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Final Essay
Geology 107
Highline College

Risk affects each person differently. In this paper I will be discussing both my own risk and the risk of the Pacific Northwest region based on the two major geologic hazards of this area, earthquakes and mass movements. We will also be briefly discussing tsunamis and volcanoes.

Risk is defined as the impact an event can have. It is calculated by multiplying hazard by value by vulnerability. Hazard is something we recognize as dangerous based on prior knowledge or experience. This can be assessed by looking at the magnitude (how big it was) and the frequency (how often it happens) of the event. To find the frequency, we have to calculate the recurrence interval. The recurrence interval can be found by taking the time in years that we have data for and dividing it by the number of events that happened in that timeline. The probability of the events occurring, and the size of the event will tell us the hazard. The next factor in calculating risk is value. If there is less value to something, there is consequently a lower risk. Value can be measured in money, human lives or whatever is at risk of being lost. We can reduce the value of things lost by creating zoning laws so people don't build in unsafe areas. Vulnerability is the percent of value likely lost. We can make ourselves less vulnerable by being educated about what to do in case a catastrophic event occurs. The state also sets building codes in order to make sure that buildings are less vulnerable in case of natural disasters. These three components multiplied together will tell us what our risk is. Many people misperceive their risk because they underestimate their vulnerability. We rank things to be lower risk if we feel that we have more control over them. We can also misperceive risks that we don't know are actually risks because of lack of awareness. The consequence of misperceiving risk is often death.

Different materials pose different hazards. For this reason, it is important to know what material you live on so that you can build and plan accordingly to your risk. The area of the

Puget Sound alone has many different materials and land formations. There are lots of different types of geologic hazards in the Pacific Northwest. Many of these hazards can be attributed to plate tectonic movement. Plate tectonics is the theory describing the movement of the Earth's lithospheric plates. Some plates collide, some separate, and some slide past each other. Plates colliding with each other are called Convergent plate boundaries. When two plates collide, one plate goes underneath the other. This is called subduction. Plates that pull apart from each other are called divergent plate boundaries, and plates that slide past each other are called Transform boundaries. (Hyndman, D. and Hyndman, D., 2014, pp. 17.)

The coast of Washington State is along a convergent plate boundary called the Cascadia Subduction Zone. According to the *Pacific Northwest Seismic Network, (2013)*, the Cascadia Subduction Zone is the oceanic-continental convergence between the Juan de Fuca and North American Plates. As time goes on, the Juan de Fuca plate slowly subducts underneath the North America plate. You can see this happening in the diagram below. Being just off the coast of Washington, this subduction zone puts everyone in the area in great danger for a high magnitude earthquake if the plates were to slip. The Cascadia Subduction zone can be held at fault for the many of the mountains in the Puget Sound area, such as the Cascade mountain belt, the Olympic mountains, etc. The volcanos of the cascade mountains run parallel to the oceanic trench.

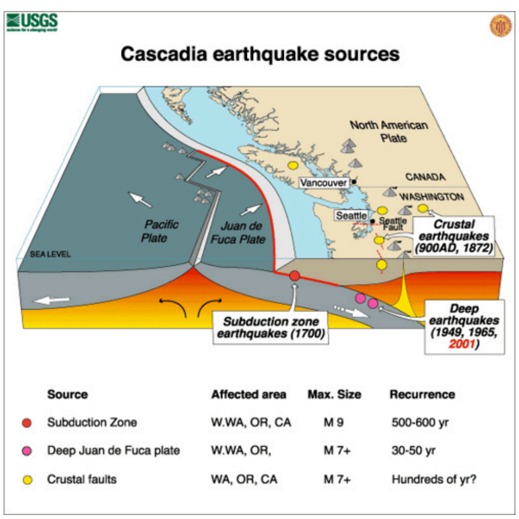


Image Showing: Cascadia Earthquake Sources (PNSN,2013.)

My house is in the city of Kent, located in King County, Washington. I live in a single family three-floor house that was built in the early 1970's with wood framing. The bottom floor of my house is underground so that the third story is only two stories above ground. My house is build on a sloping property so my house is about ten feet or so above street level. I live at the top of West Hill Kent, which is a steep hill leading down to the Kent Valley. There is a river directly at the bottom of the hill, called Green River. There is minor construction work in the surrounding neighborhood, but no major new development. My house sits on Till, which is abbreviated as Qvt. Till is a glacially deposited material composed of many different types of sediment in a range of sizes, generally up to a few tens of meters thick. (Booth, Troost, and Waldron, 2004.) The larger area I live in is called the Pacific Northwest. For purposes of this paper, the Pacific Northwest is the area shown on this map.

Image Showing Satellite Photograph of the Pacific Northwest (Wikipedia Commons.)

If we were to lose the place we live, it would be losing everything. We would have no where to go, and no belongings. We would likely lose our pets and our modes of transportation, as well as everything else in our house. My boyfriend is my next door neighbor, and if my house was lost, his house would likely be as well. I have no other friends or family living within ten miles, so hopefully if there was a natural disaster, they live in a safer place than I. I work for my other neighbor, and her house would also likely be destroyed if there was a disaster. This would mean I also could not work, and I would have no money to be able to get the things I lost back. My family works at least an hour away from home, so they might not be able to get to their place of work if a disaster was to occur. If they were there at the time it happened, I would hope that they would be safe. School is very important to me, and I live only five minutes from Highline College. School would be shut down if there was an emergency. If it was shut down for a long time, I would not graduate high school on time. I'm still financially dependent on my parents, and this would be very hard on them. Their lifes savings is invested in our house, and it would be very hard to start from the ground up at this point in their lives. I would have a lot to lose because everything I love, my activities, and my belongings are all clustered in one small area. If there was a disaster in my area, I would be devastated.

The first risk I that we will assess will be earthquakes.Throughout this section of the paper, I will be discussing both the regional and my personal risk of earthquakes.

