Petersburg's Resilience to a Tsunami

Petersburg, AK. Photo credit: Julia Murph.

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Abstract

In this paper, we address the resiliency of Petersburg, Alaska concerning tsunamis. We will first cover the geography of Southeast Alaska. This will include Southeast's foundation, tectonics, landslides, turbidity currents, and previous earthquakes to form a basis for further discussion. We found that the silt buildup on the Stikine delta is a cause of concern. There is a possibility of an earthquake causing a shift in the silt buildup, which could cause displacement in the water, triggering a tsunami. We will then discuss the physics of waves and how bathymetry effects tsunamis. Petersburg's bathymetry is monotonic, which means that in the event of a tsunami, the bathymetric features would not significantly dissipate any of the tsunami's energy. Petersburg is a fishing community that is especially vulnerable to a potential tsunami. Because the town and it's industry are located at a low elevation, a tsunami would decimate the economics, shipping, and transportation as well as expose the population to hazardous materials. Finally, we will cover short-term and long-term preparation in the case of a tsunami, including the current level of preparedness and suggestions for future monitoring and planning. We outline a system to assess key infrastructure exposure, sensitivity, and cascading effects to determine total vulnerability. While the likelihood of a tsunami striking Petersburg is low, the town is highly exposed to the disaster and would face catastrophic damage if a tsunami were to occur.

Introduction

Tsunamis have a history in Southeast Alaska, whether caused by earthquakes, landslides, or both. These natural disasters have been cited in many cultural tales of Southeast Alaska. A Tlingit legend, *The Man of Lituya*, or *Kah Lituya*, is a monster that dwells deep in the ocean caverns near the mouth of Lituya Bay. He enslaves people that come near his domain, and transforms them into bears that will warn him of new trespassers. He and the bears grab the surface of the water shake it; creating a tsunami when anyone approaches (Emmons, 1911). Fishermen have experienced tsunamis in Lituya Bay as well. In 1958, an earthquake triggered a landslide that created a 518 meter wave; the largest tsunami in recorded history (Kiffer, 2008).

In this paper, we will evaluate Petersburg's resiliency in the case of a tsunami given local geology and geography, as well as the effects of tectonics, landslides and turbidity on the geography of Petersburg. In addition to this, we will assess the effects of a tsunami on Petersburg's economy and its population of nearly 3,000 people (United States Census Bureau, 2013). We will also evaluate our existing plan and suggest improvements. Finally, we will go into long-term preparedness for the effects of a tsunami and our method for assessing vulnerability of community services and infrastructure.

Petersburg and its geological foundation

The Pacific coast of North America is part of the Ring of Fire. The Queen Charlotte fault along the coast of Southeast is in a constant state of subduction (Gehrels and Berg, 1994). This area has some of the world's largest earthquakes. For example, the 9.2 magnitude earthquake in Prince William Sound in 1964 was the second largest earthquake recorded since the dawn of modern seismology (Decoded Science, 2013). The 1964 earthquake triggered a tsunami that claimed more than 100 lives throughout Southeast (USGS, 2012).

Petersburg, Alaska is situated in a seismically unique landscape comprised of a complex network of thrust, normal, and strike-slip faults that have cut the bedrock into a jagged pattern (Gehrels and Berg, 1994). Fault types of Southeast include the thrust fault, where the ground on one side of the fault "thrusts" above the adjacent side; the low-angle normal fault, where the ground on one side of the fault has moved downward; and the steep dip-slip fault, where tension produces movement and one block slips downward (Kalbas et al., 2007). There are ten tectonic plates in Southeast Alaska, five of which are active: the Alexander, Chugach, Stikinia, Taku, and the Wrangellia plates (Gehrels and Berg, 1994).

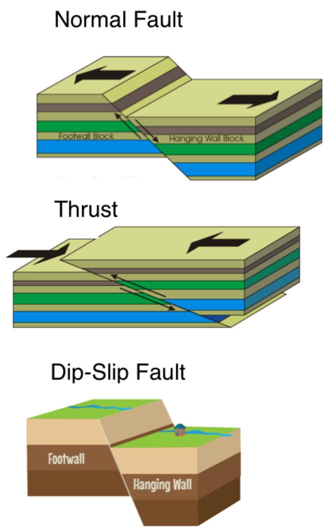

Figure 1: Visual example of Normal faults, Thrust faults, and dip-slip faults. Source: Hardwood, 2011; It's Not My Fault, 2015.

