Sea Level Rise in Edmonds, WA: Expected Impacts & Recommended Actions

Project Report

Disaster Reduction and Emergency Planning Studio

ENVS 476, Spring 2017

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Western Washington University

Sustainable Communities Partnership

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Western's SCP program focuses the energy and ideas of faculty and students upon the issues that cities face as our society transitions to a more sustainable future. SCP partners with one community each academic year, facilitating a program in which many Western courses complete service-learning projects that address problems identified by the partner.

Sustainable Communities Partnership

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SCP Partner for Academic Year 2016 - 2017: The City of Edmonds, WA

SCP is proud to partner with the City of Edmonds, Washington, during the program's inaugural year. Eleven courses at Western will tackle ten projects identified in collaboration with city staff.

Acknowledgment

The Association of Washington Cities (AWC) has provided invaluable assistance during the launch of the SCP program. AWC provided seed funding, guidance regarding program design, help with promotion of the program, and advice regarding selection of the inaugural partner.

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PREFACE

The spring 2017 Disaster Reduction and Emergency Planning Studio course (ENVS 476) worked on issues related to sea level rise in Edmonds. A four-person team performed background research, developed models, ran the models, and described results. Interactions with city staff were by Skype, but the students traveled to Edmonds on June 9, 2017, to present their work to an audience of officials and interested citizens.

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SEA LEVEL RISE IN EDMONDS, WA: EXPECTED IMPACTS AND RECOMMENDED ACTIONS

By Seth Dahlquist, Drew Lindsey, Tim O'Melia, & Jacob Regge

Executive Summary

We are students affiliated with Western Washington University's Resiliency Institute. We've been given the opportunity to assist the City of Edmonds, Washington, by establishing and identifying specific risks faced by the city related to climate change and sea level rise (SLR).

Various processes contribute to global SLR, with climate change a chief contributor. Influences affecting SLR specific to the Salish Sea include oceanic tides, storm surge, local atmospheric circulation, tectonic movement, and sediment transportation. In order to accurately comprehend these influences and their collective impact, this report utilizes ESRI ArcMap and FEMA HAZUS-MH Plug-in to provide specific impacts associated with SLR and coastal flooding in the City of Edmonds in the year 2100.

The sea level of the Salish Sea is projected to rise 24 inches over the next century, with a range of four inches to over four feet. Additionally, tidal variation due to storm surge and an El Niño Southern Oscillation, which contributes to sea levels at three feet above mean higher high water (MHHW), reveals the true extent and impact of SLR in the Salish Sea. Saltwater inundation threatens both ecosystems and anthropocentric development in the Salish Sea (National Research Council , 2012; Mote, Petersen, Reeder, Shipman, & Whitely Binder, 2008).

Literature Review of Sea Level Rise

Sea level rise (SLR) occurs when the volume of the ocean increases. As oceanic water temperatures increase, so does the volume of the ocean's water: water molecules expand as they are heated. This expansion is a major driving force underlying global-scale projections.

Relative SLR on the west coast is predicted to be lower, because tectonic plate movement is causing the land to rise (DoE, Sea Level Rise and Coastal Hazards, 2012). Despite this relatively lesser risk of flooding, Puget Sound will be at risk of more severe flooding and high tides during extreme weather events (Edmonds, Sea Level Rise, n.d.). Climate change will cause these events to be more severe and occur more often, so understanding SLR is important for mitigating the effects of extreme weather events.

Long wave radiation trapped in Earth's troposphere is increasing the planet's global temperatures. Ice sheets at polar latitudes in both hemispheres are experiencing a shrinking effect (melting) due to this increase in temperature. Alpine glaciers across the planet are also exhibiting similar shrinking. This process of Earth's solid ice turning into liquid water is also raising sea levels. Within contemporary predictive models, the factor of ice-melt has been responsible for the greatest degree of SLR. A variety of variables influence local SLR within the Salish Sea. These variables include storm surge, King tides, vertical land movement, and atmospheric circulation.

Storm Surge

Storm surge is another aspect of SLR that will affect the Puget Sound area. Storm surge is defined as "an abnormal rise of water generated by a storm, over and above the predicted astronomical tide" (NationalHurricaneCenter, n.d.). Furthermore, because storm surge is a *difference* between water levels, it does not have a reference level (NationalHurricaneCenter, n.d.). Storm tide occurs when the water level during a storm rises because of storm surge and astronomical tide (NationalHurricaneCenter, n.d.).