As plates move around, they build up stress. Eventually this stress will cause cracking of brittle earth, and create faults. When the plates shift, they release energy in seismic waves. These waves can be recorded on seismograms. There are multiple types of seismic waves, which are all released at the same time; P-waves and S-waves are the ones you see on a seismogram. P-waves are primary waves. They move the fastest and rarely cause shaking. S- waves are shear waves. They do most of the damage in an earthquake, and move slower than P- waves. A seismogram measures the amplitude of earthquake waves over time. If you look at a seismogram after an earthquake hits, you can see that the P- wave reaches the station before the S-wave does. This can tell us when the earthquake hit that particular seismogram, but not what time the earthquake actually hit. If a P-wave arrives _____ seconds before an S- wave, you can use a time travel graph to find the distance from the epicenter of the earthquake. The epicenter is the point on land above that focus of the earthquake. If you do this with two other seismograms in the area, you can use triangulation to find the location of the epicenter. On the graph, you can also see the origin time of the earthquake. You can see that it took the P- wave ____ seconds to travel the distance from the epicenter, and you subtract that time from the time of P-wave arrival to find the time that the earthquake hit. There are also other types of earthquake waves called surface waves, love waves, and rayleigh waves. Seismograms are important because they can help us pinpoint the exact location of the epicenter of the earthquake. Scientists find this information helpful for keeping a record of earthquakes in the area. The records formed by geologists can form patterns and help distinguish exactly where a fault lies. This can be helpful to us in the Pacific Northwest because there is believed to be more faults here than those that we already know exist.

The intensity of an earthquake is the measure of damage and deaths that it caused. One way to measure intensity is to use something called the Mercalli Scale. What we use today is called the Modified Mercalli Intensity (MMI) scale, because has been modified many times by different scientists to fit closer to todays standards (Richardson, Eliza, 2014). The MMI scale uses Roman Numerals on a scale of I-XII to describe the different levels of shaking and damage that houses and individuals experience. The Mercalli scale is more user- friendly than the Richter Magnitude scale and would likely be more efficient at getting the severity of an earthquake into the public eye. This is because people tend to misunderstand how Richter Magnitude works.

Richter Magnitude is the most common method of describing the size of an earthquake.The magnitude is the amount of energy released as a fault fractures. People tend to underestimate great earthquakes because they see the damage that is done by a magnitude five earthquake, and think “a magnitude eight earthquake can’t be THAT much worse.” However, what they don’t know is that there is a tenfold increase between a magnitude five and a magnitude six earthquake alone! Each increase by one on the magnitude scale will increase the amplitude of an earthquake by ten. a magnitude eight earthquake, in reality is 1,000 times worse than a magnitude five earthquake. Also, each whole number increase in magnitude corresponds to approximately 31 times more energy that the last whole number value. You can use a graph called a nonogram to find the richter magnitude of an earthquake using the distance from the epicenter (km) and amplitude of the highest seismic wave (mm.) A misunderstanding of how Richter magnitude works can be deadly. Ignorance increase our vulnerability and therefore our risk.

Magnitude and intensity do not always correlate. For example, if an earthquake is deeper in the earth, it will have a lower intensity. The earthquake still could have released a magnitude seven amount of energy, but since it was deeper, the earthquake waves dissipated before they reached the surface and in turn caused less damage. Also, the type of construction used in buildings, and the type of land you live on can affect the intensity you feel. It will not affect the magnitude of the earthquake. We have deep earthquakes here in the pacific northwest. by the time they reach land, they have dissipated enough to make them much less dangerous to us, with a much lower intensity shaking.

Another part of determining your risk of an earthquake is determining the frequency of occurrence. To find the recurrence interval for an earthquake, you have to know the number of earthquakes you have had, and records of when the earthquakes happened. You divide the number of earthquakes that you have records for by the years that you have on record. For example, by looking at the Pacific Northwest Seismic Network (PNSN) website, I found that there have been 1,240 magnitude three earthquakes in the last 20 years. I divide 20 years by 1,240 earthquakes to get a recurrence interval, or frequency of 0.0161 years. This means that there are many magnitude three earthquakes in any given year. For magnitude four earthquakes, I looked at data from the last 30 years. There were 52 magnitude four earthquakes in this time frame (PNSN, n.d.); 30 years divided by 52 earthquakes equals a recurrence interval of 0.5769 years. For magnitude five earthquakes, we begin to see a change in that there are fewer earthquakes than the amount of years on record, meaning that there is fewer than one earthquake per year. There have been 23 magnitude five earthquakes in the last 45 years (PNSN, n.d.) 45 years divided by 23 earthquakes equals 1.9595 years. For magnitude six earthquakes, there has been 16 earthquakes in the past 155 years (PNSN, n.d.), which gives us a recurrence interval of 9.6875. And lastly, for magnitude seven earthquakes, there have been three in the past 155 years (PNSN, n.d.), which equals a recurrence interval of 51.6667 years.

I then graphed the recurrence intervals for these points on a magnitude vs. period graph. I found that as the period (years per earthquake) got larger, so did the magnitude. This makes sense with my data because bigger earthquakes are less frequent, so there should be less years in between them. After plotting my points, I drew a line of best fit on the graph and continued it to magnitude eight and nine earthquakes. I was not given the recurrence intervals for magnitude eight and nine earthquakes, but by extending my line of best fit on my graph, I found that magnitude eight earthquakes will have a frequency of approximately every 250 years, and magnitude nine earthquakes will have a frequency of approximately every 1,500 years. I know that there is evidence of a magnitude nine earthquake in the Pacific Northwest 1,100 years ago, and again 315 years ago. This means there was 785 years in between them. This doesn't quite fit in with my data; however, a recurrence interval is just an average, not a strict restriction. I believe I calculated my data correctly.

I have to say, these numbers don't sound too promising. Statistically, I have a very high chance of experiencing some of these earthquakes in my lifetime. To find the probability of one of these earthquakes happening in any given year, you divide one by the recurrence interval. For example, the recurrence interval for a magnitude eight earthquake is 250 years. Divide one by 250 and you get 0.004. To find the probability of an earthquake happening in your lifetime, you need to use the recurrence interval, and the probability of the event in one year. You must also know that the average lifespan is approximately 70 years. The formula you would use to find the probability of an earthquake in your lifetime is $1\text{-}P_s = (1\text{-}P_i)^n$. P_s is what you're solving for; it means probability of a series of events. P_i is the probability in any one year, and n is the number of years in your lifetime. To set this equation up for a magnitude eight earthquake would look like $1\text{-}P_s = (1\text{-} .004)^{70}$. This equation comes out to .24, which means that there would be a 24% chance of a magnitude eight earthquake happening in your lifetime.

