UNIVERSITY of WASHINGTON

LIVABLE CITY YEAR 2017–2018
IN PARTNERSHIP WITH
CITY OF TACOMA

CITY OF TACOMA

MITIGATING THE IMPACTS FOR PORT-RELATED VULNERABILITIES

UNIVERSITY OF WASHINGTON
URBAN DESIGN AND PLANNING

URDP 549: HAZARD MITIGATION PLANNING

INSTRUCTOR
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WINTER 2018

LIVABLE CITY YEAR

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Student looking across the water at the Port of Tacoma. TERI THOMSON RANDALL

Mt. Rainier overlooking the Port of Tacoma.
Cover Photo Credit: City of Tacoma

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ABOUT LIVABLE CITY YEAR

The University of Washington's Livable City Year (LCY) initiative enables local governments to engage UW faculty and students for one academic year to work on city-defined projects that promote local sustainability and livability goals. The program engages hundreds of students each year in high-priority projects, creating momentum on real-world challenges while enabling the students to serve and learn from communities. Partner cities benefit directly from bold and applied ideas that propel fresh thinking, improve livability for residents and invigorate city staff. Focus areas include environmental sustainability; economic viability; population health; and social equity, inclusion, and access. The program's 2017–2018 partner is the City of Tacoma; this follows a partnership with the City of Auburn in 2016–2017.

The LCY program is led by faculty directors Branden Born (Department of Urban Design and Planning), Jennifer Otten (School of Public Health) and Anne Taufen (Urban Studies Program, UW Tacoma), with support from Program Manager Teri Thomson Randall. The program was launched in 2016 in collaboration with UW Sustainability and Urban@UW, with foundational support from the Association of Washington Cities, the College of Built Environments, the Department of Urban Design and Planning, and Undergraduate Academic Affairs.

LCY is modeled after the University of Oregon's Sustainable City Year Program, and is a member of the Educational Partnerships for Innovation in Communities Network (EPIC-N), the collection of institutions that have successfully adopted this new model for community innovation and change.

For more information, contact the program at uwlcy@uw.edu.

LIVABLE CITY YEAR

ABOUT TACOMA

The third largest city in the state of Washington, Tacoma is a diverse, progressive, international gateway to the Pacific Rim. The port city of nearly 210,000 people has evolved considerably over the last two decades, propelled by significant development including the University of Washington Tacoma, the Tacoma Link light rail system, the restored urban waterfront of the Thea Foss Waterway, the expansions of both the MultiCare and CHI Franciscan health systems, and a significant influx of foreign direct investment in its downtown core.

Washington State's highest density of art and history museums are found in Tacoma, which is home to a flourishing creative community of writers, artists, musicians, photographers, filmmakers, chefs, entrepreneurs, and business owners who each add their unique flair to the city's vibrant commercial landscape. The iconic Tacoma Dome has endured as a high-demand venue for some of the largest names in the entertainment industry.

A magnet for families looking for affordable single-family homes in the Puget Sound area, Tacoma also draws those seeking a more urban downtown setting with competitively priced condos and apartments that feature panoramic mountain and water views. The city's natural beauty and proximity to the Puget Sound and Mount Rainier draws hikers, runners, bicyclists, and maritime enthusiasts to the area, while its lively social scene is infused with energy by thousands of students attending the University of Washington Tacoma and other academic institutions.

The City of Tacoma's strategic plan, Tacoma 2025, was adopted in January 2015 following unprecedented public participation and contribution. The plan articulates the City's core values of opportunity, equity, partnerships, and accountability, and expresses the City's deep commitment to apply these values in all of its decisions and programming. Each Livable City Year project ties into the principles and focus areas of this strategic plan. The City of Tacoma is proud of its 2017–2018 Livable City Year partnership with the University of Washington and of the opportunity this brings to its residents.

Tacoma

TACOMA 2025 STRATEGIC PLAN

The *Mitigating the Impacts for Port-Related Vulnerabilities* project supports the Livability goal of the Tacoma 2025 Strategic Plan and was sponsored by the City's Fire Department.

Goal #1 Livability
The City of Tacoma will be a city of choice in the region known for connected neighborhoods, accessible and efficient transportation transit options, and vibrant arts and culture. Residents will be healthy and have access to services and community amenities while maintaining affordability.

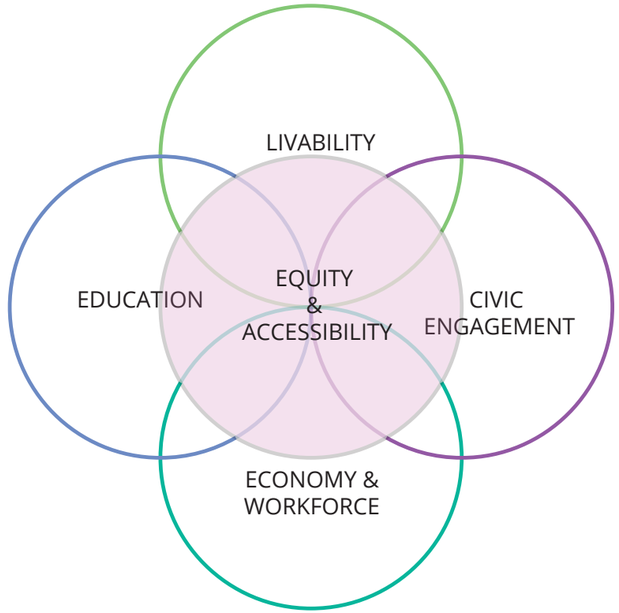
Goal #2 Economy and Workforce
By 2025, Tacoma will be a growing economy where Tacoma residents can find livable wage jobs in key industry areas. Tacoma will be a place of choice for employers, professionals, and new graduates.

Goal #3 Education
Tacoma will lead the region in educational attainment amongst youth and adults. In addition to producing more graduates from high school and college, more college graduates will find employment in the region. Lifelong learning and access to education will be prioritized and valued.

Goal #4 Civic Engagement
Tacoma residents will be engaged participants in making Tacoma a well-run city. The leadership of the city, both elected and volunteer, will reflect the diversity of the city and residents and will fully participate in community decision-making.

Goal #5 Equity and Accessibility
Tacoma will ensure that all residents are treated equitably and have access to services, facilities, and financial stability. Disaggregated data will be used to make decisions, direct funding, and develop strategies to address disparate outcomes.

tacoma2025
shared vision | shared future



RESOURCES

Tacoma 2025 Strategic Plan: https://www.cityoftacoma.org/tacoma_2025

Tacoma Fire Department:
https://www.cityoftacoma.org/government/city_departments/fire/

Livable City Year: https://www.washington.edu/livable-city-year/

University of Washington Urban Design and Planning:
http://urbdp.be.washington.edu/

Executive Summary

A group of University of Washington graduate students participating in a Hazard Mitigation Planning course, collaborated with the Port of Tacoma and the City of Tacoma to research ways in which they could increase Port safety and protect the viability of Port operations following a hazard event. With the guidance of professor Bob Freitag, students sought to explore innovative solutions for hazard mitigation at the Port and to develop thoughtful recommendations centered on the concerns and priorities of the City and Port. Students worked in teams where each team focused on one of the following topics: hazard mitigation planning, evacuation and safety, Unreinforced Masonry (URM) Structures and landfill development, and implementation of green infrastructure.

