and economic threats to the region. Located in Pierce County, Washington, Rainier towers over the Seattle-Tacoma metropolitan area, with a population of more than 2.5 million (PCEM 1999). Pierce and King county support a large number of businesses. In addition, the area attracts many tourists annually. US Highway 12, a major roadway in Washington State, would be significantly affected by an eruption of Mount Rainier. This highway supports a large transient population, because it is one of few transportation corridors across the Cascade Range.

Populations outside the direct blast zone may also experience damaging effects. Flooding may reach as far as Southwestern Washington and Northwestern Oregon, as mudflows move down drainages into the Columbia River. Ash deposits may cover parts of Central and Eastern Washington, as happened during the 1980 Mt. St. Helen's eruption.

Because of Rainier's great elevation, its glacier ice load exceeds that of any other mountain in the continental United States (Hoblitt 1998). This factor, along with Rainier's steep slopes, poses a threat for large eruption-triggered debris flows, which could travel at high speeds and great distances. Many rivers originate on Mount Rainier: the Cowlitz, which flows into the Columbia; and the Carbon, Nisqually, Puyallup, and White.

The above factors make it necessary to prepare for future eruptions. By studying past eruptions at Rainier and the eruptions of Mount Saint Helens, estimates can be made to predict the possible destruction that could occur from future eruptions at Mount Rainier.

Scientists believe that Rainier will have a similar eruption to St. Helens, Rainier's closest neighboring volcano. The extent of damage could be much more extreme at Rainier, due to greater development on and around Rainier's slopes.

Vulnerability Assessment

Vulnerability is the susceptibility of resources to harmful impacts from hazard events (NOAA 2001). A significant part of a vulnerability analysis is the study of hazards, risks, and probabilities. But, knowing where the vulnerabilities are is key in order to make the most of pre-disaster planning efforts. A vulnerability assessment is the beginning step for developing and prioritizing mitigation strategies. Vulnerability assessments require examinations in multiple fields of study, including physical, social, environmental and economic sciences.

Methods

The guidelines set forth in NOAA's Vulnerability Assessment Tutorial were followed during this study. This tutorial is designed to analyze any natural hazard and it's effects on a populated area. In this study only volcanic hazards were taken into consideration. Six analyses were preformed: a Hazards Analysis, a Critical Facilities Analysis, a Societal Analysis, an Economic Analysis, an Environmental Analysis, and a Mitigation Opportunities Analysis. The flow chart in Figure 2 shows the steps of analysis. These analyses were all preformed using ESRI's ArcView GIS software and extensions. First, volcanic hazards were identified and given a hazard ranking. In each of the intermediate analyses (facilities, societal, economic, and environmental), sets of vulnerable sites or populations were identified. Overlays were preformed between the hazards theme and each of the vulnerability themes. Finally, a mitigation analysis was preformed to locate potential opportunities for future planning.

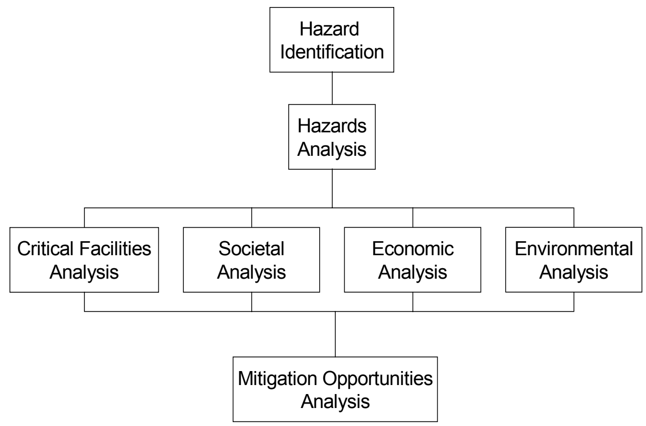

Figure 2. Flow chart of vulnerability analysis.

The Geoprocessing Wizard extension was used to perform the clip, merge, and intersect commands. The Projector extension was used to obtain a consistent projection across the data. Results from overlay analysis are displayed in frequency tables, as well as graphically in figures.

Hazards Identification

In a classic volcanic eruption, pyroclastic material is expelled into the atmosphere by means of an eruption column. The bottom of this column, where material is ejected from the vent, is known as the gas thrust zone. The convective thrust zone is above the gas thrust zone. In the convective zone pyroclastic material is lofted toward the top of the troposphere. When the eruption column meets the stratosphere the material extends into a mushroom shape, eventually dropping to the ground. The area affected by the eruption column and fallout material, is called the blast zone.

In a directed blast, one that is erupted from the side of the volcano, such an eruption column is not produced. A directed blast can occur as a result of depressurization triggered by an earthquake-initiated landslide, such as at Mt. St. Helens' 1980 event. The affect of a directed blast can be seen several miles from the volcano. The blast will either remove or destroy everything within a few miles. The temperature of materials from the blast cloud can range between 100 and 300 degrees (Scott 1989).

Tephra is the term for rock fragments and ash material that is ejected into the atmosphere during an eruption. Fallout material is largest near the volcano and will decrease in size as it moves away from the volcano. The height of the eruption column, the temperature of the air, and the wind speed and direction all determine the distance that ejected particles will travel away from a volcano (Riley 2001).

Lahars are volcanic mudflows. They are similar to pyroclastic flows, but they contain more water. Lahars form in several ways. They can form from snow and ice, which mix with loose debris. They can also form from pyroclastic flows, which release water that then mixes with debris. Or from a pyroclastic flow which dilutes itself with river water as it travels down slope. A natural dam may fail, creating a lahar. A lahar may even form from rainfall on loose material such as ash.

Lahars usually travel down valleys, with velocities varying from a few miles per hour up to 60 miles per hour. The velocity depends on the channel width, slope, volume of flow, and grain size (Hoblitt 1998).

A pyroclastic flow is an avalanche of hot ash, pumice, rock fragments, and volcanic gasses that move down the side of a volcano at high-speeds. Temperature within a pyroclastic flow may reach more than 500° C (USGS 2001). A pyroclastic flow may be generated by an eruption of magma and rock fragments or by the fallout from a blast column (USGS 1999).