Tsunamis are generally caused by the large amounts of energy released by either earthquakes, landslides, volcanic eruptions, or meteorites (University of Washington, 2013). Among these, landslides are of considerable concern in Southeast Alaska. While the Horned Cliffs is one area that concerns people in Petersburg, geology shows that a landslide at this location is highly unlikely (Baichtal, pers. comm.). The Horned Cliffs are composed of granodiorite and tonalite (Gehrels and Berg, 1994). Tonalite is volcanic in origin and being so, it is less prone to giving out and causing a landslide (USGS, 2014).

Alaska ranks amongst the top states in the US on landslide susceptibility (USGS, 2013). Slopes at an angle of 70% or greater have the greatest chance of a landslide occurring (Swanston, 1973). In August 2015, a series of landslides triggered by wind and rainfall struck Sitka, Alaska.

The 2.5 inches of rain in under 24 hours is what is thought to have caused the landslides that claimed three lives (Woolsey, 2015).

In addition to terrestrial landslides, turbidity currents and sediment slumps can cause tsunamis. According to a study of the bathymetry of Frederick Sound, including the mouth of the Stikine River, the slump of sediment build up on the Stikine Delta was mentioned as a likely occurrence (NOAA, 2009). The Stikine River drains about 52,000 square kilometers, unloading large amounts of sediment where the river meets the sea (McClelland, 1992). When the fresh and saltwater meet, the freshwater spirals outward, depositing sediments to the ocean floor below before mixing with the saltwater (National Geographic, 2015). In January 2013, an earthquake created a sediment slump off of the Stikine River Delta that broke a communications cable between Petersburg and Wrangell (Wilt, 2015).

The geographical features and tendencies of Southeast Alaska add to the possibility of a tsunami strike near Petersburg. However, bathymetry affects wave motion which directly determines where a tsunami would travel if it occurred in Southeast waters.

Waves and Bathymetry

Tsunami waves are similar in characteristics to common ocean wind waves, but differ in size, energy, and initiation. Normal ocean waves can have wave periods of 10 seconds and wavelengths of 150 m. Tsunamis on the other hand can have wave periods upwards of an hour and have wavelengths longer than 100 km (University of Washington, 2013). As a wave approaches a shore, wave shoaling occurs. A tsunami’s large amount of energy is condensed in this process, forcing the wave speed to decrease and the wave height to increase dramatically, up to 30 m. This height is often referred to as runup height (University of Washington, 2013). This high energy wave moves up onto land, damaging the surroundings. Once the wave has stopped, the water proceeds to rush back into the ocean, dragging with it all of the new debris.

According to Provost and Lyard (2003), bathymetry is one of the major controlling factors that affect ocean wave dynamics. This applies particularly to long wavelength ocean waves, or tsunamis. A wave's propagation speed and wavelength are directly dependent upon the local depth, making accurate bathymetry crucial in establishing models and predictions on how ocean waves will act. Due to the destructive nature of tsunamis and their wave height, additional analysis of both bathymetry and topography is needed to predict exactly how a tsunami would affect the land and sea. On average, Tsunamis range from 10 to 30 meters high, thus the minimum inundation zone should be within the 10 meter mark (University of Washington, 2013).

The Geophysical Institute of the University of Alaska Fairbanks has completed many projects mapping and predicting the possible effects of earthquake-generated tsunamis on coastal communities of Alaska. These communities include Kodiak, Hoonah, Gustavus, Elfin Cove, Sitka, Seward, Cordova, and Valdez. Because the island placement of Southeast Alaska prevents the spread of offshore tsunamis, Petersburg is designated as low threat, therefore, no bathymetric map has been created (Decoded Science, 2013; Suleimani et al. 2015). However, even with the low possibility of a tsunami, should one occur, Petersburg's bathymetry is relatively monotonic, meaning that there are no bathymetric features that could dissipate the large force (Holman, 1995). The soft slopes of Petersburg's beaches would allow a high energy wave to build quickly and cause damage to our low elevation town.

As Day (2006) presented, Bellingham has an established assessment of tsunami hazards which details the city's research on inundation and the possible damages of a tsunami. A tsunami wave of 1.5 meters creates a much greater amount of damage than a storm wave of 3 meters due to the amount of force behind the tsunami. Additionally, they state that a 1.5 meter tsunami can easily drown individuals. Petersburg is relatively flat compared to Bellingham, with its mean elevation at 11 meters, thus large amounts of property damage can be expected (Google Earth, 2015). Most of this property damage is attributed to strong water currents and water borne debris (Day, 2006). The combined factors of Petersburg's monotonic bathymetry and low elevation creates the opportunity for a highly devastating tsunami (Holman, 1995).