There are three different types of earthquakes we are in danger of in the Pacific northwest. The first kind is a deep earthquake. These earthquakes occur 30-40 miles below the surface of the Earth (Seattle Post-Intelligencer, 2002). In a deep earthquake, breaks in the subducting slab are what produces the earthquakes. This type of earthquake typically has less of an impact because much of the energy from these quakes dissipates before hitting the surface of the earth, (Seattle Post-Intelligencer, 2002) but they still can create significant to extensive damage. The shaking from a deep earthquake can last anywhere between 15 and 30 seconds. An example of this in the Pacific Northwest would be 1949 earthquake in Olympia, the 1965 Seatac earthquake, or the Nisqually earthquake in 2001. We see deep earthquakes every 20 years or so. Seeing as the average lifespan is 70 years, there is a very high probability of experiencing at least one of these in your lifetime.

The second type of earthquake in the Pacific Northwest is a subduction zone interface earthquake. This occurs offshore at the point when the Juan de Fuca plate slides under the North America plate. Normally, the plates are locked together but they build up stress as they push, resulting in either uplift or subsidence of the North America plate. Eventually the plates slip and bounce back, dropping what has been lifted up. An example of this is the Olympic mountains. The Olympics rise by a few inches every year because of the stress on the subducting plates. When the subduction zone interface earthquake occurs, the mountain range will drop back down the amount that it has been raised every year. This type of earthquake typically has the highest magnitude, and is considered to be the “biggest” of the three types. They can last anywhere between one to five minutes and occur on average every 400-600 years (Seattle Post-Intelligencer, 2002.) The last known megathrust earthquake in the Pacific Northwest was in

January of the year 1700. (PNSN, 2013 [2]) They produce the greatest aftershocks. The probability of experiencing an earthquake like this in your lifetime is much slimmer than that of the deep earthquakes we get here in the pacific Northwest.

The final type we see in the Pacific Northwest is shallow crustal earthquakes. This accounts for faults that run through Washington State, such as the Seattle and Tacoma faults. Shallow crustal earthquakes occur when crustal stress from the subducting Juan de Fuca plate causes fractures in the North America Plate (Seattle Post-Intelligencer, 2002.) These type of earthquakes typically last between 20 to 60 seconds and can produce violent shaking up to magnitude seven.Seattle Post-Intelligencer, 2002.) This is the type of earthquake that produces the highest intensity earthquake with the most shaking, because they are so close to the surface. They also cause the most damage to structures. The recurrence interval for this type of earthquake is unknown because there is only one in our records, and it occurred approximately 1,100 years ago.

I believe that while the subduction zone interface earthquakes are the “biggest,” they are not the ones creating the most damage. Subduction zone interface earthquakes create a shaking that has the possibility of totally collapsing skyscrapers, which we have lots of in Seattle. However, I am mostly worried about shallow crustal earthquakes happening in the Pacific Northwest. Even though they aren’t the greatest magnitude, they are closer to where we live (right under us in some cases, with the Seattle and Tacoma Faults,) and produce more shaking. Higher intensity shaking means the most damage, with the greatest amount of damage to residential houses and older brick buildings (Seattle Post-Intelligencer, 2002.)

A scenario is a description of what could happen in an earthquake. The Washington State Department of Natural Resources (DRN) has put together different scenarios that are possible in Washington state to show what kinds of effects they might have.The first scenario I looked at was the Seattle Fault.

The last rupture of the Seattle fault was around 1,100 years ago, according to the Washington State Department of Natural Resources. It was approximately a magnitude seven earthquake. I examined a scenario where the Seattle fault produces a 7.1 magnitude earthquake. If this scenario were to happen midday, there would be 17,677 total people injured (DNR, 2013 [a].) There would be 18,193 people requiring shelter, 38,156 buildings completely or extensively damaged, and $5.3 billion in income lost (DNR, 2013.[a])

I also looked at the Tacoma fault. It is likely that the Tacoma fault ruptured along with the Seattle fault 1,100 years ago. If this scenario were to happen midday, there would be 6,070 total people injured (DNR, 2013 [b]) There would be 7,146 people requiring shelter, 19,867 buildings completely or extensively damaged, and $1.8 billion in income lost (DNR, 2013 [b])

After looking at the Seattle and Tacoma scenarios, I took a look at Cascadia. The last rupture of the Cascadia fault was on January 26th, 1700, with a recurrence interval of approximately 500 years (DNR, 2013 [c].) This means that there is a 1/500, or .2% chance that the Cascadia Earthquake will occur in any given year. The magnitude of the scenario I'm looking at is a 9.0 on the Richter scale. Cascadia is a subduction zone- interface earthquake, so it is likely to be followed by "thousands of aftershocks, few of which could be large enough to cause additional damage and produce tsunamis" (DNR, 2013 [c].) The scenario report states that King County will feel most of the impact of the quake, followed by Clallam, Grays Harbor, Jefferson, King, Mason, Pacific, and Pierce Counties. Twenty-three counties in total will be affected by this earthquake. The injuries that would occur if the earthquake were to happen midday at 2pm would be around 7,534 people (DNR, 2013 [c].) There would be 11,630 people requiring shelter, 43,681 buildings extensively damaged, 8,768 buildings completely damaged, and $3.8 billion in total income lost (DNR, 2013 [c].)

The last scenario I looked into is an earthquake in Seatac, Washington. The historical records show that the average recurrence interval for M6.5 or greater earthquakes in Washington State is approximately 30 years (DNR, 2013.[d]) That means that there is a 1/30 chance or 0.033 probability that a M6.5 earthquake or larger will happen in any given year. The magnitude of the scenario I analyzed was a 7.2. Deep earthquakes tend to do less damage than shallow earthquakes of comparable magnitude because earthquake waves in deep earthquakes lose much of their energy before they reach the surface. Since this was a deep earthquake, there is not likely to be aftershocks that are big enough to be felt. If the Seatac earthquake were to hit at 2PM, injuries would be substantial. 146 people in King county would have fatal or near- fatal injuries, and 388 others will also need to be hospitalized (DNR, 2013. [d]) There would be 3,871 individuals requiring shelter, 9,924 buildings will be been extensively or completely damaged, and he total income loss in this scenario would be around 1.7 billion (DNR, 2013. [d].)

After analyzing the scenarios for Seattle, Tacoma, Cascadia, and Seatac, I personally feel that when this earthquake occurs, my community will be adequately prepared. The damage is slight enough that it will probably inconvenience people, but we will get back on our feet easily. Though it was a different kind of earthquake, it seems to be equivalent in damage to the

Nisqually earthquake we experienced in 2001. We dealt with that pretty well. However, this will likely affect the state of our economy because it will cost a lot to fix.