There are two types of pyroclastic flows, ignimbites and nuee ardentes. Ignimbites contain large amounts of gas and fluid, while nuee ardentes contain denser material. Small pyroclastic flows can move as fast as 10 to 30 meters per second, while larger flows can move at rates of 200 meters per second (Byant 1991). Nuee ardentes have been known to extend 50 km and ignimbrites, because of their lighter materials, can extend 200 km (Byant 1991 and Scott 1989).

The optimal method for assigning hazards ranking to the various hazardous threats would be a scientific, quantifiable probability assessment. Unfortunately, probability data are inconsistent among the diverse hazard types. They are also, rarely accessible or usable at the local level. As an alternative, a relative risk matrix was used as a general guide for addressing the different hazards. Factors used in the Relative Risk Matrix included hazard frequency, area of impact, and magnitude of damages associated with the hazards. The matrix gives a relative ranking that will guide the vulnerability assessment process, as well as, the hazard mitigation.

Rationale For Hazard Ranking

Once the volcanic hazards were identified, they were ranked with a weighting system. For this study, the factors frequency, area of impact, and magnitude were given a value from 1 to 5, one being the lowest potential risk and 5 the highest. Then the *equation (Frequency + Area of Impact) x Magnitude = Total* was applied to calculate a total risk for each hazard (Table 1).

Table 1. Relative Risk Matrix

Hazard	Frequency	Area of Impact	Magnitude	Total
Blast	3	4	4	28
Tephra 1	3	5	2	16
Tephra 10	3	2	3	15
Lahar Case M	1	5	5	30
Lahar Case I	3	3	3	18
Lahar Case II	4	2	2	12
Lahar Case III	5	1	1	6
Plyroclastic Flow	1	1	4	8

Information on past eruptions and hazardous events were analyzed to establish relative risk values. A set of hazards zoning maps for Rainier were produced by the Cascade Volcanic Observatory (Hoblitt 1998). These maps are predictive models of where and to what extent volcanic processes may affect given areas. This set of maps includes: debris avalanches and lahars, pyroclastic flows, tephra falls, and lateral blasts. These maps were used in this study to identify areas at risk for volcanic hazards. For each of the Hazards listed in the above matrix, the frequency, area of impact and magnitude of the past events were considered.

When creating the hazard zoning maps, scientists at the Cascade Volcanic Observatory used a mobility equation. Mobility is the ratio L/H, where H is the elevation difference between the eruptive vent and the farthest point reached by the hazard, and L is the horizontal distance between those same two points.

Small to moderate eruptive events at Mount Rainier have occurred every few hundred years in the past 10,000 years (Hoblitt 1998). To establish the blast zone boundary a L/H value of 11 was used, and the eruptive vent was assumed to be at the summit (Hoblitt 1998). Because the volcano lacks high ridges and topographic barriers on the northwest side, the zone extends farthest in that direction. Experience at other volcanoes suggests that a sector no more than 180 degrees would be affected. Figure 3 displays the blast zone predicted by CVO scientists.

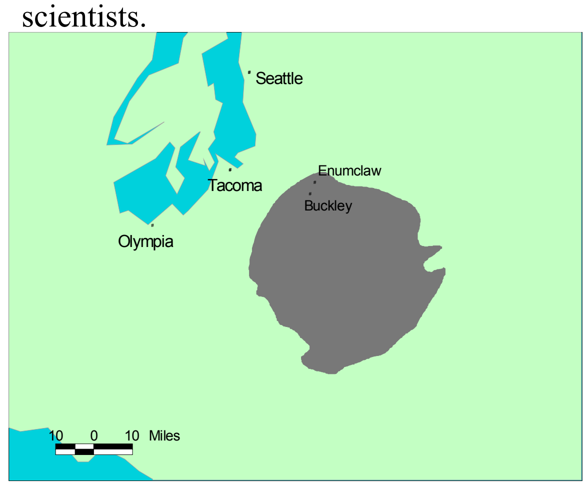

Figure 3. Predicted blast zone.

Tephra deposits have been divided into two categories by size, 1 to 10 cm and greater than 10 cm. Tephra that is 10 cm or less, is considered to be non-pumice-bearing. While tephra greater than 10 cm, could bear significant amounts of pumice (Figure 4). To establish tephra zone maps, scientists examined the deposits of past eruptions. They delineated twenty-five non-pumice-bearing tephra layers.

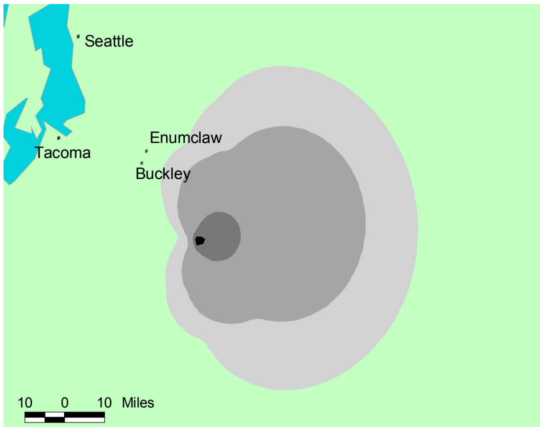

Figure 4. Predicted Tephra Extent.

The average time between pumice-bearing eruptions is about 900 years (Hoblitt, 1998). Deposits show the occurrence of eleven pumice-bearing eruptions in the last 10,000 years. Deposits of this type are most likely to occur east of the volcano, within a few tens of kilometers of the summit.

Lahar boundaries are based on the activities of flows that took place over the past several thousand years. Lahars are divided into four classes. Each lahar class has a different method of formation. Ordered in decreasing area of impact and increasing frequency, the classes are Case M, Case I, Case II, and Case III.

The largest lahars, Case M, are too infrequent to approximate an annual probability. Only one lahar of this magnitude is known to have occurred at Rainier in 10,000 years (Hoblitt 1998). A Case M lahar has 10 to 20 times the volume of the Case I lahar.

A Case I lahar is a high-magnitude, low frequency flow. Six to thirteen Case I lahars have occurred in the past 5600 years; therefore they have a recurrence interval of 500 to 1000 years (Hoblitt 1998).

Case II flows typically have a recurrence interval near 100 to 500 years (PCEM 1999). Melted snow and glacial ice during a volcanic eruption is the most common source for this class of lahar. The melt-water picks up loose sediment form the volcano's slopes and drainages. Class II lahars have an intermediate magnitude and frequency.

Figure 5. Predicted lahar extent.