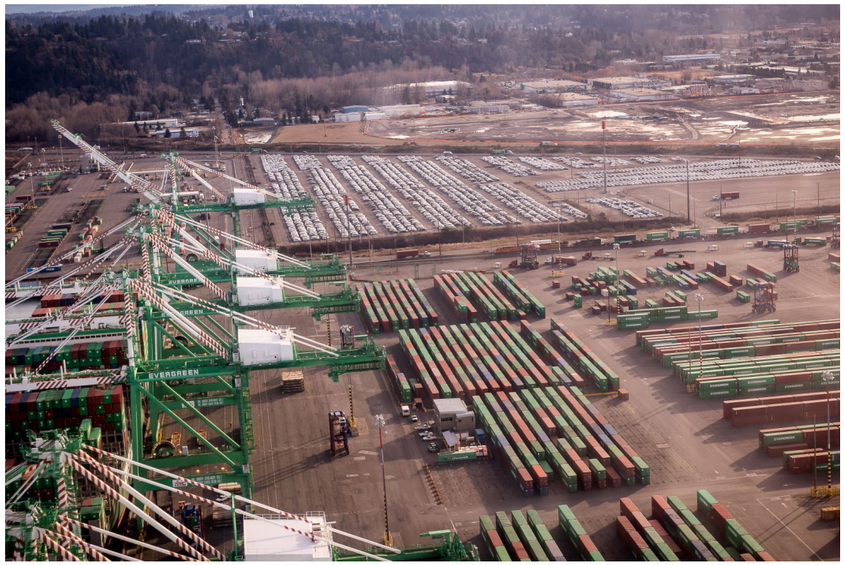
Each team developed useful recommendations for the City and the Port based on their research to address topics of concern and mitigate social, economic, and ecological impacts of hazard events. The hazard mitigation team suggested that stakeholders collectively address the regional economic significance of the Port, relocate non-essential site dependent activities and occupants to offsite locations, and integrating hazard mitigation into local planning.

The evacuation and safety team developed an evacuation model and evaluated the risks and vulnerabilities of the Port for different natural disaster scenarios. The team offered strategies that would maximize the safety of Port personnel and protect business continuity though vertical evacuation opportunities for location dependent critical functions and evacuation exercise.

The ecological infrastructure team offered a tool kit that presented alternative solutions to reducing risks and explored how ecosystem services and natural infrastructure alternatives can be employed to reduce damage from earthquakes, tsunamis, sea level rise, and hazardous material spills.

The unreinforced masonry team directed their efforts towards two hazard mitigation challenges associated with URM's including historic districts located within the City of Tacoma and Port. The team suggested that the Port fortify and strengthen the fill sites to provide foundation for buildings and roads and rehabilitate or retrofit URMs to withstand earthquakes.

Further, students highlighted challenges to achieving effective hazard mitigation in which the most notable barrier identified was the lack of coordination and communication between regional jurisdictions and overall lack of urgency around hazard mitigation for the Port and City.



Top: Shipping containers at the Port of Tacoma, the third largest cargo terminal in the United States. BRIAN HARRIS, WIKIMEDIA COMMONS
Bottom: Aerial photo of the Port of Tacoma. Daily about 30,000 people move through the Port. D COETZEE, WIKIMEDIA COMMONS

PORT OF TACOMA

The Port of Tacoma (Port) encompasses more than 2,700 acres of industrial tide flat land at the mouth of the Puyallup River in Puget Sound. In 2015, it began jointly operated with the Port of Seattle based on an agreement known as the Northwest Seaport Alliance. Combined, the two ports are the third largest cargo gateway in the United States, handling between 9-13 million tons of cargo and more than $25 billion in commerce annually. On a typical day, up to 30,000 people move in and out of the Port, including onsite personnel who operate terminals and truck drivers who transport cargo onto and off the site.

Based on its location, the Port of Tacoma is heavily relied upon by local, national and international businesses for trade, financial revenue, and employment. Subsequently, the Port's location also leaves it vulnerable to a variety of natural hazards as it is in situated near an active volcano, adjacent to several major fault lines, and within the tsunami inundation zone. In addition, due to historical development patterns involving landfill techniques and on-site hazardous materials, the Port and the surrounding regions are also subject to man-made hazards.

Students met with personnel and emgerency manangers at the Port of Tacoma to learn more about the natural and man-made hazards that threaten the Port. TERI THOMSON RANDALL

University of Washington graduate students participating in URDP 549: Hazard Mitigation Planning collaborated with the City of Tacoma and the Port of Tacoma to research ways in which they could better protect the viability of Port operations from potential hazards.

The Port's primary goal for the class was to identify strategies that will improve Port safety and ensure continuity of Port mission critical functions after a hazard event. By achieving these two objectives, people's lives can be saved, injury can be avoided, infrastructure damage can be reduced, and the region's economy will be protected. Students produced four different projects based on Port's primary objectives stated above. With the help, expert knowledge, and guidance from professor Bob Freitag, students sought to explore innovative solutions for hazard mitigation at the Port and to develop thoughtful recommendations centered on the concerns and priorities of the City and Port.

While the Port is at risk to a wide range of natural and technical hazards, students reduced the scope of hazards so that each project narrowed in on the same hazard scenarios. Hazard selection was based on high probability of occurrence and severity of impact, both of which result in significant damage to the functionality of the Port and threatens human life and safety. Further, the following hazards represent a diverse portfolio of events that can happen in conjunction with one another, as well as autonomously. The selected hazards include: flooding, earthquakes, tsunamis, and hazardous materials (HazMat). Each of these events have great potential to affect the daily and long-term goals and operations of the Port and were later confirmed by Port of Tacoma Officials and Tacoma Emergency Managers as areas of high concern.

Profiling a hazard is an essential component to the hazard mitigation planning, as it sets the stage by defining the characteristics and thresholds of a hazard. To begin this process, students used a hazard profile matrix (Figure 1), to methodically break down the four identified hazards by threats, impacts, and capabilities. Students used this approach to explore plausible tools and strategies to reduce risk and inform strategic planning and decision making. The following hazard profiles are included to demonstrate the process students used to define and understand each hazard (flooding, earthquakes, tsunamis, and hazardous materials).