The Pacific northwest had a lot to worry about if an earthquake of any size was to happen. Things that we need to worry about include ground and building stability, slope stability, falling objects, tsunamis, liquefaction, and fire. We also need to be aware of power, water, gas, and electric lines, sewer mains, and roads. The pacific has billions and billions of dollars to lose if we remain unprepared like this, along with the live of many people. This is not something we should continue to be ignoring. *Image showing: outside view of my house*

By analyzing your own home, you can see how prepared you'll be for an earthquake. I live in Kent, which is a city located inside of King County, Washington. My house is located approximately 16 miles south of Seattle. I live in a single family, three-floor house that was built in the early 1970's with wood framing. The bottom floor of my house is underground so that the third story is only two stories above ground. My house is build on a sloping property so my house is about ten feet or so above street level.

I live at the top of West hill Kent, which is a steep hill leading down to the Kent Valley. There is a river directly at the bottom of the hill, called Green River. There is minor construction work in the surrounding neighborhood, but no major new development. My house sits on Till, which is abbreviated as Qvt. Till is a glacially deposited material composed of many different types of sediment in a range of sizes, generally up to a few tens of meters thick. (Booth, Troost, and Waldron, 2004.) Different materials pose different risks because some are more likely to experience natural disasters such as landslides. For this reason, it is important to know what material you live on so that you can build and plan accordingly to your risk.

Image showing: my fireplace, outside view. I have a fireplace attached to my house, and we have wood-burning fires frequently. It would be dangerous to use a fireplace if the it had not been inspected since an earthquake. My chimney was last inspected in November of 2014. It is free of creosote, however it was damaged in the last earthquake and it needs to be rebuilt. We have been using it every year since the earthquake and we haven't had problems with it so far, however it is in danger of collapsing if there was another earthquake. The photo does not show the cracks running through the chimney, but it does show where a few pieces of the stone on my chimney have broken off as a result of the Nisqually Earthquake of 2001. Primary earthquake hazards include fire, liquefaction, mass- wasting, debris falling, ground- rupture, and tsunamis. These can all be caused by an earthquake, and the most common is debris falling.

My house has natural gas. The shut off valve is outside on the side of my house. This controls all of the gas that goes into the house. When you twist the knob, gas is shut off. *Image showing: the gas shut off valve outside my home. The knob is on the top right corner.*

Knowing where the shut off valve is in your home is important because gas lines can break during earthquakes and ignite, causing fires. Its important to know if your water heater is gas or electric. The one in my house is gas. The yellow knob functions to shut the gas off to the hot water tank. There is also a gas shut off to the furnace next to the hot water heater.

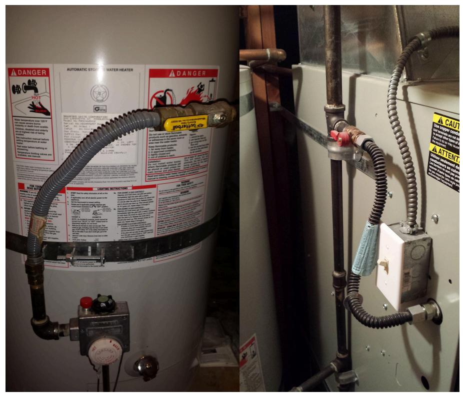


Image showing: gas shut offs to hot water heater and furnace

The red knob turns the gas off to the furnace. In the event that I could not get outside in an emergency, I could shut off all of the gas in my house using the red and yellow knobs. The light switch turns off the furnace itself. The orange knob is the shut off to the water coming in to the hot water tank. If there was an earthquake, I could shut this off to try and prevent flooding.

Image showing: hot water shut off valve

Water heaters are heavy and can detach from the wall in the event of shaking. If your water heater is strapped down, it is less likely to do so. My water heater is bolted to the wood beams surrounding it.

Image showing: water heater secured to the beams.

It is also important to know where the electrical panel is in your house so you can shut off the power to your house. Mine is difficult to get to, as it's located behind the fridge in my garage. It should really be in a more accessible place. To shut off the power to my house, I would use the switch that's on the top right of the panel. This shuts off the power to everything.

Image showing: electrical panel and shut-off

Shaking during earthquakes can cause other heavy things to fall too. When I look around my room, there are many potential hazards if an earthquake were to occur. I have a picture frame above my bed and if it were to fall on me while I was sleeping, it could be very dangerous. I also have a lot of books and glass bottles on the shelf above my reading chair. I sit there often and it would also be very dangerous to me if there was an earthquake.

Images showing: picture above my bed and bookshelf in my reading nook

Because the damage to my house could cause my family to be trapped or without water and other necessities, it is important that my family and others have an earthquake kit. When I was younger, my family had an emergency kit in my house that had a bunch of water and some non perishable food and other items in it. I think it would be important to have food and water in an emergency kit, as well as flashlights, portable radios, batteries, sleeping bags, some tools, a lifestraw, toilet paper and feminine hygiene products, a first aid kit, and a change of clothes for everyone. I do not have plans to get one right now because I cannot afford it, but as soon as I have a little extra money, I want to put one together. This doesn’t have to be done all at once, I will start buying things a little bit at a time so that I can slowly build up my kit.

If we were to lose the place we live, it would be losing everything. We would likely lose our pets and our modes of transportation, as well as everything else in our house. My boyfriend is my next door neighbor, and if my house was lost, his house would likely be as well. I have no other friends or family living within ten miles, so hopefully if there was a natural disaster, they live in a safer place than I. I work for my other neighbor, and her house would also likely be destroyed if there was a disaster. This would mean I also could not work, and I would have no money to be able to get the things I lost back. My family works at least an hour away from home, so they might not be able to get to their place of work if a disaster was to occur. If they were there at the time it happened, I would hope that they would be safe. School is very important to me, and I live only five minutes from Highline College. School would be shut down if there was an emergency. If it was shut down for a long time, I would not graduate high school on time. I'm still financially dependent on my parents, and this would be very hard on them. Their life's savings is invested in our house, and it would be very hard to start from the ground up at this point in their lives. I would have a lot to lose because everything I love, my activities, and my belongings are all clustered in one small area. If there was a bad earthquake in my area, my life would be changed forever. I place the value of my life and that of my family very high, so my risk goes up a lot because I have lots of value in the equation.