Case III flows are moderately small, but occur often, with recurrence intervals of 1 to 100 years (Hoblitt 1998). They are not eruptively triggered, and rarely move beyond the National Park boundary. Glacial outbursts and storm-generated runoff are the most common sources for Case III lahars. During the 20th century, there have been 4 such flows. One such flow occurred August 15, 2001, as melt-water broke through an ice dam on the Van Trump Glacier and flowed down the Nisqually River (Bernton 2001). Case III lahars pose a significant hazard in and around Mt. Rainier National Park, but have little impact on populations in the lower reaches of Rainier's drainages. The recurrance time for a Case III lahar is less than 100 years (Hoblitt 1998). Figure 5 shows the predicted extent of all lahars (Case M, I, II, and III).

To build the pyroclastic flow hazard zone (Figure 6), a L/H value of 4.2 was used. This L/H value produces a boundary that extends a few kilometers beyond all of Mount Rainiers's known pyroclastic flows and pyroclastic surge deposits.

Figure 6. Predicted pyroclastic extent.

Hazards Analysis

The difference between risk and vulnerability is an important distinction in this step. Risk consideration areas identify geographical areas most likely to be affected by a given hazard. The people and resources located within the risk consideration areas are considered to be at risk from hazards and may or may not be vulnerable to hazard impacts. The vulnerability of the people and resources within the risk areas is a function of their individual susceptibility to the hazard impacts.

In this portion of the study, the union command within the Geoprocessing Wizard was used to merge all hazard layers together. A total risk value was assigned to all areas by accumulating each hazard's weighted risk value (Blast + Tephra 1 + Tephra 10 + Lahar M + Lahar I + Lahar II + Lahar III + Pyroclastic Flow), as shown in Figure 7. Areas that have the potential to be affected by multiple hazards have a higher total risk.

Although the borders of hazard zones are shown with lines, the extent of hazard does not change abruptly at these boundaries. The hazard decreases gradually away from the volcano or with the height above the valley floor. Areas directly outside the hazard zones should not be thought of as hazard-free, because the boundaries can only be roughly located. Too many uncertainties exist about the source, size and mobility of future events to locate hazard-free zones with complete assurance.

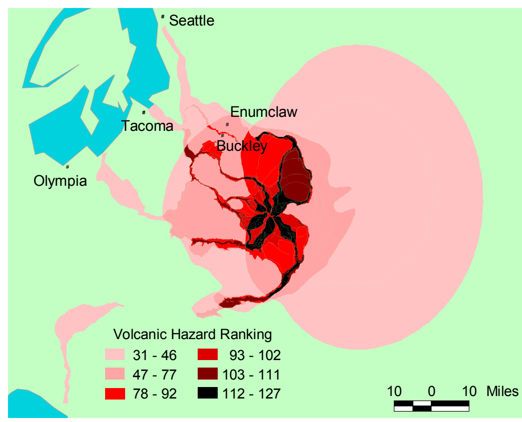

Figure 7. Predicted extent of all hazards with ranking.

Scope of Work

The Enumclaw-Buckley area was chosen as the study area, because the potential area that would be affected by an eruption at Mount Rainier is so large, spanning four counties. Located on the Northwest side of Mount Rainier, the communities have a combined population of approximately 22,534 and have an area of 5071 acres. The communities lie within the White River valley. The White River heads at Mount Rainier and flows 68 miles, draining 494 square miles (Bentler 2000). Fed by the Emmons and Fryingpan glaciers, the

White River flows westward, running into the Puyallup River and eventually flowing into the Puget Sound near the city of Tacoma. The White River forms the boundary between Pierce and King county. Enumclaw lies in King County, while Buckley is in Pierce County (Figure 8).

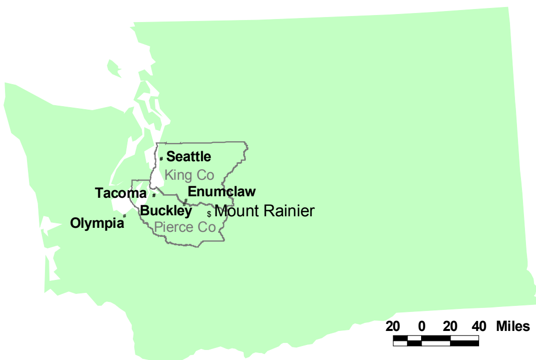

Figure 8. Location of Emunclaw and Buckley in relationship to Mount Rainier.

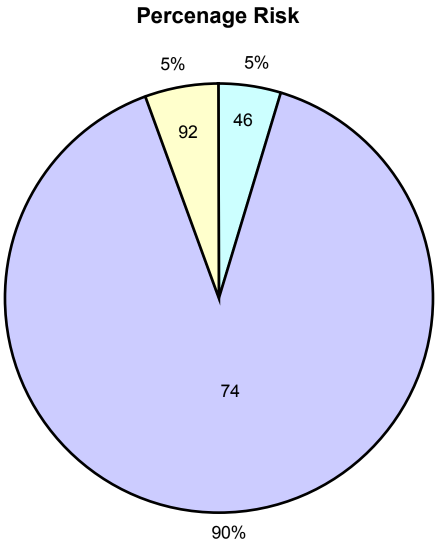

Figure 9. Percent of risk level in the one mile community buffer area.

The community limits were buffered to one mile. This buffer was used to perform the analyses. The chart in Figure 9 shows the percentage of hazard risk levels that make up the one-mile community buffer area. The communities are composed of only three hazard levels: 92 (high risk), 74 (moderate risk), and 46 (lower risk). The majority of the communities fall in the moderate risk zone. While the area directly around the White River makes up the high-risk area and the Northwest corner is lower risk.

Table 2. Summary table of Critical Facilities at Risk. The streets and roads span all three risk levels, therefore acres total miles are shown for each risk level.