Figure 1: Hazard Profile Matrix

Risks and Opportunities = (Change * Impacts / Capabilities)		
Resilience (Ability to self-correct, self-organize, and tolerate and benefit from change) No Adverse Impact (NAI) (adverse impacts avoided or mitigated)		
Change*	**Impacts**	**Capabilities**
Primary and Secondary	**Beneficial or Adverse**	**Approaches and Tools**
Hazards, threats, disturbances, vectors	Consequences, effects, exposures, vulnerabilities, targets	Strategies, tactics, talents, customs, resources
Thresholds	Interdependencies	Objectives
Chronic/Episodic • Location • Severity (magnitude/intensity) • Timing • Frequency	• Human capital • Manufactured capital • Natural capital • Social capital	• Stakeholder - individual/organizational • Phases in Emergency Management - prepare/respond/recover • Approaches (**Impacts**) - retreat/accommadate/protect • Approaches (**Profile**) - riverine: stormwater: off-channel/in-channel/transport; coastal: reduce energy: near shore buffering/shore protection/ littoral transport • Tools - revenue, grants, regulation, warning
Disaster: Realized Risk / Benefit: Realized Opportunity		

* Episodic / Chronic

BOB FREITAG

FLOODING

The Port is located on a low-lying waterfront area within the flood zone therefore it highly susceptible to flooding. The Port of Tacoma is threatened by coastal storm flooding from Puget Sound and riverine flooding from the Puyallup River. An emerging threat to the Port pertains to the regional impacts associated with sea level rise. Based on the National Research Council's sea level is projected to rise by 2.1 feet in Tacoma by 2100 (from a 1992 baseline). While the true impact of sea level rise is uncertain, current sea level rise projections suggest that the frequency and severity of flooding in the Port will increase (source). The existing threat of flooding, in conjunction with future sea level rise, can result in a variety of consequences for the Port, increasing the vulnerability of critical infrastructure, business operations, and safety.

Figure 2: Severity of Flooding to the Port of Tacoma as a Result of Sea Level Rise

LCY STUDENT TEAM

EARTHQUAKE

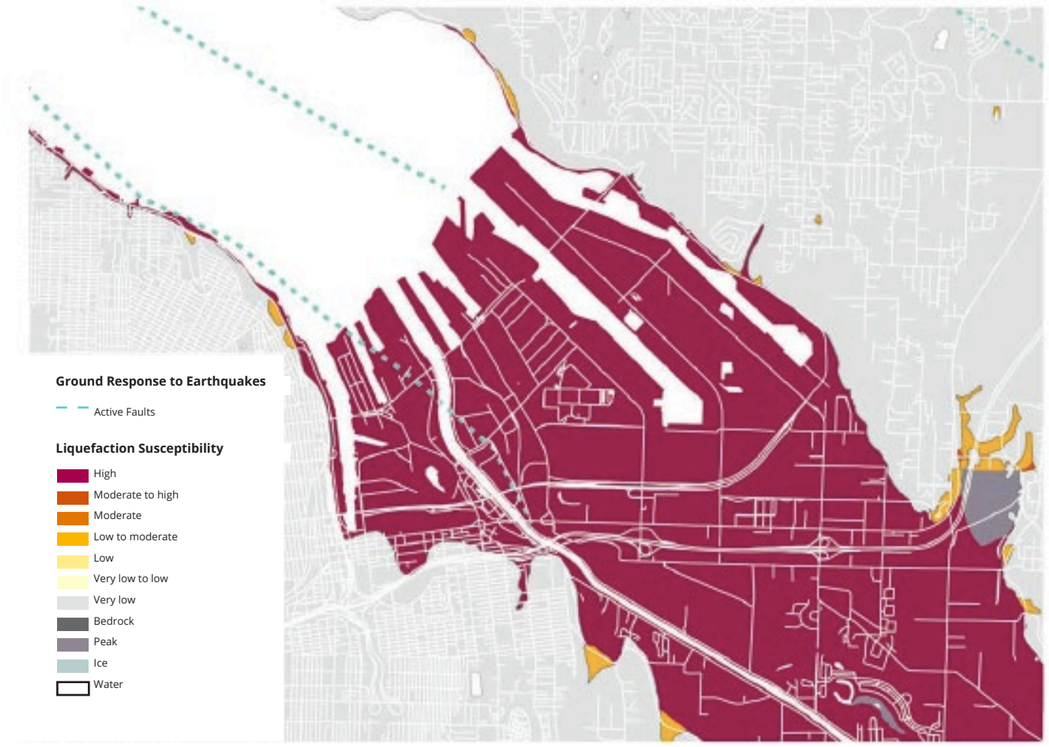
The Port is located approximately 10 miles south of the Tacoma Fault while also in the destruction line of the Seattle Fault and the Cascadia Subduction Zone. The Seattle and Tacoma Faults are the most eminent threat to the Port as these are active fault lines that are located close to earth's surface, resulting in severe ground shaking in confined areas. The Seattle and Tacoma faults are predicted to have the capacity of generating a 7.0 magnitude earthquake, where the Cascadia Subduction Zone is can yield a 9.0 magnitude or greater seismic event (US Geological Survey, 2010).

As the Port is built on tidal lands of the Puyallup River, it is highly susceptible to liquefaction after an earthquake event. Further, falling buildings, debris, and unstable machinery from the earthquake and liquefaction will create additional hazards.

An earthquake generated by the Seattle Fault, Tacoma Fault, or the Cascadia subduction zone would pose a high threat to Port infrastructure and operations, as damages could be severe enough to cause an indefinite shutdown. If this were the case, terminal tenants might decide to move their business elsewhere. The potential resulting loss in revenue would have a significant impact on the Port, initiating a rippling effect through dependent businesses and the overall regional economy. For example, after a 6.9 magnitude earthquake and tsunami in 1995, the severely damaged Port of Kobe in Japan fell from 6th to 39th place in a global ranking of ports. Seventeen years later, Kobe still has not regained its former status (Fukushima 1995; Pachakis & Kiremidjiaan 2004). Such losses for Tacoma would be incredibly detrimental for the area as the Port is a critical economic driver.

Earthquakes, like the one experienced in 1995 by port-city Kobe, Japan, have long-term, adverse impacts on regional economies. KENPAI, WIKIMEDIA COMMONS

Figure 3. Liquefaction Susceptibility



Students developed a map to better understand which areas of the Port are susceptible to liquefaction during an earthquake event. Deep red shading on the map signifies areas of high susceptibility. The dashed lines, shaded blue, demonstrate the presence of two active fault lines. LCY STUDENT TEAM

TSUNAMI

In a tsunami event, the severity of the wave is determined by the severity and proximity of the preceding earthquake. The Port is at risk of a tsunami event under scenarios involving all three aforementioned faults (Seattle Fault, Tacoma Fault, Cascadia subduction zone). Under all three tsunami scenarios, Port-owned property and critical infrastructure are vulnerable to significant damage, potentially deeming them unfit to serve core functions needed to sustain economic activity. However, the amount of flooding is significantly different depending on the fault which triggered the earthquake .

HAZARDOUS MATERIALS

Hazardous materials are materials that, when not properly contained, pose a risk to life, health, the environment, or property because of their chemical, physical, or biological properties. If large enough, spills can shut down Port operations for a significant amount of time. There are several potential sources of hazardous materials located within the tideflat region of the Port including, but not limited to: oil and chemical spills or releases, illegal methamphetamine sites, liquid pipelines, and the Commencement Bay-Nearshore tideflats superfund site. Hazardous material release have happened with high frequency and varying levels of severity, where large incidents have occurred once every five years while small incidents are more frequent. For example, in 2011, Pierce County reported 249 response incidents for hazardous materials (source).