Effects of a potential tsunami

Petersburg's economy consists mainly of commercial fisheries and seafood processing. Seafood processing and fishing makes up 42.52% of Petersburg's economy (Cabrera, pers. comm. 2015). Petersburg vessels harvest salmon, halibut, black cod, king crab, tanner crab, and herring during different seasons of the year (UFA 2014). Many fishermen utilize their vessels year-round by taking advantage of all available fisheries (Fishery Statistics, 2013).

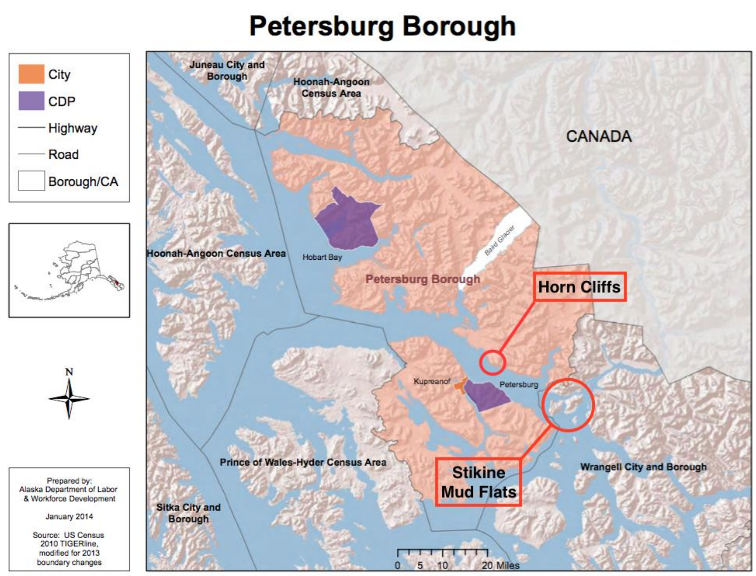

Figure 2: Map of the Petersburg Borough with locations of Horn Cliff and Stikine Mud Flats. Source: Alaska Department of Labor, 2014.

Petersburg is vulnerable to inundation due to its low elevation. Many houses and local shops in Petersburg are located along the coast. The three harbors that house a large majority of our commercial fishing fleet are also directly on the water. A natural disaster such as an earthquake generated tsunami could potentially take lives, injure others, and ruin our economy.

Because there are no figures such as inundation maps for a tsunami tailored to our community, it is hard to know what the direct effects will be. From factors such as bathymetry, tidal ranges, seasons, variations in times, and town layout, it is possible to extrapolate an idea of the damage and dangers posed by a tsunami.

Using the minimum inundation of 10 meters as a possible figure for our community can give a loose idea of what we would be dealing with. Tidal ranges in Petersburg can typically range from -0.95m to 5.66m (Tide Forecast, 2015). This drastic tidal range means that the inundation could become more severe and pose more of a direct threat to sea side homes at a high tide.

Time of day is an important factor to consider for the safety of Petersburg's residents. If a tsunami should occur during the day, most people would be awake, likely in the downtown area or in their places of work on Main Street or near docks. In a perfect scenario, these people would be able to migrate to safe elevations quite easily. In contrast, a tsunami occurring during the night would catch people in their homes, possibly fast asleep making evacuation more difficult.

The day of the week in which the tsunami struck would also contribute to the risk community members faced. For example, weekdays during the school year would result in children being separated from parents which could increase panic levels. Sundays would suggest less activity in the highly exposed downtown area, due to off days for local businesses.

Seasons play a big role in population fluctuation. During the summer months, tourism and production at the canneries and docks increases. A tsunami strike at this time would mean a risk for an increased amount of civilians, as well as more damage to our main industry. Furthermore, the Whatcom County Natural Hazard Identification and Mitigation report (2003) mentions possible effects to transportation and shipping. With the ferry terminal and Alaska

Marine Lines being at low elevations, a tsunami could damage both, leaving Petersburg temporarily dependent on air transportation for all supplies.

The Whatcom County report (2003) also discusses the additional effects of hazardous materials. Local seafood processors such as Icicle Seafoods, Trident, and Ocean Beauty, contain considerable amounts of ammonia for freezing purposes. Petro Marine's large fuel tanks are also located at low elevation. In the event of a tsunami, the seafood processors and oil tanks could be destroyed, releasing hazardous chemicals that would harm the population, if they were not contained. To mitigate such impacts to Petersburg, procedures and plans can be created to prepare for such an event.