Vulnerable Population Facilities		
Facility Type	Total Risk	Count
Daycare	74	16
Hospital	74	1
School	74	21
Service & Infrastructure Facilities		
Facility Type	Total Risk	Count
Airport	74	1
Police Station	74	1
Fire Station	74	1
City Hall	74	1
Bridge	92	3
Service & Infrastructure Linear Features		
Facility Type	Total Risk	Miles
Streets & Roads	46	6.718
Streets & Roads	74	181.405
Streets & Roads	92	6.648

Critical Facilities Analysis

This analysis focused on locating the key facilities and resources in the community that are vulnerable to volcanic hazards (NOAA 2001). The Critical Facilities were split into two categories: vulnerable population facilities and transportation & infrastructure. Vulnerable population facilities include schools, colleges, daycares, and hospitals. Transportation and infrastructure include roads, railroads,

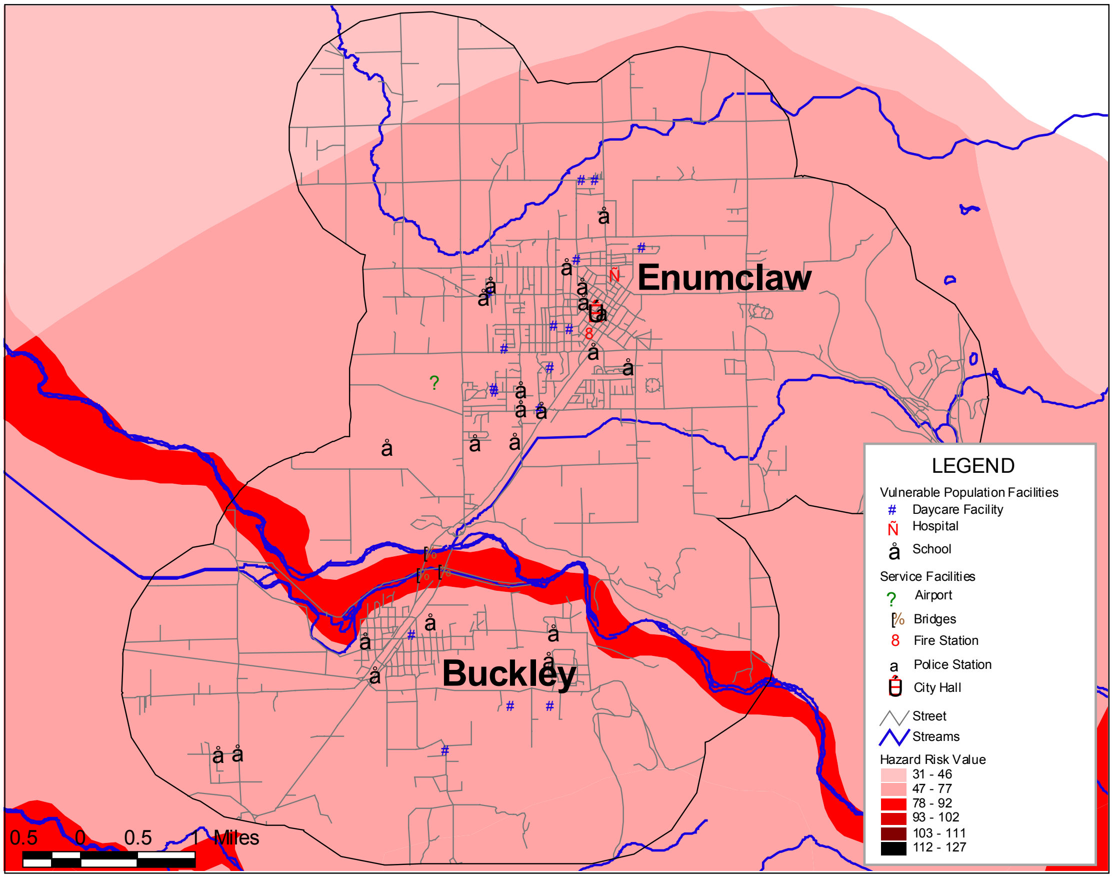

Figure 10. Facilities vulnerable to volcanic Hazards.

airports, utilities, radio towers, fire stations, police stations, and government offices. Data sources are described in Appendix A. The facilities were overlain on the hazards layer to identify intersections of critical facilities with high-risk areas (Figure 10). The results were summarized in Table 2.

Societal Analysis

The societal vulnerability analysis identifies potential population areas of special needs that might be vulnerable to volcanic hazards. These areas commonly include large populations of low-to-moderate income households who would most likely require public assistance and services to overcome the impacts of a disaster. These special consideration areas have inadequate financial resources for seeking personal mitigation efforts. They also are more likely to be uninsured or underinsured for hazard damages. Other factors may exist in these areas, such as mobility, illiteracy, or language barriers, which could impair disaster recovery efforts. By focusing on these areas, a community can lessen the vulnerability of individuals, and aid in reducing potential impacts on public services.

Table 3. Summary table of societal analysis. Xs denote elevated population counts in societal consideration areas. Populations are split by hazard risk level. Total acres are shown for each demographic/hazard area.

Non-English Speaking Population	Population over 65	Single Parent with Children Families	Housing Units with No Vehicle	No High School Diploma	Housing Rental	Households Below Poverty	Households with Public Assistance Income	Total Risk	ACRES
		X				X		46	0.050
				X				46	475.658
						X		46	149.900
Total								46	625.608
Non-English Speaking	Over 65 Years	Single Parent Families	No Vehicle	No High School Diploma	Rents	Living in Poverty		Total Risk	ACRES
X		X	X		X	X		74	488.485
	X	X		X	X	X		74	488.518
	X	X				X		74	284.296
	X	X		X		X		74	334.941
	X		X	X				74	461.247
		X	X			X		74	431.691
		X				X		74	1326.746
		X			X	X		74	3136.854
		X		X				74	614.764
		X		X		X		74	1173.904
		X		X		X		74	69.543
				X		X		74	582.753
				X		X		74	1245.714
				X				74	2034.141
				X				74	708.176
					X	X		74	2364.364
						X		74	475.357
Total								74	16221.494
Non-English Speaking	Over 65 Years	Single Parent Families	No Vehicle	No High School Diploma	Rents	Living in Poverty		Total Risk	ACRES
		X	X			X		92	202.338
		X			X	X		92	197.817
		X		X				92	511.252
				X		X		92	16.491
				X				92	101.234
					X	X		92	193.159
Total								92	1222.291

Demographics were analyzed to define populations of special consideration. Residents in special consideration areas are often renters. Single parent households may point to areas where special childcare needs should be considered. Areas of high elderly populations and populations without vehicles may indicate special mobility needs. Populations with low education attainment rates may need help in filing for disaster assistance. Even modest damage from a volcanic hazard could have a major financial impact on residents living at or below the poverty level and households on public assistance.