Half-way through the quarter, the class took a field trip to the Port of Tacoma, where students had the opportunity to meet with the Port's Chief of Security, Port Staff, and Tacoma Emergency Managers. The site visit included a presentation by the Chief of Security and allowed time for discussion about Port priorities and top hazards of concern. This meeting provided students with the chance to present their scope of work to Port Officials and Emergency Managers, with time for questions and constructive feedback. Conversations with Port Officials and Emergency Managers substantiated the students selection of the four hazards and confirmed identified objectives relating to safety and continuity of business.

Figure 4: Tsunami Scenarios

The entire Port of Tacoma is designated as a Tsunami evacuation zone. This map displays two different tsunami scenarios, one generated by a Tacoma fault line and one by a Seattle fault line. LCY STUDENT TEAM

Research Methodology

Prior to project development, students conducted a preliminary literature review on the federal and state hazard mitigation planning process, various hazards which threaten the Tacoma region, and the Port's significance to the State's economy. Through their research, the class selected two objectives to frame their projects around:

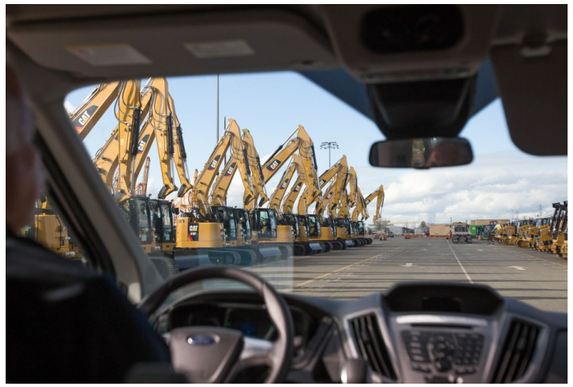
1. Reduce loss of life and injury
2. Ensure retention of core Port mission critical functions after a hazard event

These two were objectives were selected as they were recurring goals and values expressed in various plans, publications, and websites of key stakeholders within the Port of Tacoma such as: The State of Washington, Pierce County, City of Tacoma, Puyallup Tribe, Port of Tacoma, and industry.

Following their initial research, students had the opportunity to meet with Toryono Green, Deputy Chief Administration for the City of Tacoma, where together, the class and Green selected Port priorities to focus on, discussed hazards of concern, and identified research needs. The inception of students projects stemmed from the conversations had during this meeting, producing four research questions associated with one of the following research topics:

1. Hazard mitigation planning
2. Evacuation and safety
3. Unreinforced masonry (URM) structures
4. Ecological infrastructure

Students divided into four teams and designed their projects with the intent to provide useful information and recommendations for the Port to enhance safety, protect economic vitality, and bolster environmental sustainability.



The Port of Tacoma supports thousands of domestic jobs and funds public services and infrastructure through local tax production, ultimately generating billions of dollars for Washington's economy. As of 2014, 40% of jobs in Washington State were either directly or indirectly connected to international trades (Port of Tacoma 2016).

Students receive an insider's tour of the Port of Tacoma with Chief of Security Gerry Fiola. TERI THOMSON RANDALL

HAZARD MITIGATION PLANNING: GAPS AND OPPORTUNITIES

The hazard mitigation planning team assessed the mitigation strategies from the Port of Tacoma, Pierce County, and Washington State to identify shared goals among stakeholders, as well as gaps in those plans. doing so across jurisdictional mitigation plans, the group's goal was to strengthen hazard mitigation planning and encourage interjurisdictional collaboration. The group identified several strategies that can help ensure consistency amongst different stakeholders' plans, reduce vulnerabilities to hazards, and help facilitate better hazard mitigation planning.

To effectively develop mitigation measures and ensure continuity of mitigation plans, the group recommended that stakeholders (Port of Tacoma, Pierce County, and Washington State) actively recognize the economic significance of the Port, move non-essential activities and occupants to offsite locations, and increase intergradation of hazard mitigation into local planning. Stakeholders might consider taking a cooperative and more active approach to recognizing the Port, given their reliance on the Port for goods and services. The purpose of a coordinated mitigation strategy is to add structure and to establish baseline strategies among stakeholders at various levels. While each municipality has their own hazard mitigation plan, it is essential that jurisdictions have a similar understandings of hazard events to guide planning around shared goals.

Removing non-essential activities and occupants from the Port will help reduce overall vulnerabilities. There are elements of the Port, such as docks, cranes, marinas, and fuel facilities, which cannot be relocated and must remain within the Port. However, there are other activities and occupants that do not directly contribute to the Port's core functions. For example, housed within the Port is a federal immigration detention facility and prisoner reentry facility (Tideflats Emergency Response Plan 2016). Encouraging relocation of these occupants and restricting non-essential development within the Port can reduce hazard risk and encourage more strategic utilization of resources.

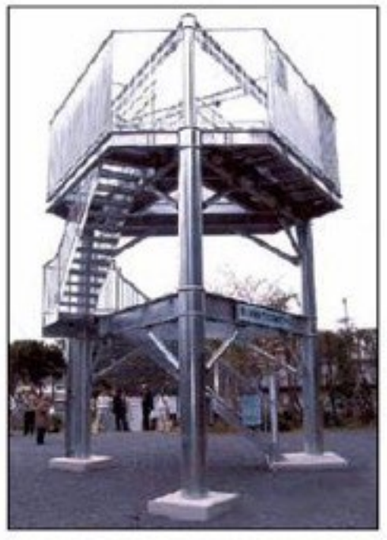
In addition, the team recommended that hazard mitigation should a key driver of zoning, planning, and building requirements within the Port's boundaries. Hazard mitigation strategies should not just be limited to a single plan developed by emergency managers, but rather incorporated into all elements of the community, such as economic development, government services, and private businesses. Further, one of the largest gap found in the Port of Tacoma's plan was their lack of completion or transparency in the development of the Port Business Continuity Plan. A business continuity plan allows for stakeholders to become familiar with threatening hazard events and better understand what actions need to be taken relative to the emergency. Development and implementation of a business continuity plan could help ensure that hazard mitigation planning is a priority across Port Tenants and can ultimately lay the groundwork for recovering the core functions of the Port to achieve their economic goals and values.

ENHANCING PORT SAFETY

The evacuation and safety group evaluated the risks and vulnerabilities of the Port by running the HEC-LifeSim simulation model from the U.S. Army Corps of Engineers. The model was based on different natural disaster scenarios to evaluate potential evacuation strategies that would maximize the safety of Port personnel and protect business continuity.

From this work, the team found that no single model significantly reduced evacuation times. Furthermore, the student team found that

This snapshot from a simulation model displays the Port of Tacoma's road network and evacuation locations. LCY STUDENT TEAM



Example of a vertical evacuation platform.

transportation is the greatest barrier to evacuation. This is largely because the operational conditions at the Port are highly complex as there is extensive train activity, an abundance of drayage truck traffic, and dense semi-truck traffic, all of which frequently block Port streets and rail line crossings (Fiola 2018). The key transportation infrastructure challenges identified by the team include: limited Port egress routes, high traffic volumes during business hours, two closed routes that require detours to navigate the Port, and poor road conditions that necessitate slow travel speeds.