I believe that while the subduction zone interface earthquakes are the "biggest," they are not the ones creating the most damage. Subduction zone interface earthquakes create a shaking that has the possibility of totally collapsing skyscrapers, which we have lots of in Seattle. However, I am mostly worried about shallow crustal earthquakes happening to me personally. Even though they aren't the greatest magnitude, they are closer to where we live (right under us in some cases, with the Seattle and Tacoma Faults,) and produce more shaking. Higher intensity shaking means the most damage, with the greatest amount of damage to residential houses (like mine) and older brick buildings (Seattle Post-Intelligencer, 2002.) I am not as worried about deep earthquakes because they tend to have a much weaker intensity by the time they reach us.

My house is not in the area of possible ground rupture of the Seattle Fault. (Barnett, Ballantyne, D.B., Haugerud, R.A., Meagher, E.A., Weaver, C.S., 1999.) I live approximately thirteen miles from the closest area of possible rupture on the Seattle Fault. However, I am much closer to the area of ground rupture for the Tacoma Fault, living just three and a half miles away. My house is two miles from the nearest liquid fuel pipeline, eleven miles from the nearest natural gas pipeline, and four piles from the nearest 5kV electrical line. (Barnett, Ballantyne, D.B., Haugerud, R.A., Meagher, E.A., Weaver, C.S., 1999.) Because of my proximity, it is possible, although not super likely, that my house will experience fire or explosion should the Seattle Fault rupture. It is very likely that I will experience pretty heavy shaking in a Seattle Fault earthquake. If the Tacoma Fault ruptured, I would also feel shaking effects.

The Seattle Fault could possibly generate a tsunami and endanger people living near the Puget Sound at low elevations. Fortunately, my house is pretty high above sea level, and about seven miles away from the Puget Sound. Since I'm so high up, my house is very unlikely to feel the affects of a tsunami.

I live about one mile from the top of a steep hill. If a landslide was to happen because of an earthquake, I'm fairly certain that I'm far enough away that my house would be safe. According to the map, *Liquefaction Susceptibility for the Poverty Bay Quadrangle, Washington,* (1995), my house has a low liquefaction susceptibility.

During the Nisqually earthquake of 2001, my home sustained shaking at a level VII on the MMI scale. This is described as having the effects of being “difficult to stand, furniture broken,...noticed by people driving motor cars.” (Dewey, et.al.,2002) There is slight damage to homes and more damage to poorly-built homes and structures. As far as intensity, my house was surrounded by areas that got some pretty high intensity shaking, but I was in a pocket that seemed to have less acceleration during the earthquake.

Previously, I analyzed four scenarios that told me what an earthquake would look like on the Seattle, Tacoma, Cascadia, and Seatac faults. These scenarios can also help me determine my own personal risk for this type of shallow fault earthquake.

In the Seattle earthquake scenario, the Mercalli intensity for the shaking at my house is a VII-IX, which means severe to violent shaking. The hospital closest to my house is Valley Medical Center. They are most likely to have slight to moderate damage when this earthquake occurs, and there will be 17 out of 303 beds available on day one (DNR, 2014.[a]) None of the schools near me have a high probability of having moderate damage. The school closest to me in Sunnycrest Elementary. This school has recently been rebuilt, to there is only a high probability that the will have no damage, or slight. (DNR, 2014.[a]) There are no natural gas facilities near me as shown on the map. The closest one pictured is ten miles away, and it is most likely to experience moderate to extensive damage (DNR, 2014 [a].) However, seeing as my house has Natural gas lines, there is likely one closer. The bridges closest to my house will all likely experience moderate to high damage (DNR, 2014.[a]) These bridges are mostly all on our biggest interstate, I-5, and highway 167. My house has a low risk of liquefaction, however, the area less than a mile from my house will likely have high liquefaction so this will also impact me (DNR, 2014 [a].)

For the Tacoma scenario, the Mercalli intensity for the shaking at my house is a VII-IX, which means severe to violent shaking. The hospital closest to my house is Valley Medical Center. They are most likely to have slight damage when this earthquake occurs, and there will be 68 out of 303 beds available on day one (DNR, 2014. [b]) Many of the schools near me have a high probability of having moderate damage. The school closest to me in Sunnycrest Elementary. This school has recently been rebuilt, but they are still mostl likely to experience slight to moderate damage. (DNR, 2014. [b]) There are no natural gas facilities near me pictured on the map. The closest one pictures is ten miles away, and it is most likely to experience slight to moderate damage (DNR, 2014. [b]) However, there are likely natural gas facilities closer by. The bridges closest to my house will all likely experience moderate to extensive damage, and the one closest to my house (an Interstate-5 overpass) will be completely collapsed. (DNR, 2014.[b]) These bridges are mostly all on our biggest interstate, I-5, and highway 167. My house has a low risk of liquefaction, however, the area less than a mile from my house will likely have high liquefaction so this will also impact me (DNR, 2014. [b])

I feel that a shallow crustal earthquake on the Tacoma fault will be the most damaging to myself and my community. Although a subduction zone interface earthquake will produce bigger magnitude quakes, we are farther away from that earthquake. My house sits very close to the Tacoma fault, and as I've analyzed in different scenarios, my community will have the most extensive damage during the Tacoma fault earthquake. Bridges will collapse, there will be liquefaction, and natural gas facilities will be damaged (DNR, 2014 [b].)

Taking a look at the map for the Cascadia earthquake scenario, I found that the shaking at my home had a Mercalli intensity of VII. The hospital closest to me is likely Valley Medical Center. They are likely to experience no damage from the earthquake, with a 25% chance of slight damage. (DNR, 2014. [c].) 223 of the 303 beds will be available on day one of the quake (DNR, 2014. [c].) None of the schools near my house will receive a high amount of damage. The closest one to me, Sunnycrest Elementary, has only a 1% chance of having a moderate amount of damage (DNR, 2014. [c].) It has recently been rebuilt. The closest gas line is the Northwest Piping Corporation in Renton, and it has a 22% chance of experiencing moderate damage. It is most likely to have slight damage (DNR, 2014. [c]) The highway (I-5) bridge closest to me is right next to my house. There is a 5% chance of it experiencing slight damage, and it is most likely to experience no damage. (DNR, 2014. [c]) There are no bridges near me that will experience moderate to high damage.