To determine special consideration areas, demographic data were extracted from 1990 Census data at the block group level. Although 2000 Census data was available for many of the demographics, income and economic data were not. In order to keep the data consistent, 1990 data were used for all demographics. Eight Census data categories were selected as high-needs determinate factors: single parent with child families, households below poverty, populations over age 65, non-English speaking population, populations with no high school diploma, households with public assistance income, rental households, and housing units with no vehicle.

The percentages for the above special consideration populations were found for each block group by taking the count, dividing it by the total population and then multiplying the result by 100. The average for each county was used as a base to gage whether a block group had an elevated special consideration population. If the population percentage for the block group was higher than the county's average percentage, it was considered an area of special consideration.

To further target areas for potential hazard mitigation activities, intersections of special consideration areas with high-risk areas were identified. The results were summarized in Table 3. These results will help the communities to determine where to focus mitigation strategies.

Economic Analysis

The loss of income due to business interruptions and closures after a natural disaster may be one of the most devastating costs to a community. In order to identify a community's economic vulnerability to hazard impact, a key step is to identify major economic sectors and economic centers. These centers are areas where the local economy would be greatly impacted by hazard. Therefore the locations would be ideal targets for certain hazard mitigation strategies.

The Puget Sound Region supports a large number of businesses. Its location allows easy access to the Pacific Ocean, which makes it an ideal commerce center. King County is home to seven Fortune 500 companies (EDC 2000). The Port of Tacoma is the sixth largest container port in North America and among the top 25 in the world (PCEM 1999). Table 4 lists Puget Sound's top employers. Leading this list is the Boeing Company, employing approximately 67,000 (EDC 2000). Boeing has multiple plants throughout the region. Microsoft Corporation, located in Redmond, employs approximately 15,400 persons.

The economic analysis was separated into three phases. The first phase used the Census Bureau's 1990 economic data. The workforce fields were used to determine the economic areas in which the residents of the study area are employed. Table 5 summarizes the results.

Table 4. Top 20 employers in the Puget Sound Region.

Top 20 Employers Central Puget Sound Region*	
Company	# of Employees
The Boeing Company	67,000
Microsoft Corporation	15,400
Safeway	9,851
Sisters of Providence Systems	9,423
Group Health Cooperative	8,800
Fred Meyer	8,100
Nordstrom Inc.	6,756
Alaska Air Group, Inc.	6,234
Qwest	6,100
The Bon Marche	5,409
Albertson's	5,400
Quality Food Centers	5,200
Virginia Mason Medical Ctr.	5,200
Multi Care Health System	4,755
Weyerhauser Company	4,600
Swedish Health Systems	4,444
Safco Corp.	4,000
Washington Mutual Inc.	4,000
Franciscan Health System	3,900
Costco Wholesale, Inc.	3,900
Source: Puget Sound Business Journal's Book of Lists 2000 *Central Puget Sound Region includes King, Kitsap, Pierce, and Snohomish counties.	

Table 5. Total risk of employees per work force.

# of Workers in Field of Work			Total Risk
Manufacturing	Trade	Service	
317	296	140	46
2288	2254	880	74
511	533	286	92

Both the Enumclaw and Buckley communities are rural, yet there are large cities within each of the counties they are in. These cities have their own distinct demographics. Seattle is in King County, and it has a very metropolitan professional profile. While Pierce County's largest city is Tacoma, which is home to two military installations and a more labor-intensive workforce. These cities have skewed the averages for the counties and may be a consideration for future studies.

Because the majority of the Enumclaw – Buckley workforce commutes to larger cities (Tacoma, Seattle, Bellevue, and Redmond), in phase II the commuting distance within the census data was analyzed. A buffer analysis was preformed on the community boundary to simulate four commute distances; less than 15 minutes, 15 to 29 minutes, 30 to 44 minutes, and greater than 44 minutes. These buffers were overlain on the hazards layer, along with major roadways. Figure 11 shows the economic centers and major commuting buffers that would be affected by volcanic hazards.

In the final phase of the economic analysis zoning data were collected from King County and Pierce County websites. The zoning maps were intersected with the volcanic hazards layer. Figure 12 shows the land zoned agricultural, forested, and mineral and the level of risk.

Environmental Analysis

The environmental analysis had two phases. The first identified locations where secondary environmental impacts may occur after an eruption. A secondary impact is a new hazard, such