Given these constraints, there are alternative strategies that can provide a place of refuge in situations where evacuation out of the inundation zone may not be feasible or where high ground may not exist. One such tactic is vertical evacuation, which is an elevated platform that sits above potential tsunami wave height with a ramp or series of stairs leading to the top of the platform. Vertical evacuation structures can be located on-site and are designed to withstand the force and effects of a tsunami wave. With strategic planning, vertical evacuation platforms have the potential to decrease retreat time and to reduce road traffic, meaning that more vehicles can evacuate at a faster rate. The team found that this approach would effectively meet the Port's safety objective and is likely fundable. As such, the team suggests the Port make a funding request to FEMA's Mitigation Grant Program for a set of vertical evacuation structures to be installed across the Port of Tacoma. It is worth noting that, in order to maximize efficacy, planners need to carefully select site locations, develop signage, update evacuation plans, and train on-site staff.

To strengthen overall safety of all Port personnel, the team also recommended the development of a continuous training program for Port employees and on-site staff. By implementing a routine training program, staff will become aware and familiar with the potential hazards which threaten the Port, leading to more informed decision making during a hazard event that can decrease evacuation response time and increase overall safety.

ECOLOGICAL INFRASTRUCTURE

This team developed a toolkit of green infrastructure that can protect the Port from natural and man-made hazards. The toolkit instead serves as a first step in implementing green infrastructure solutions. By providing these building blocks, the team hoped equip the Port of and related stakeholders with the necessary information to consider such solutions when planning for hazards. The team explored how ecosystem services and green infrastructure could be implemented to reduce damage from the earthquakes, tsunamis, sea level rise, and hazardous material spills. To determine where green infrastructure solutions would be effective at protecting against hazards in addition to being feasibly applicable within Port property, the team produced a series of maps that specifically focused on the four identified hazards. Each map includes multiple scenarios for each hazard to illustrate the differences of impact and the magnitude of severity. In addition, the team also mapped land ownership and land-uses types within the Port. These maps served as a key resource for the team and helped to inform the development of their ecological infrastructure toolkit.

The toolkit consists of nine innovative and natural (or environmentally sensitive) "green infrastructure" approaches that, in addition to providing ecological services, can protect the Port of Tacoma from various hazardous events (Figure 5). These tools consist of: seismic forests, soft channels, vertical evacuation berms, living breakwaters, water-reuse systems, shoreline setbacks, green stormwater infrastructure, aquatic vegetation, and solar energy systems. The team notes that, in many cases, benefits would be maximized if multiple tools are implemented concurrently. By explaining these solutions, the team equipped Port officials with information to better understand the value of such green infrastructures, and to subsequently justify investing in them.

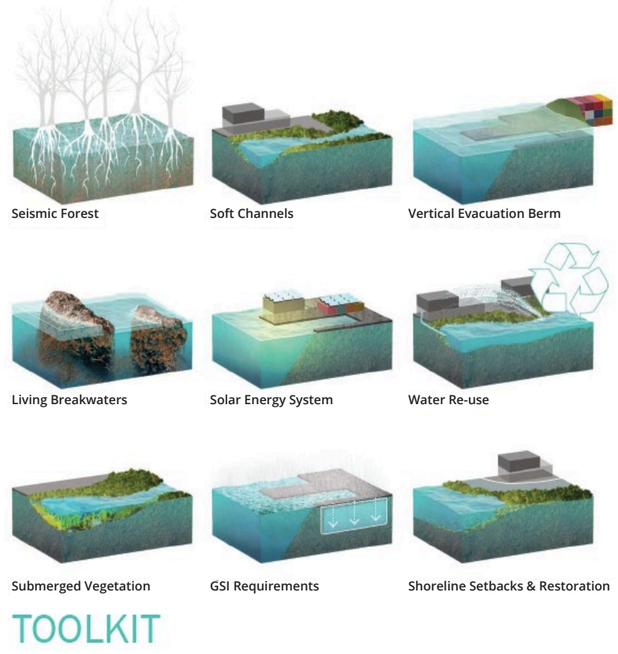
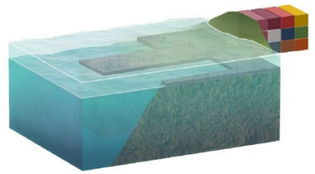
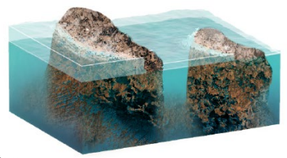


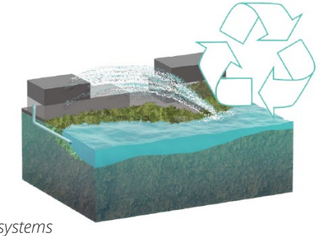
Figure 5: Students developed nine different green infrastructure tools that not only enhance the Port's ecological function, but also reduce the impacts from a hazardous event. Students created nine graphic icons to represent the recommended tools. LCY STUDENT TEAM



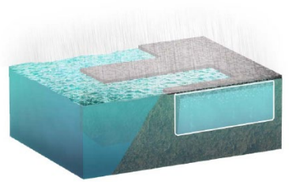
Vertical evacuation berm



Living breakwaters



Water re-use systems



Green stormwater infrastructure

ECOLOGICAL TOOLKIT
Vertical Evacuation Berm

To maintain critical infrastructure after a tsunami event, a vertical evacuation berm can make use of unused, stored shipping containers to provide access to protected high ground in an emergency.

Living Breakwaters

Living breakwaters are hard structured habitats, that can function like oyster reefs and rocky habitats, which can reduce and prevent infrastructure damage from storms surges and tsunamis by decreasing wave attenuation. These structures are built to mimic shellfish habitat and oyster beds resulting in an increase in habitat for marine organisms while also protecting the Port and other critical infrastructure from hazards.

Water Re-Use Systems

Planted on underwater long lines, native seaweed can be positioned one foot off the bottom of the Puyallup River and channel inlets. Gracillis, a species of native seaweed, metabolizes nutrient pollution and absorbs metals, cleaning waters that have been impacted by debris or material spills from hazardous events. It also tolerates air, and therefore would survive tidal impacts.