<u>Short-Term Preparation</u>

Vulnerability to community disasters decreases when a community has a high capacity to address the hazard with low exposure to the disaster itself (Figure 3) (Courtney, 2007). Petersburg lies farther along the x axis of figure 3, as it has a low elevation and relies primarily on fishing for its economy. If a disaster such as a tsunami were to occur, Petersburg would likely face problems in evacuation and economic recovery. Petersburg could increase its resilience to such hazards through proper planning. Resilience is "the capacity of a system to absorb disturbance and re-organize while undergoing change so as to still retain essentially the same function, structure, identity and feedback" (Walker et al. 2004).

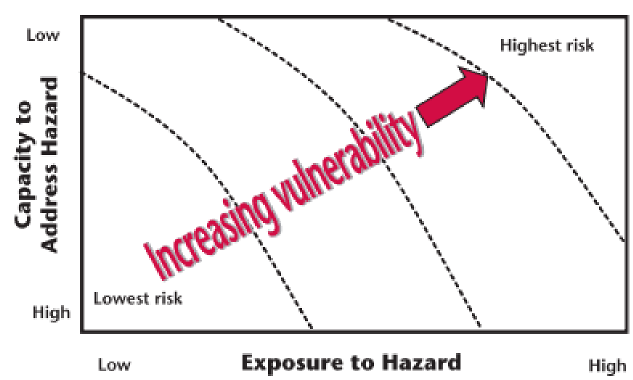

Figure 3: This graph details the level of vulnerability taking into the exposure to and ability to address a hazard. Source: Courtney, 2007

For a town to be resilient, there are several steps to take towards preparedness. Monitoring and evaluating severe changes in the environment, such as earthquakes and weather patterns, is crucial to community safety. As a fishing community, Petersburg's livelihood depends on marine forecasts provided by the National Weather Service. When an earthquake is detected, NOAA's National Tsunami Warning Center cites its location and magnitude, along with warning, advisory, and watch zones for coastal communities (National Tsunami Warning Center, 2015).

Along with atmospheric conditions, it is important to monitor changes in the terrestrial environment. Since Sitka's 2015 landslides, scientists have initiated research into changing meteorological events and soil conditions (Woolsey, 2015). This information will allow the towns to re-evaluate community development plans.

Response plans developed for direct response to a potential disaster contribute to community resiliency. Plans should include temporary housing, relocation of essential public services, and evacuation routes, plans, and maps. In the case of a disaster, keeping citizens safe is the first priority. It is important for all homeowners to know where the safe zones in their community are, and if their house or business could be in danger. In Petersburg, safe grounds are considered to be located above 30 meters in elevation, leaving the ball field, grocery store, post office, fire hall and airport as potential evacuation sites. Evacuation needs to be coordinated to minimize congestion and make these routes safe and efficient. Once a town knows their safe zone, relocation points can be designated. In the event in which relocating citizens is necessary, the hospital is able to receive a total of 250 portable hospital beds within 72 hours of a disaster, and the public schools are able to be used as temporary housing if homes or public buildings have been destroyed (Miller pers. comm. 2015).

A warning system cannot be effective without educating the public. If individuals are not able to understand the warning information or do not know how to respond, the best of plans will serve little purpose. Comprehensive public awareness campaigns should provide constant reminders about hazard risks, warning procedures, and evacuation plans within coastal communities. To ensure the success of evacuation, drills should be practiced often. Practicing evacuation is also useful in providing feedback to community leaders or disaster management in order to improve the process.

The last step to resilience is a community's ability to respond quickly in the face of a rapidly approaching coastal disaster. In Petersburg, citizens are alerted to coastal disasters using a siren located at the high school. Petersburg's public radio station broadcasts the alarm and makes announcements. Ever since Petersburg's evacuation in 2013, adjustments have been made to better our safety plan. In 2013, the designated evacuation site was found to be too small. Improved plans include relocation of the primary safe zone to the airport, which also lies in a safety zone (Miller pers. comm. 2015). If evacuation or emergency medical assistance were needed, aircraft would be able to easier reach said victims.

Long-Term Preparation

In addition to short-term emergency planning, long-term preparation can also lead to a more resilient community. A community's ability to bounce back from a natural disaster, such as a tsunami, depends on the damage to infrastructure, businesses, and residential areas. For practical purposes, in this mitigation plan we are not proposing town relocation. Instead, the following plans adapted from Bellingham's.