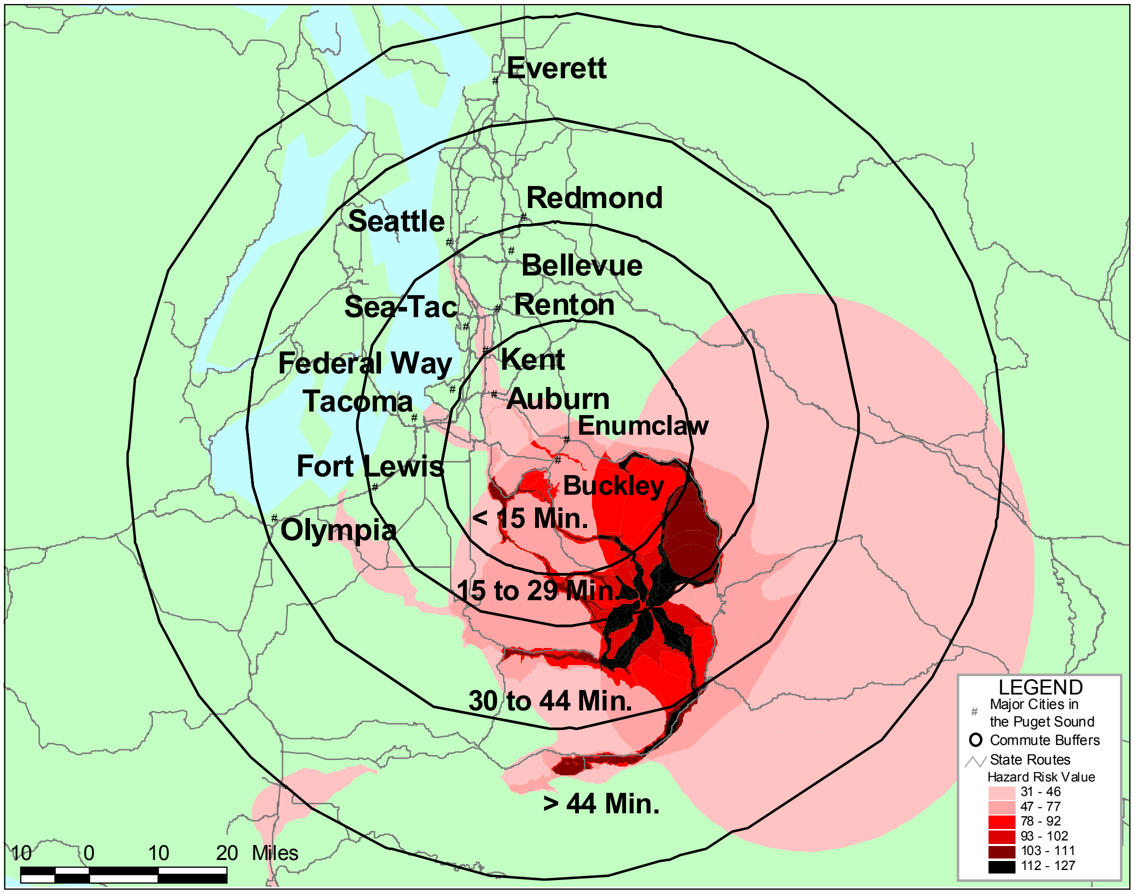

Figure 11. – Commute buffers.

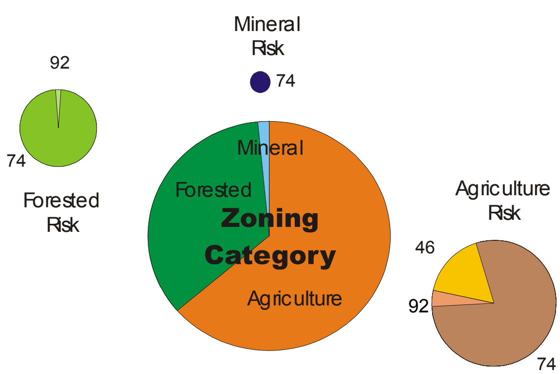

Figure 12. Risk levels for land zoned as agriculture, forested, and mineral.

as toxic release or hazardous spills that occur as a result of a natural event. To identify potential secondary hazards the following layers were intersected with the hazards risk layer: national pollutant discharge elimination systems, superfund sites, group a & b wells, dams, confirmed & suspected hazardous waste sites, and underground storage tanks (Figure 13).

The second phase of the environmental analysis identified significant environmental resource locations, particularly those with sensitivity to secondary hazard impacts. The proximity of these environmentally sensitive locations to the secondary risk sites was analyzed to determine the overall risk. The environmentally sensitive locations that were considered for this analysis were old growth forest, Marbled Murlette habitat, and Northern Spotted Owl habitat, both listed as threatened species. The overall habitat of the area was also examined to get a sense of what else would be affected (Figure 14).

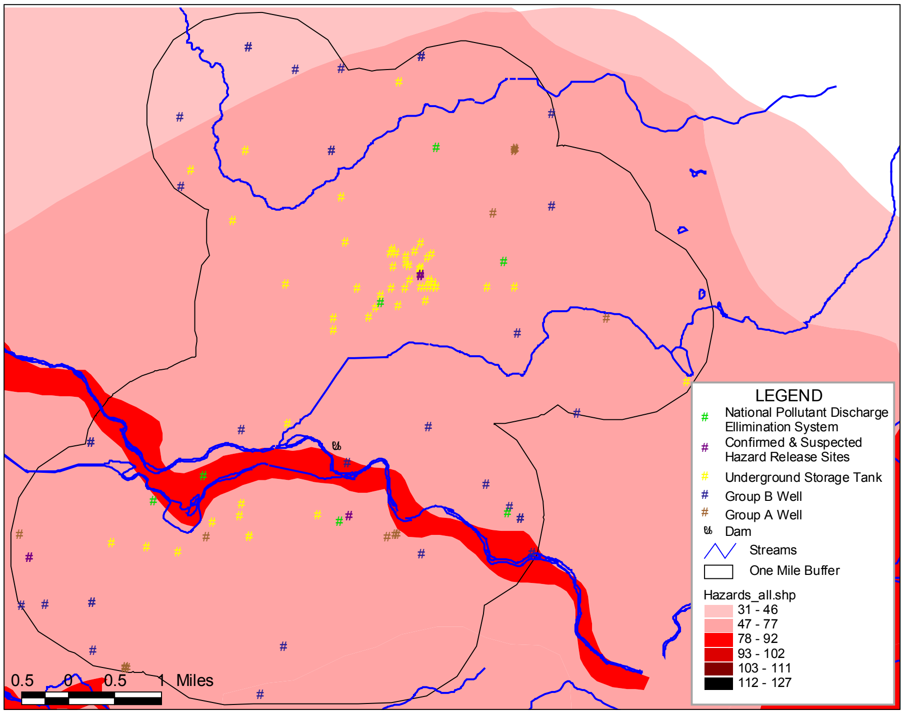

Figure 13. Volcanic risk of secondary hazards.

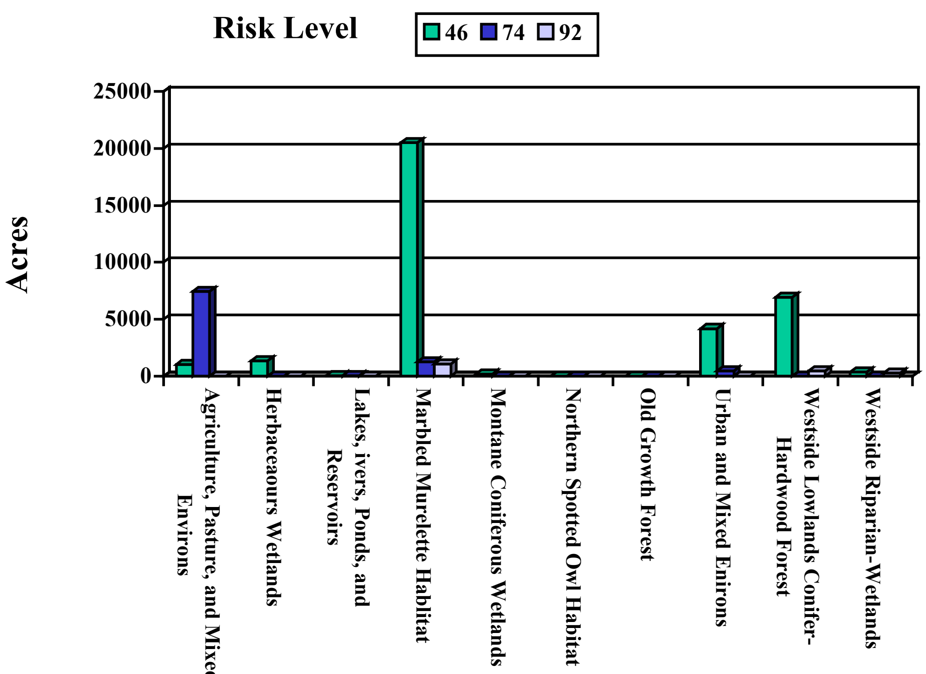

Figure 14. Summary of sensitive habitat vulnerability.