The final scenario I looked at was the Seatac fault rupture scenario. The Mercalli intensity for the shaking at my home would be a level VII, which means I would be experiencing very strong shaking. Should I get hurt, the hospital closest to my house is Valley Medical Center in Renton. There is a very low chance that the hospital will have moderate damage. They are most likely to experience no damage, or slight (DNR, 2014. [d]) 187 out of 303 beds will be available the day of the event. Sunnycrest Elementary is the closest school to my house. They were very recently rebuilt, so there is only a one percent chance that they will experience moderate damage to the building, and they’re most likely to experience no damage at all (DNR, 2014. [d]). The closest gas line to me is the Northwest Piping Corporation in Renton, and it has a 29% chance of having moderate damage. It is most likely to have slight damage (DNR, 2014.

[d]) The I-5 highway overpass bridge closest to me has a 93% chance of having no damage at all, and the bridge closest to me that will experience damage of any kind is one mile away from my house and has a 17% chance of slight damage (DNR, 2014. [d].)

The map also shows the amount of households that will likely be displaced when the Seatac earthquake occurs. My area is one of the better ones surrounding me, as only five households in my area will be displaced, and three individuals will require short- term shelter (DNR, 2014. [d]) The areas surrounding me will have much more displacement, with people in the hundreds being displaced and requiring shelter. (DNR, 2014. [d])

Anyone can calculate the ground shaking and damage that is likely to occur at their home. I live in the Yorkshire neighborhood of Kent. There is a 10% probability that in the next 50 years, I will experience an earthquake that produces a hard rock ground acceleration exceeding 25% g (USGS, 2010.) However, the map I used for this uses calculations for bedrock, and I have to do some math to calculate what the risk is according to what I live on. My house sits on till, which is abbreviated as Qvt (Booth, Troost, and Waldron, 2004.) Qvt tells me that my peak ground acceleration (PGA,) will really be triple what it would be if my house was on bedrock. If I multiply my PGA by three, I get my actual calculation. I have a 10% probability that I will experience a shaking that produces ground shaking acceleration exceeding 75% g in the next fifty years.

The Modified Mercalli Intensity Scale (MMI) tells me that my peak ground acceleration of 75% g will equate to an earthquake with an intensity of IX. This means that buildings will be partially collapsed, and even well designed buildings will move off of their foundations. (Dewey, et al., 2002.) This will be a large earthquake that will cause damage my area.

Even more information on the potential damage to your home can be found by looking at the way your home is built. My home is a wood frame, single family house between one and three stories, built in the 1960s (ABAG, 2003.) My house would likely experience chimney damage, and damage or collapse to our garage, which has living space above it. Our chimney is made of old, unreinforced masonry. According to the ABAG, (2003,) around 1% of homes of my building type will be uninhabitable should an earthquake of MMI level IX occur. This doesn't seem like much, but since there are hundreds of thousands of homes like mine, this will still mean a ton of people. I still worry about the effects an earthquake like this will have on me and the buildings around me. My school and other places that I go daily are not made of the same material that my house is, and may have higher chances of being totaled in a large- scale shaking.

Overall, my risk for earthquakes varies. Depending on the type of earthquake that happens, where it happens, and where I am, my hazard and vulnerability to a quake will change. This means my risk will vary a lot. The value of my property is important, and would cost a ton of money to re-build, but I am most concerned with the value of the lives of my family members and I. Life is something you can't get back with all of the money in the world. I feel much more uneasy about my risk of earthquakes now that I know more about how often they happen. I was in the pool of people who misunderstood my own risk because of misperceiving the Richter scale. Also, because I had never experienced a big one, I felt slightly disconnected from them. After doing research on all of the different earthquake hazards in this area, I have definitely re-thought my need for an emergency kit, as well as my perception of risk. Earthquakes have the potential to do way more damage that most people in the Pacific Northwest could even comprehend. Public education needs to change in a major way, and this is becoming more and more important to me with the more research I do.

If there was a tsunami risk at my house, it would come from the east. My house is 433 feet above sea level and 1.73 miles from Puget Sound, which means the land slopes at an average 7-9% grade from my house to the water (Google Earth, 2015). Tsunamis can move pretty far, but I am over 400 feet above sea level so if a tsunami were to occur here, I believe my house would be safe. I do not live in an area that has been mapped by the Department of Natural Resources (DNR). I do not frequent any areas that have been mapped for tsunamis on the DNR website. I go camping twice a year at Ocean Shores on the coast of Washington, however, and this area has been mapped for evacuation routes by the DNR. I also know the evacuation route from where I stay because there are tsunami evacuation route warning signs all over the area.

The next topic in my essay is mass movement. The Puget Sound area is famous for mass movements. In this section, I will be discussing both our regional susceptibility and my personal risk for mass movements. I will also discuss why they happen and how we can mitigate them.

There are three types of mass movements that I will be focusing on in this paper: creep, translational slides, and rotational slumps. Creep is a very slow-moving, gradual downslope movement caused by ground shrinkage and expansion. You can tell if creep is happening if you see trees bent. This can happen because the ground is moving the trees away from their original spots, but they still want to bend up to the sun, so they curve. Fences and piping that's perpendicular to the slope will become bent, tilted, or broken. You can also tell that creep is happening by looking at the underlying layers of the ground to see if the rock and sediment has moved or become tilted. This is easier to do if a structure is old, or thee ground is untouched by humans.

Slides move much faster than creep. There are many ways slides can occur, on a wide variety of slope materials. You can tell a slide has happened by looking at the landscape, roads, utilities and buildings, vegetation, and water. (WA Department of Ecology, n.d., [3]) You can also tell where some areas are landslide prone because they will have human reinforcements. Three common ways that people engineer solutions to mass wasting include taking water out of the slope, adding vegetation, and reinforcing the slopes by means of a cage or triggered, controlled landslides. (WA Department of Ecology, n.d., [4])

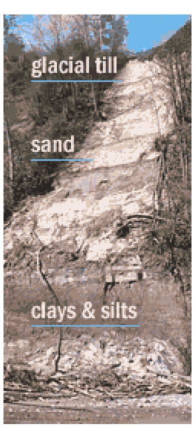
There are two major types of fast- moving landslides that we experience in the Pacific Northwest. The first is called a rotational slump. A rotational slump is a type of slide where the land slips on a curving slope, concaving inward. We see evidence of these types of landslides when we see hills that look like they have a number of ridges in them. The vertical part of the ridge will have no vegetation if the slope has slid recently. This part is called the headscarp. The hillside will vaguely resemble stairs if a rotational slump has happened there. The bottom of the slope forces soil upwards, pushing displaced material past the bottom of the slide. This is called the toe.