Green Stormwater Infrastructure

Green Stormwater Infrastructure (GSI) has been found to be a cost effective strategy for managing stormwater and alleviating flooding (Wang 2013). GSI solutions reduce the amount of stormwater entering stormwater drains by increasing infiltration of water into the soil and, subsequently, the water table. This helps to alleviate system capacity issues during peak runoff, and therefore can reduce the severity of inundation (Foster 2011). There are numerous types of GSI, including bioswales, rain gardens, green roofs, rainwater cisterns, and permeable pavement. Of particular note, bioswales and rain gardens can filter pollutants and settle sediments, thereby keeping contaminants out of waterways like the Puyallup River and Commencement Bay (Sources and Solutions: Stormwater 2017)

Unreinforced Masonry

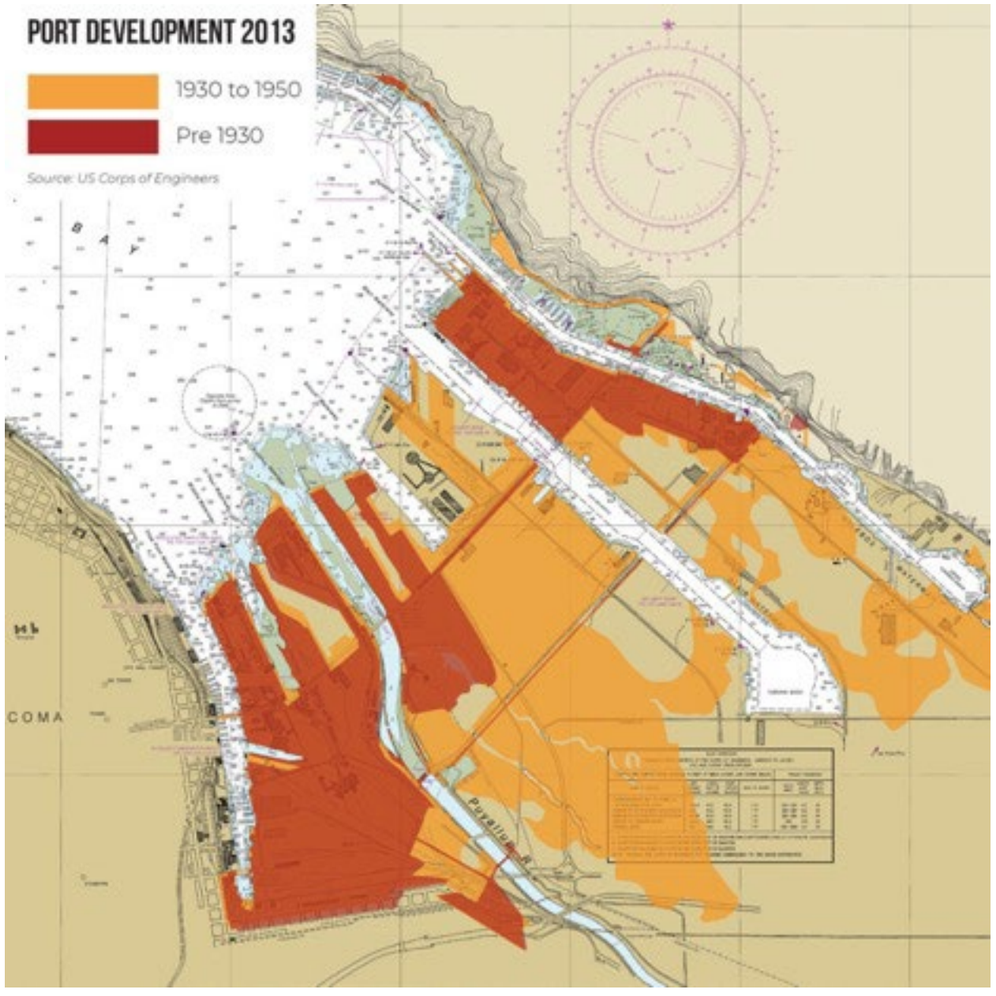
An Unreinforced Masonry (URM) building consists of load-bearing and non-bearing walls composed entirely of brick, adobe, or terra cotta. Due to the engineering of these structures, URM buildings are vulnerable to systemic failure, shearing, and collapse under the stress of seismic activity. These structures therefore pose a threat to those who live and work in their proximity.

The City of Tacoma has many URM buildings within its jurisdiction that also possess historic and cultural significance and belong to the inventory of historic structures. These structures also tend to represent some of the more affordable residential stock in the area, making up a significant portion of affordable housing in the business core (City of Seattle 2017). While these structures are subject to stringent review and design standards on the local, state, and federal levels, many buildings have not yet been renovated to withstand a seismic event.

Therefore, the fourth team directed their efforts towards two hazard mitigation challenges associated with URM's and fill development. First, the team identified buildings at high risk of failure in two historic districts within the City of Tacoma, based on overlap between URM masonry and earthquake hazard, as well as the age and condition of individual buildings. Second, to further understand the areas in most critical need of reinforcement, they analyzed the history of fill development in the Port by evaluating historic USGS maps.

The team's research indicates that fill development of the Puyallup River Salt Marsh and Commencement Bay were underway in the early 1900s, with the majority of the fill in place by 1950. Under the best circumstances, new fill was comprised of local stone and soils. More likely, fill consisted of whatever material the builders could find – trash, waste from local mills and factories, fallen timber. Due to fill development, there are some areas within the Port that are structurally unstable and are more vulnerable to hazards than others. Effects of erosion during a tsunami or flood will be unpredictable, however the likelihood that land may give way to sinkholes and subsidence are high. Although the Port has implemented retrofitting projects to Port structures in effort to further protect the Port, reinforce vulnerable infrastructure and increase resiliency.

To align with the Port's safety objective, the team suggests that the Port fortify and strengthen the fill that provides the foundation for buildings



In 2013, the US Army Corps of Engineers created this map to illustrate the Port's development. The red shading indicates areas of fill, likely composed of waste materials from historic lumber industry, that occurred prior to 1930. US CORPS OF ENGINEER

and roads. Modern sonar technology can be utilized to search for voids in the fill. When voids are found, they safety measures may need to be taken to avoid use until retrofit can occur. Fill can then be excavated, and modern techniques utilized to meet current codes. During this process, safe haven areas can be created by increasing the elevation of fill to accommodate workers who might be caught in the area during a hazard event.

The team also recommends that, in order for the City of Tacoma to reduce the risk posed by existing URMs, URM's must be rehabilitated or retrofitted to withstand earthquakes. Both options have an economic and societal impact and the stakes get higher when a building has historical significance. After prioritization, then the City can move forward with incentives and disincentives and use a combination of legislation, zoning, deadlines, assistance, shared costs, and education. In most cases, proactive actions can be taken to less the danger created by URM's.

This figure displays the concentration of URM buildings in the downtown area. Overall, URM vulnerability is concentrated along the axis of downtown Tacoma. LCY STUDENT TEAM

Conclusion

After completing their research, the four student teams presented their finding to the class as well as to Port of Tacoma staff. When reporting back, it became clear that while the four teams were focuses on separate topics, they all arrived at similar shared recommendations.
First, as the Port of Tacoma is entirely within the tsunami inundation zone students from several groups made recommendations around evacuation strategies and route. In order to minimize loss of life, injury, and damage to business assets, the students recommend the development of evacuation routes, transportation infrastructure improvements (such as paving), shelter locations at the Port of Tacoma like vertical evacuation platforms and berms, and establishing evacuation gathering locations in the cities of Tacoma and the City of Fife.

Both the evacuation group and the hazard mitigation group suggested the relocation of non-essential activities and occupants, like the federal immigration detention facility, off-site and away from the Port as this will significantly reduce vulnerabilities and improve safety of individuals. Additionally, this would allow for a more strategic allocation of limited hazard mitigation resources. In addition, the two groups suggest that hazard mitigation should drive zoning, planning, and building requirements within the Port's boundaries.