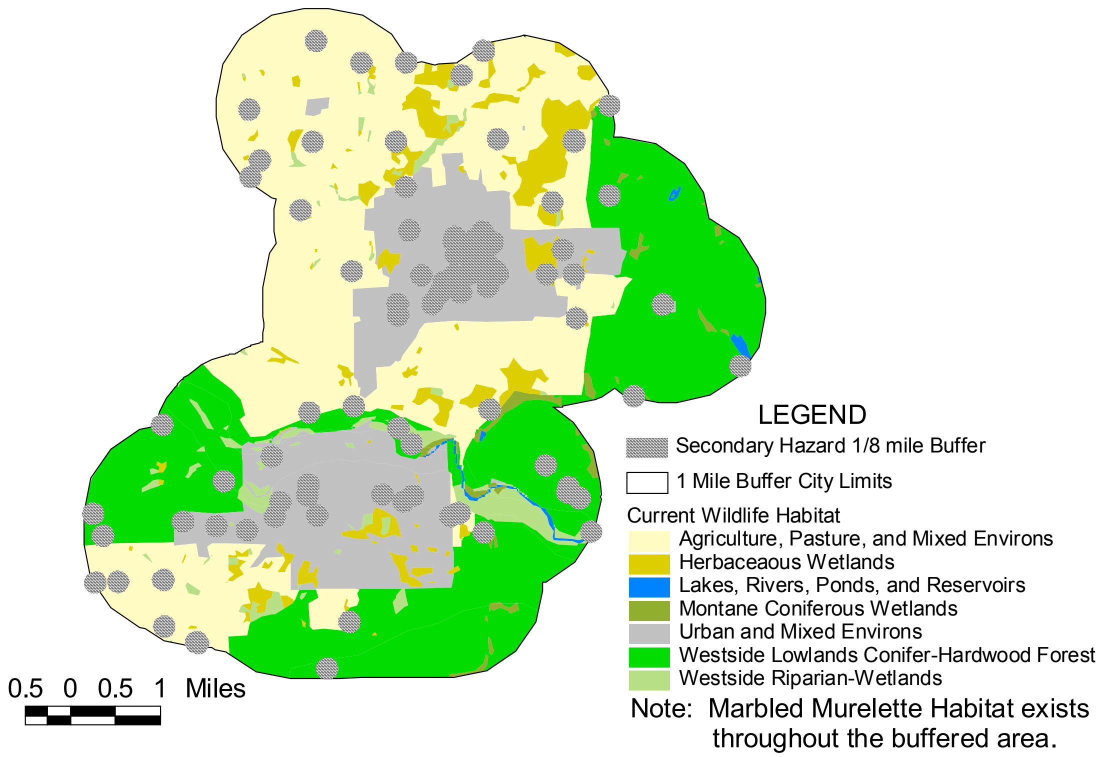

Figure 15. Secondary hazards, sensitive habitat, and hazard risk.

A 1/8-mile buffer was created around secondary risk sites and overlain on the environmentally sensitive areas to determine which of the areas would be considered "at risk" from secondary hazard impacts. Finally, both buffers and sensitive areas were overlain on the hazards risk layer (Figure 15).

Mitigation Opportunities Analysis

Mitigation is the continuing effort to lessen the effects that natural hazards have on people and property. It is the basis of emergency management. Mitigation involves keeping homes away from floodplains, building bridges to endure earthquakes, and creating and enforcing building codes to protect property from damage (FEMA 2002). The first step of this analysis was to identify opportunities other than the existing developed areas for reducing future hazard vulnerability. Using zoning maps, large tracts of undeveloped land and areas designated for future growth were identified. These areas were overlain on the hazards risks layers (Figure 16). This information provides an overview of the potential for future development in high-risk locations. With this information mitigation strategies can be developed that specifically target new development.

The second step in this analysis was to locate housing that would be prone to greater damage from a natural disaster. Mobile homes and houses built before 1970 are at greatest risk for damage. Unfortunately, 1990 Census data does not distinguish mobile homes from other housing structures; therefore this step was not completed. However, the 1990 Census data does list counts of houses older than twenty-five years. This data was overlain on the hazards risk layer to identify high concentrations of older housing structures within high-risk hazardous areas (Table 6).

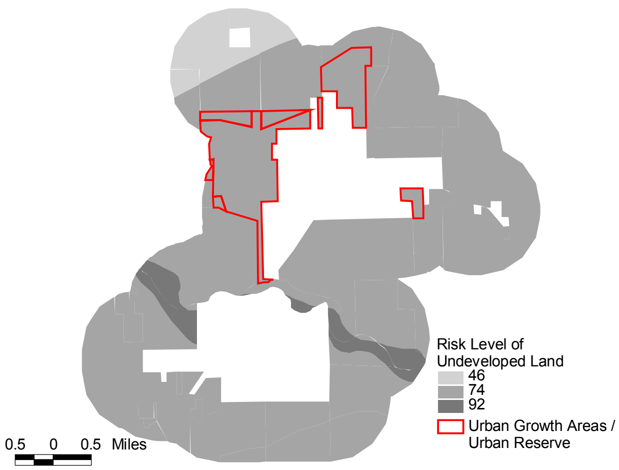

Figure 16. Undeveloped landing in high-risk areas.

Table 6. Count of older housing structures within risk areas.

Total Risk	Count of Houses
74	95
92	86
Total	181

Results & Conclusion

Although mitigation projects should be multi-hazard and attempt to address as many hazards as possible, after examing the hazards risk layer, it is clear that the Enumclaw – Buckley communities are most vulnerable to damage form a lahar moving down the White River valley. Therefore, future hazard mitigation projects should focus on minimizing damages from the following hazards in priority order: Lahars, blast zone damage, tephra fallout damage, and pyroclastic flow. Hazard mitigation projects should also be prioritized according to applicability in high-risk and moderately high-risk areas.