According to the National Research Council of the National Academies (2011), when assessing vulnerability of certain areas and structures in the case of a tsunami, two main factors should be considered: exposure and sensitivity. Exposure refers to an object's proximity to the tsunami. Sensitivity refers to the severity of damage the building would take when hit with a tsunami (National Research Council, 2011). Another important factor to address when determining comprehensive community resilience is that of "cascading effects" (United States Department of Homeland Security, 2015). The term "cascading effects" refers to the damage done or aid prevented to the surrounding population when the building is damaged (United States Department of Homeland Security, 2015).

To determine total Petersburg vulnerability, we would need to rank all of Petersburg's key businesses based upon three parameters above. The three buildings below serve as an example, with each item ranked on a scale of 1 to 5; 1 being minimal risk and 5 being maximum risk (Table 1).

Rank	**Building/Facility**	**Exposure**	**Sensitivity**	**Cascading Effects**	**Total Vulnerability (Average)**
1	Icicle Seafoods	5	5	4	4.7
2	Hospital	3	4	5	4.0
3	Fire Hall	1	2	4	2.3

Table 1: Sample vulnerability ranking developed to assess businesses in Petersburg.

The fire hall is our least vulnerable with a rank of 3. Petersburg's fire hall is located at an elevation above 30 meters, giving it a low exposure value (1). The new fire hall, constructed in 2013, has a low sensitivity (2). However, should it be damaged beyond function, Petersburg's ability to fight fires and other hazards would be nullified, earning it a cascading effects value of four. Overall, the low exposure and sensitivity of the fire hall, have given it a total vulnerability of 2.3.

Following this, the hospital is ranked number 2 in regards to total vulnerability. Petersburg's hospital is an older building that lies around 15 meters in elevation. For this reason, the hospital has reasonable exposure (3) and fairly high sensitivity (4). Should the hospital be destroyed, aid for injured persons after the tsunami would be difficult, giving the hospital a cascading effects value of five. Overall, the hospital's vital importance and sensitivity along with medium exposure give it a total vulnerability of 4.0.

The most vulnerable building in our example is Icicle Seafoods with a rank of 1. Icicle Seafoods is in an extreme scenario. It is a old building that is located along the waterfront, making it a highly exposed (5) and sensitive (5) building. In addition to economic impacts, a possible ammonia leak could cause catastrophic damage, creating a high cascading effects value (4). All of these factors concerned, Icicle Seafoods earns a total vulnerability of 4.7.

If Petersburg were to resituate key buildings identified above to mitigate, or at least dampen the effects of a tsunami, plans of similar cities and boroughs can be consulted. Bellingham's comprehensive tsunami preparedness plan outlines future development plans along their waterfront (Day, 2006). First, the proposed plan requires that new buildings be elevated 1.52 meters to better prepare for rising water levels (Day, 2006). However, costs to redevelop Petersburg's downtown area to a height above the 30 meter inundation zone would be prohibitive.

Alternatively, the structure of the buildings themselves could be considered. Research in Bellingham's plan shows that refurbishing old buildings and reinforcing their foundations would not be cost effective nor would the reinforcements withstand the pressure of the tsunami (Day, 2006). Petersburg's city center is full of older buildings that would be better off being torn down and reconstructed in any redevelopment plan. Residential areas must be also addressed as they put lives in direct danger (National Research Council, 2011). Future residential construction areas could have a minimum elevation cap of 30 meters above sea level.

Conclusion

Natural disasters are a constant threat to the coastal communities of Southeast Alaska, and for this reason these communities must be resilient. Resilience involves two key factors, measuring vulnerability and making plans and changes (Walker et al. 2004). In our research, we focused on the waterfront community of Petersburg, Alaska and the town's economy. We found that Petersburg is at low risk for a tsunami; however, it is possible a tsunami could be caused by a landslide or underwater slump, which could be triggered by an earthquake. Bathymetric features could also contribute to the damage caused by a tsunami. Petersburg's economy is heavily based on fishing. If a tsunami were to strike, this industry would be destroyed due to its low lying elevation and the population could be exposed to hazardous materials. Community plans should be updated regularly in order to keep up with any new coastal developments or technologies, as well as changes in the geological layout. Determining and implementing long-term preparation plans for public, educational, and industrial awareness is key to minimizing the loss in a community should a natural disaster strike (National Weather Service, 2001).

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