Further, all group stress that due to the economic significance of the Port of Tacoma and its impact on the State and local economies, it is essential that the City of Tacoma and other stakeholders protect the Port from the worst impacts of potential disasters. As a first step toward jurisdictional hazard mitigation planning, the City of Tacoma and the State of Washington need to more actively recognize the Port as an indispensable asset. Any interruption to Port functions may have devastating repercussions for the economic well-being of Washington businesses, employees, and residents, many of whom are closely connected to the Port. With such a large land area, diverse businesses, and various jurisdictions, planning for hazards in this context is inherently complex. Students highlight that it is essential for jurisdictions and partners to recognize that planning is a process that requires consistent and open communication with all stakehdolders that support Port functions and emergency response. By engagins in consistent communications, stakeholders can identify the capabilities, resources of each group and delegated responsibilities accorindingly so that hazard mitigation actions are streamlined across jurisdictions.

Finally, students recognized that it is critical that the Port is able to quickly recover from a hazard event. The development and implementation of a business continuity plan for the Port could help to achieve objectives around safety and outline a strategy for how to efficiently resume operations following an event. A business continuity plan can allow for Port personnel and terminal tenets to become familiar with the various types of hazard events and establish a better understanding of what actions need to be taken dependent on the emergency. This plan would include a systematic procedure for stakeholders to follow directly following the emergency and into the weeks and months following, ultimately laying the groundwork for economic recovery.

A common challenge mentioned among student projects is effectively communicating how strategic mitigation planning can help the Port and businesses not only reduce their risk to hazards, but also save costs in the future. Hazard mitigation may be perceived as being in conflict or competing with the interests of those that operate businesses within the Port because of the potential financial resources required to comply (FEMA 2013). Across student groups, it was echoed that these perceptions may be successfully challenged through a focused understanding of common objectives and cooperative, strategic thinking about planning. Ultimately, by reducing gaps across hazard mitigation plans, fortifying fill sites, and exploring natural infrastructure solutions, the State, County, and the Port can better ensure that, when a hazard event strikes, they have done what they can to protect the well-being of the people, infrastructure, and economy of Tacoma.

Professor Bob Freitag's Hazard Mitigation Planning class (URDP 549) during a tour with Port of Tacoma's Chief of Security Gerry Fiola (third from left). Professor Freitag is fourth from right. TERI THOMSON RANDALL

Middle top: Students discuss their findings during class on the Seattle campus.
All other photos: During a visit to the Port of Tacoma, students hear presentations from Gerry Fiola (bottom) and Marty Kapsh (top left) with the Port of Tacoma's Security Team, as well as from representatives of the City of Tacoma's Fire and Public Works departments, the US Coast Guard, and FEMA.
TERI THOMSON RANDALL

Appendices

Appendix A

HEC-LifeSim is an agent-based simulation model developed by the US Army Corps of Engineers for evaluating the potential for loss of life from a flood event. The model simulates the re-distribution of population in response to an emergency warning by implementing a traffic simulation model, which interacts directly with the flood wave propagating throughout the area of risk. The images displays the road network and evacuation destinations near the Port.

Appendix B

Students in the safety and evacuation group used the US Army Corps of Engineers HEC-LifeSim simulation model to evaluate various evacuation scenarios, displayed below.

Example 1: Simulation of peak evacuation egress paths (11th Street Bridge closed). LCY STUDENT TEAM

Example 2: Simulation of vehicles unable to evacuate over 11th Street Bridge. LCY STUDENT TEAM

Appendix C

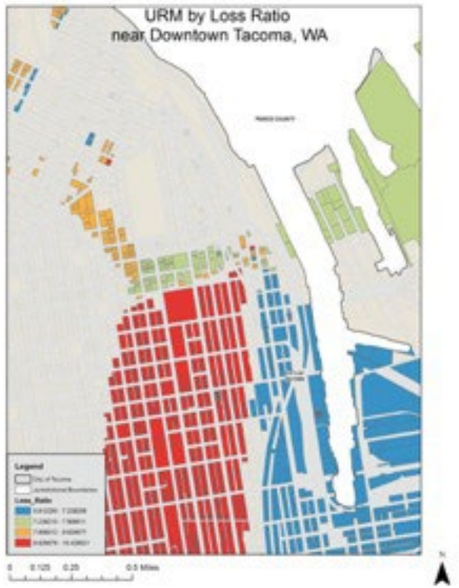


Figure shows that most URMs in the downtown Tacoma area date between 1913 and 1919, where the most recent construction was in 1986.

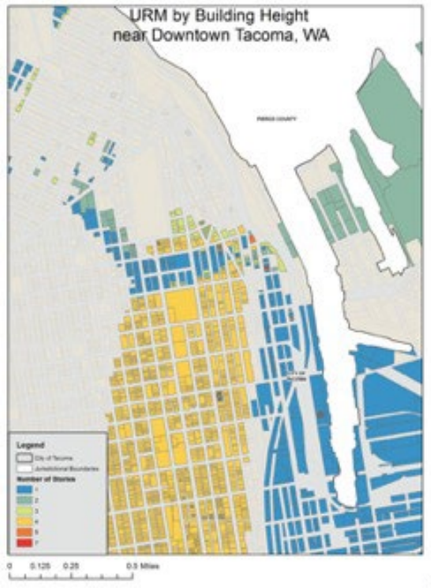


Figure shows that many downtown URM structures are only one story high (blue shading), but the areas around the North Slope and Old City Hall are home to taller buildings, of 3-7 stories. (light green-red shading).

GIS Sources:
GIS layers from FEMA
GIS layers from City of Tacoma - district boundaries, legal boundaries, land use

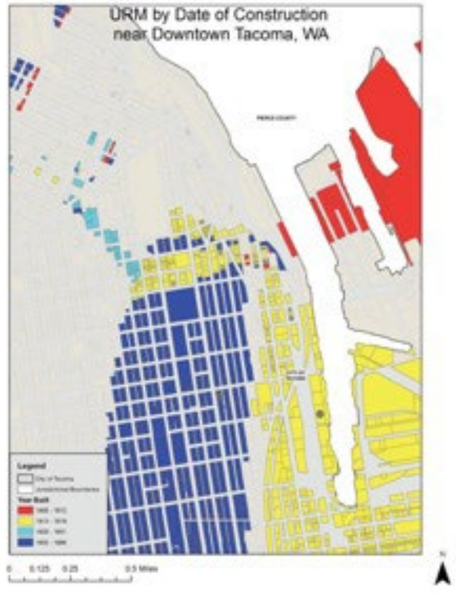


Figure shows that the average loss ratio for buildings in the study is between 6% and 10% (yellow). This is greater than the City of Tacoma average.

Figure shows the North Slope neighborhood features a mix of older and newer buildings; many were built prior to the 1970s (orange) and the advent of seismic code requirements. Tacoma has second-highest number of pre-seismic code buildings in Pierce County, following the City of Sumner. In the area surrounding Old City Hall, most buildings date to 1915-1921, but there are also several post-seismic code structures.