Three bridges and one major highway are within the area designated as the highest risk level in the study area. This roadway is the main connection between the two communities.

A structural assessment should be performed on all facilities within risk areas. These facilities should have evacuation plans in place and practice regular drills.

Once the targeted populations were examined, single parent, low education, and poverty populations seem to be of highest concern in this area. In order to meet the needs of these special consideration populations the community should target these populations with special hazard mitigation education. Information could be delivered through local churches, schools, and community centers. Special evacuation plans need to be in place for populations with mobility needs (elderly and household without vehicles).

Businesses located in high-risk and moderately high-risk areas should be targeted for mitigation strategies. The communities need to develop a special business education program for major employers. Businesses employing a large number should be highest priority for these programs.

Where major commute routes fall within lahar flood zones, alternative routing should be preplanned to allow economic flow to continue.

To address secondary environmental hazards, the communities must conduct a disaster awareness survey on businesses with high environmental sensitivity. A detailed structural assessment needs to be conducted on all secondary risk sites to identify needed mitigation actions.

To ensure that hazards are considered during zoning and subdivision application processes, existing development regulations should be evaluated. Areas with large percentages of older housing structures and mobile homes in high-risk areas should be considered in buy out programs.

Suggestions for Future Analysis

Volcanic triggered earthquakes also pose a high-risk in this area and there fore should be included in a comprehensive hazards analysis. Because little spatial data exists for this hazard, it was not considered in this study.

Further studies should be done in the high-risk areas to identify facilities that have high-risk structures. Buildings that are over twenty years old are considered to be higher-risk. A parcel-by parcel driving survey could be conducted to determine the number and type of vulnerable facilities in high-risk areas.

The economic information within the Census data was not specific enough to complete a thorough economic analysis. More in depth economic studies need to be done to fully understand the economic impact of volcanic activity at Mount Rainier. The community's largest employers and major routes to these employers need to be identified and analyzed, as well as the structures that house these employers.

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Appendix A - Data Sources

1. 2000 Census Block Group - US Census Bureau http://www.ofm.wa.gov/census2000/download.htm
2. Airports – Washington State Department of Health http://198.187.3.168/gis/default.htm
3. Blast – United States Geological Survey Cascade Volcanic Observatory http://vulcan.wr.usgs.gov/volcanoes/rainier/hazards/OFR98-428/framework.html
4. Bridges – Washington State Department of Transportation http://www.WSDOT.WA.gov/gis/geodatacatalog/default.htm
5. Colleges – Washington State Department of Health http://198.187.3.168/gis/default.htm
6. Confirmed & Suspected Hazardous Sites - Washington State Department of Health http://198.187.3.168/gis/default.htm
7. Current Wildlife Habitat – Northwest Regional Ecological Office http://www.reo.gov
8. Dams – Washington State Department of Health http://198.187.3.168/gis/default.htm
9. Daycare Facilities - Washington State Department of Health http://198.187.3.168/gis/default.htm
10. Group A Wells - Washington State Department of Health http://198.187.3.168/gis/default.htm
11. Group B Wells - Washington State Department of Health http://198.187.3.168/gis/default.htm
12. Health Centers - Washington State Department of Health http://198.187.3.168/gis/default.htm
13. Hospitals - Washington State Department of Health http://198.187.3.168/gis/default.htm
14. King County Zoning – King County http://www.metrokc.gov
15. Lahar I - United States Geological Survey Cascade Volcanic Observatory http://vulcan.wr.usgs.gov/volcanoes/rainier/hazards/OFR98-428/framework.html
16. Lahar II - United States Geological Survey Cascade Volcanic Observatory http://vulcan.wr.usgs.gov/volcanoes/rainier/hazards/OFR98-428/framework.html
17. Lahar III - United States Geological Survey Cascade Volcanic Observatory http://vulcan.wr.usgs.gov/volcanoes/rainier/hazards/OFR98-428/framework.html
18. Lahar M - United States Geological Survey Cascade Volcanic Observatory http://vulcan.wr.usgs.gov/volcanoes/rainier/hazards/OFR98-428/framework.html
19. Marbled Murlette Habitat – Northwest Regional Ecological Office http://www.reo.gov
20. National Pollutant Discharge Elimination Systems – Environmental Protection Agency http://www.epa.gov/r10gis/r10mapseries.html
21. Old Growth Forest – Northwest Regional Ecological Office http://www.reo.gov
22. Pierce County Zoning – Pierce County http://www.healthdept.co.pierce.wa.us/gishome.htm
23. Puget Sound Top 20 Employers – Puget Sound Business Journal http://www.bizjournals.com/seattle

24. Pyroclastic Flows - United States Geological Survey Cascade Volcanic Observatory http://vulcan.wr.usgs.gov/volcanoes/rainier/hazards/OFR98-428/framework.html
25. Radio Towers – Washington State Department of Transportation http://www.WSDOT.WA.gov/gis/geodatacatalog/default.htm
26. Railroads - Washington State Department of Transportation http://www.WSDOT.WA.gov/gis/geodatacatalog/default.htm
27. Roads - Washington State Department of Transportation http://www.WSDOT.WA.gov/gis/geodatacatalog/default.htm
28. Schools - Washington State Department of Health http://198.187.3.168/gis/default.htm
29. Sewage Treatment Facilities - Washington State Department of Health http://198.187.3.168/gis/default.htm
30. Sole Source Aquifers - Environmental Protection Agency http://www.epa.gov/r10gis/r10mapseries.html
31. Northern Spotted Owl Habitat - Northwest Regional Ecological Office http://www.reo.gov
32. Superfund Sites - Environmental Protection Agency http://www.epa.gov/r10gis/r10mapseries.html
33. Tephra 1 - United States Geological Survey Cascade Volcanic Observatory http://vulcan.wr.usgs.gov/volcanoes/rainier/hazards/OFR98-428/framework.html
34. Tephra 10 - United States Geological Survey Cascade Volcanic Observatory http://vulcan.wr.usgs.gov/volcanoes/rainier/hazards/OFR98-428/framework.html
35. Toxic Release Inventory - Environmental Protection Agency http://www.epa.gov/r10gis/r10mapseries.html
36. Underground Storage Tanks - Washington State Department of Health http://198.187.3.168/gis/default.htm