The second type of fast moving landslide we see here is called a translational slide. These slides happen on areas that are more shallow, and parallel to the slope. In most cases, trees and soil that are sitting parallel to a slope will slide off of the bedrock because it becomes saturated with water. These often move faster and farther than rotational slumps. We see evidence of this when trees and other debris, like houses, are moved from their original spot on or underneath the hill, pushed away from the slide. (Hyndman, D. and Hyndman, D., 2014. pp. 198.)

The six factors that contribute to landslides in the Puget Sound are: geology, gravity, weather, groundwater, waves, and human actions. As groundwater rises in the months december through march, we have a higher risk of landslides. Clearing of vegetation, poor drainage practices, and onsite septic systems are all human actions that can all add to groundwater. If groundwater gets too high, till and other soft materials can slip off of bedrock and create a landslide. (Washington State Department of Ecology, n.d.)

The till that appears atop many hills in the area glacially deposited, Vashon aged, hardpan till. This was deposited around 13,000 years ago, when a giant glacier moved through the land of the Pacific Northwest. The next layer below till is called esperance sand. Esperance sand was deposited "by streams issuing from the ice sheet while it was located some distance to the north." The bottom layer is made up of Lawton clay. This was deposited pre- glacial advance by a giant lake. When rain and other water sources dampen till, they leak down into the esperance sand. Once both layers are saturated, water reaches the clay. Since clay is much less permeable, the water does not soak through, but instead creates a slick surface in which the first two layers can easily slide off of. (Gerstel et al., 1997)

Image Showing: Puget Sound Geology (Washington State Department of Ecology [2])



In March of 2014, there was a large landslide in Oso, Washington, that killed many people. The cause of the Oso landslide was groundwater. The was incredibly heavy rainfall in the month of march over 24 inches above average for that month. The river running through the base of the slope, as well as nearby logging may have also played a part by eroding the slope and undercutting the hill. There is a long history of landslides in the area , which makes it prone to future landslides. The debris flow in the Oso landslide happened in two phases, with the layers of till (churned up from previous landslides) coming down the slope, and then large pieces of the cliff breaking off and coming down as well. Forty-three people were killed, and the damage was extensive, with complete destruction of the area. Similar to the landslides of December 1996 to January 1997, the Oso slide occurred in area that experienced heavy rainfall, and was in an area that was known to be landslide-prone. (Doughton, S., 2014)

Groundwater is a major factor in most Puget Sound landslides. The Puget Sound area experiences its prime rain months from November to February. In the month of November, the ground is experiencing a change from dryness to dampness. Dampness does not cause landslides. However, in the months following November, the ground becomes more and more saturated. that is why we see our prime landslide months happening from December to March. Landslide recurrence intervals can be calculated the same way as landslides, using the time recorded, divided by the number of landslide events. There have been five “bad” landslide years in the last 104 years we have on record. A bad landslide year is one where the amount of landslides had been *significantly* worse than those preceding. To find the recurrence interval for bad landslide years, I took the number of years we had recorded and divided it by the amount of bad landslide years we had. I got a recurrence interval of almost 20.8 years. I divided the 20.8 by one to get a 4.808% chance that any given year could be a bad landslide year.

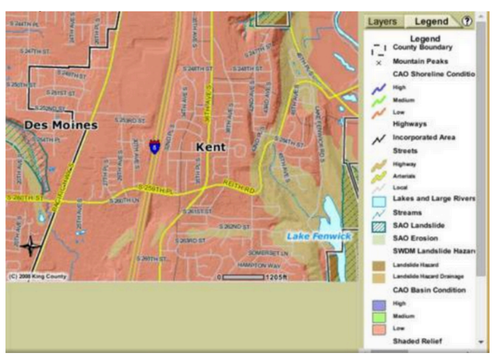
Reviewing a map from compiled City of Seattle information, I noticed that almost all of the landslides that occurred between December of 1996 and January of 1997 occurred in known landslide areas. There are two major ways that we can decrease our risk of losing more people to landslides. One is public education. Cities should make their people aware of the danger that they are living on. It only seems ethical. Everything in their power should be used to make the people living in dangerous areas aware of the danger they face, as well as keeping developers from building in unsafe areas, or areas with a history of landslides. Unfortunately, many people will not be willing to uproot their families and the lives they have built, so the second solution is to work on mitigating the hazards; reinforcing slopes, preserving vegetation, and improving surface drainage are all examples of this. This will be the most effective way to mitigate landslide risk in an area already so densely populated. It will be expensive, but the gain from it is less lives lost to landslides in the long run.

Each year, the United States Geological Survey spends $2.4 million dollars on landslide hazards, and $49 million dollars on earthquake hazards. (Bell, B., 1999.) I believe that this is unfair, because landslides are the most widespread geologic hazards. Landslides are much more preventable that earthquakes and if we spend more hi public education, I believe that fatalities would go down significantly. Landslides are one of the most preventable types of natural disasters, and living in the Pacific Northwest, you would think that we would be working harder to prepare for landslide hazards, in addition to earthquake hazards.

In 1982, a landslide occurred in San Francisco California. Two houses went down in the slide, one of which had three sleeping children inside. None of the children survived. Since 1992, new houses have gone up on both lots, and no one has made it a big deal. I believe that if any “soft” solutions to landslides had been put in place, this would not have happened. Hard solutions to earthquakes include things like debris dams, retaining structures,drainage systems, and graded slopes. These things take lots of time and money to put into place. Hard solutions reduce your hazard in a landslide by making it so that the mass movement is less likely to happen, or hurt you if it does happen. Soft solutions to earthquakes are things like having zoning laws and building codes to prevent people from building on landslide prone areas. These things rely on avoidance of landslides that are inevitable. Soft solutions reduce your value in a landslide. If no one builds in unsafe areas, then no lives will be lost or anything monetarily valuable. (Bell, B., 1999.)

After reading this article, I believe that a combination of both soft and hard solutions will help to solve the landslide problem in the Puget Sound area. In many places, the damage is already done and people have built on unsafe lands. I think that we should set up a landslide warning signal in areas that are prone to landslides, and those areas should be monitored under USGS budget. There should be mandatory evacuation when the hazard gets bad. Educating these people about the risk they're subjecting themselves will also help. We can implement hard solutions here as well, by reinforcing the cliffs and hills that these people have already built on. For the rest of the Puget Sound that is undeveloped, we should develop stricter building codes for landslides. (Bell, B., 1999.)