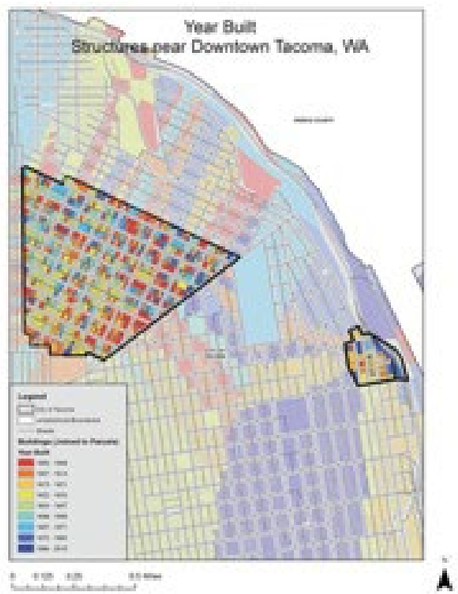


Figure shows that the loss ratio ranges from 7% to 15% for some buildings in the North Slope and for most buildings in the Old City Hall district.

References

City of Tacoma. (n.d.). Tacoma's historic districts. Accessed at http://www.cityoftacoma.org/cms/One.aspx?portalId=169&pageId=67725

Climate Central (2016). Sea level rise and coastal flood exposure: Summary for Tacoma, WA. Surging Seas Risk Finder file created July 21, 2016. Retrieved March 02, 2018, from http://ssrf.climatecentral.org.s3-website-us-east1.amazonaws.com/Buffer2/states/WA/downloads/pdf_reports/Town/WA_Tacoma-report.pdf

Danseco, J. C., Rhinehart, A., Burkhardt, J. D., Anderson, B., & University of Washington, T. (n.d.). UW Tacoma: 25 years of transformation.

Earthquake hits Puget Sound area on April 13, 1949. (n.d.). Retrieved February 25, 2018, from http://www.historylink.org/File/2063

Fiola, Gerry. After Action Report for Cascadia Rising 2016 Memo. Port of Tacoma, 2016.

Fiola, Gerry. Personal Communication to Steve Henderson, January & February 2018.

Freitag, Robert, Jeana Wiser, et al. "Project Safe Haven: Tsunami Vertical Evacuation on the Washington Coast." University of Washington, 2011. https://mil.wa.gov/uploads/pdf/emergency-management/haz_safehavenreport_pacific.pdf.

Federal Emergency Management Agency (FEMA). 2013. Integrating Hazard MitigationInto Local Planning: Case Studies and Tools for Community Officials. March 1, 2013. Accessed: https://www.fema.gov/media-library-data/20130726-1908-25045-0016/integrating_hazmit.pdf

Federal Emergency Management Agency (FEMA). 2013. Local Mitigation Planning Handbook. Accessed: https://www.fema.gov/media-library-data/20130726-1910-25045-9160/fema_local_mitigation_handbook.pdf

Federal Emergency Management Agency (FEMA). 2009. "Unreinforced masonry buildings and earthquakes: Developing successful risk reduction programs." FEMA P-774.

Federal Emergency Management Agency (FEMA). 2016. "Risk report: FEMA region X - Pierce County, Washington."FEMA. September 2016. "Risk report: FEMA region X - Pierce County, Washington."

Gibson, J., S. Moddemeyer, S. Keithly, M. Dixon, T. Gibson. 11 April 2014. Seattle unreinforced masonry retrofit policy: Benefit cost analysis. City of Seattle Department of Planning and Development. Accessed at https://www.seattle.gov/dpd/cs/groups/pan/@pan/documents/web_informational/p2232124.pdf

Foster, J., Lowe, A., & Winkelman, S. (2011). The value of green infrastructure for urban climate adaptation. Center for Clean Air Policy, 750, 1-52.

Fukushima, GS 1995, The Great Hanshin Earthquake. San Francisco: University of San Francisco Center for the Pacific Rim. http://www.jpri.org/publications/occasionalpapers/op2.html.

Historic Preservation - City of Tacoma. (2018). Retrieved February 1, 2018, from http://www.cityoftacoma.org/cms/one.aspx?objectId=67700

Mauger, G.S., J.H. Casola, H.A. Morgan, R.L. Strauch, B. Jones, B.Curry, T.M. Busch Isaksen, L.

Whitely Binder, M.B. Krosby, and A.K. Snover. 2015. State of Knowledge: Climate Change in Puget Sound. Report prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Climate Impacts Group, University of Washington, Seattle.!doi:10.7915/CIG93777D

Neighborhoods: a glimpse at Tacoma's history. (1980). Tacoma, WA: Tacoma Washington Office of Historic Preservation.

"OSHA Directorate of Training and Education | Occupational Safety and Health Administration." Accessed February 11, 2018. https://www.osha.gov/dte/.

Pierce County. 2018. Region 5 Hazard Mitigation Base Plan 2015-2020. Retrieved 27 February 2018 from: http://www.co.pierce.wa.us/943/Emergency-Plans.

Port of Tacoma. 2016. Region 5 All Hazard Mitigation Plan 20105-2020 Edition: Port of Tacoma Addendum. Accessed: https://www.portoftacoma.com/sites/default/files/attachments/Region5HazardMitigationPlan_Port_2015-2020.pdf

Puyallup Tribe of Indians. 2018. Puyallup Tribe of Indians All Hazards Mitigation Plan 2017 – 2022 Edition. Retrieved 13 February 2018 from: http://puyallup-tribe.com/publicsafety/Recommendations from the Unreinforced Masonry Policy Committee to the City of Seattle. (2017). Retrieved from http://www.seattle.gov/dpd/cs/groups/pan/@pan/documents/web_ informational/p3452259.pdf

Reitherman, R. (2009). Unreinforced masonry buildings and earthquakes: developing successful risk reduction programs: prepared for Federal Emergency Management Agency. Washington, D.C.: Federal Emergency Management Agency.

Tacoma Register of Historic Places. (2017). Tacoma, WA: City of Tacoma.

Tideflats Emergency Response Plan. 2016. Retrieved 27 February 2018 from: http://cms.cityoftacoma.org.

University of Washington. 2017. Scenario-based Flood Risk Mapping: Tacoma Workshop. Workshop Date December 4.

Venturato et. al. 2007. Tacoma, Washington, Tsunami Hazard Mapping Project: Modeling tsunami inundation from Tacoma and Seattle Fault earthquakes. National Tsunami Hazard Mitigation Program. NOAA Center for Tsunami Research. Accessed: https://www.pmel.noaa.gov/pubs/PDF/vent2981/vent2981.pdf

Wang, R., Eckelman, M. J., & Zimmerman, J. B. (2013). Consequential environmental and economic life cycle assessment of green and gray stormwater infrastructures for combined sewer systems. Environmental science & technology, 47(19), 11189-11198.

Water Recycling and Reuse | Region 9: Water | US EPA. (n.n.d.). Retrieved March 06, 2018, from https://www3.epa.gov/region9/water/recycling/

Washington Military Department. "2016 Cascadia Rising Exercise After Action Report: Catastrophic Earthquake and Tsunami Scenario," January 5, 2017. https://mil.wa.gov/uploads/pdf/training/cr16-state-aar-final.pdf.

Washington State Military Department. 2014. Washington State Enhanced Hazard Mitigation Plan. Accessed: https://mil.wa.gov/other-links/enhanced-hazard-mitigation-plan.