So I went looking for some signs of landslides or creep in my neighborhood. I didn't find any evidence in my own yard. My neighborhood is sloped slightly to the south at a 4.5° angle. Walking around, I saw little evidence of creep. I found only a few trees bent, no fractured pavement, and no tilted fencing. However, our roads were just repaved recently because they were doing work on utility lines underneath the street. I could be missing some signs of creep here, because I can't tell if the ground is cracking. The only evidence I found that might show creep were in people's individual yards. I noticed that sometimes, trees were bent going down the slope of their yard, and lots of people had cracked pavement leading up to their houses. I was unable to get pictures of these without actually going into people's yards. Creep is a much less obvious form of mass movement, so it can be hard to miss. I believe I identified some signs of creep going in the downslope direction. I also know that there is an area that has a risk of creep and other fast- moving mass movement near me, but it is hidden in the yards of those people whose houses are backed up to the freeway. This shouldn't cause too much damage. The closest mass wasting hazard zone is approximately 900 feet from my house. (City of Des Moines GIS, 2004.) This will not directly impact my house. However,my aunt lives on top of that area and would likely lose her house, if not her life in a slide there. It would be very dangerous to a lot of people because there are apartment buildings on that slope that house many people. Lastly, traffic would be much worse on military road and will affect the commute of many locals. *Image Showing: Map of Landslides in my area, King County, (2015) Areas shown in the dark pink*



area are the areas of fast-moving mass wasting hazards.

The only place I saw any human reinforcement or purposeful landslide prevention in my neighborhood was once again on the individual properties of people who had raised up houses. I saw people who had build walls of stone and concrete out in front of their houses to keep their land from sliding.

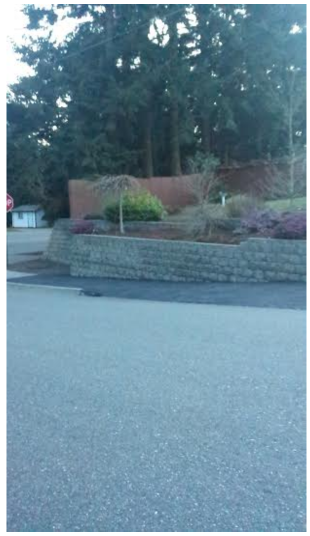
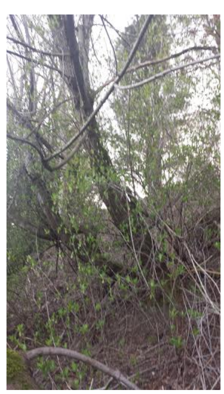
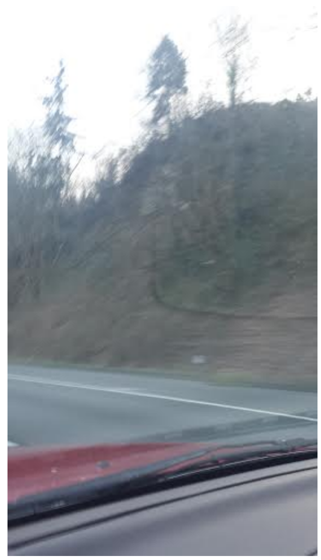


Image Showing: a retaining wall in my neighborhood

The area I identified on a map as being the closest area to my house with a risk of landslides was about a mile away, on the slope going into the Kent valley. After taking pictures in my own neighborhood, I visited this area. Here, I found evidence of creep, fast moving slides, and human reinforcement. The hill has been cut into and flattened many times to make room for neighborhoods on the hill. The first picture shows signs of creep on the areas of the hill that have not been cut into, as the trees are bent. You can clearly see where the trees have been tilted off of their original spots. *Image showing: evidence of creep*



I also found evidence of previous slides in the benches and scarps of the hill. Driving along the highway at the bottom of the hill, if you look up into the slope you will see that there has been a few small slides. You can tell by the lack of vegetation on parts of this very steep slope. It was very difficult to get a picture of this, because the only way you can see it is from the highway. My picture is blurry, but you can still make out one of the cliffs that I'm talking about if you look closely at the picture. If there was a landslide onto the highway, it is possibly life threatening, and it would certainly cause some traffic issues. The slope here should be reinforced to that the slide won't come out into the road. *Image showing: evidence of past landslides*



I did see evidence of human reinforcement on one place on the slope. The next picture shows one of the ways that humans have dealt with working around the steep topography of the hill. *Image showing: retaining wall on steep slope*

Another thing we need to worry about in the Pacific Northwest is our risk from volcanoes. When Mount Rainier erupts, my family will be safe. We are located outside of the inundation zone for case I, II, and III lahars. We are 40 miles from the nearest pyroclastic flow hazard, 20 miles from the nearest lateral- blast hazard, and 2.5 miles from the nearest inundation zone for case M lahars. This is the part that worries me thee most. 2.5 miles is not very far at all, and my family frequents that area quite a lot. (Hoblitt, R.P., J.S. Walder, J.S., Driedger, C.L., Scott, K.M., Pringle, P.T., and Vallance, J.W., 1998.)

A direct impact is described as being an impact that is directly caused by the action and occurs at the same time and place. This means that a direct impact from Mount Rainier eruption will be lahars, pyroclastic flows, and lateral blast- hazards. Although I will not experience any of these personally at my home, my community will be greatly affected, and changed forever because of them. (US Department of Transportation- Federal Highway Administration, n.d.,)

Indirect impacts are "caused by the action and are later in time or farther removed in distance, but are still reasonably foreseeable." (US Department of Transportation- Federal Highway Administration, n.d.,) This means that anything that happens because of the lahars, pyroclastic flows, and lateral blast- hazards from Mt. Rainier will be part of the indirect impact. Thousands of people will die when Mt. Rainier erupts. People of the Puget Sound area will be dealing with an immense amount of loss and population change. Many of our major cities will be destroyed, and this will result in widespread problems throughout the entire State of Washington. It will be difficult for the Puget sound to function after the eruption because I-5 will likely be closed, as well as other major roads. Entire areas will be buried and unable to be gone through or recovered. Many towns in the area will be evacuated because of fear of volcanic gasses. This eruption will essentially ruin the economy and population in the surrounding area, which will affect the people of the Puget Sound for years to come.

Throughout this paper, I have talked about my personal risk, as well as the risk of the PNW region concerning earthquakes, tsunamis, mass movements, and volcanoes. From this I took away a lot about the lifestyle changes I need to make, as well as the changes that we as a society need to make in order to be more prepared for natural disasters. I hope that I can be a part of the big changes that will be happening in the future.

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