Storm surge can be observed and measured in a variety of ways. Tide stations are used to measure water levels on the coast. NOAA calculates storm surge by, "subtracting what the water level would have been in the absence of the storm from the measured water level" (NationalHurricaneCenter, n.d.). NOAA's network of stations collect data throughout the United States. This can be an effective tool for measuring the data in real time and measuring still water (NationalHurricaneCenter, n.d.). High water marks are another way to evaluate storm surge. They can be measured using lines found on trees and structures that mark the highest elevation of water during a flood.

Oceanic Tides

In combination with SLR and coastal flooding, high tides or 'King tides' will also contribute to the increase in severity of these events (DoE, 2017). A King tide is defined as "the highest predicted high tide of the year at a coastal location. It is above the highest water level reached at high tide on an average day" (EPA, King Tides and Climate Change, 2016). King tides can occur even when they are not predicted, if the atmospheric pressure is low enough. King tides occur once or twice yearly at coastal locations (EPA, King Tides and Climate Change, 2016).

Vertical Land Movement

Geologic variables that influence Edmonds' local vertical land movement make SLR analysis an intricate process. Two mechanisms contributing to a shift in Edmonds' geologic position are tectonic subduction and isostatic rebound, both of which are increasing the elevation of Edmonds.

Tectonic subduction occurs within the Earth's lithosphere when one tectonic plate submerges under another. Western Washington is situated on the perimeter of the North American continental plate, and is experiencing an uplifting effect due to the subduction of the neighboring Juan De Fuca plate, which underlies the Pacific Ocean. Isostatic rebound is a process which involves a landmass' spatial increase in height. Also known as post-glacial rebound, this happens as a landmass which was covered by an ice sheet during a prior episode of glaciation experiences uplifting due to the removal of the ice's weight.

Measuring local sea level relative to local land level is challenging considering the abundance of influences that present both large scale geologic transformations (tectonic shifts) and small scale transformations (soil compaction/deposition). Global positioning system (GPS) sensors, along with LIDAR (Light Detection and Ranging) data have enhanced our ability to consider these processes and how they interact.

Atmospheric Circulation

The Pacific Ocean experiences trends of temperature fluctuation that oscillate over time and by location. The distribution of warm waters which transition from the Eastern Pacific to the Western Pacific follow consistent patterns. These trends are often referred to as the Pacific Decadal Oscillation (PDO). A related climate phenomena of the PDO known as the El Niño-Southern Oscillation (ENSO) demonstrates the relationship that oceanic temperatures have with tropospheric temperatures. One phase of the ENSO cycle is described as an 'El Niño event,' which takes place when sea surface temperatures in the Eastern Pacific experience a warming phase. This warm water introduced to Earth's middle latitudes transfers heat into the troposphere, where it then has potential to affect global atmospheric circulation.

Wind along Washington's coastline has a substantial effect on SLR within the Salish Sea both seasonally (El Niño) and inter-annually (ENSO). Local increases in sea level are an outcome of the Coriolis effect (which pushes ocean water toward North America's west coast) in combination with a strong northward wind. The northward wind is typically more powerful during El Niño events, which respectively increases the SLR in the Salish Sea (University of Washington Climate Impacts Group, 2008).

Sea Level Rise Impacts

Western Washington's geographic position yields an abundance of geologic and climatologic variables that collectively influence its physical characteristics. Various regions of the planet are going to experience SLR in different ways. The following sections address how SLR will affect the City of Edmonds.

Storm Surge

The intensity of storm surges will increase the severity of coastal flooding in Edmonds by as much as 4 feet (Central, Coastal Floods are Increasing, 2016). Storm surge, in combination with high tides, will pose a serious threat to the City of Edmonds. As the years go by the *likelihood* of an extreme weather event increases, and events will become more severe as climate change continues to *intensify* weather events (EPA, www.epa.gov, 2016).

Oceanic Tides

The Mean Higher High Water (MHHW) is defined as, "the average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch" (NOAA, Tidal Datums, n.d.). The average of the highest extremes occurred in 2003 and 2012. In relation to local MHHW, which represents the high tide line, an increase of 3.3 feet is expected (Central, Sea level rise and coastal flood risk, 2016). If an extreme weather event were to happen during the predicted MHHW, the city would be at risk of coastal flooding (NOAA, Datums for 9447427, EDMONDS WA, 2017).

Vertical Land Movement

Edmonds' intertidal zone is limited to natural replenishment of beach substrate. The steep coastal topography, in combination with the BNSF's railroad bed and other structures (seawalls, dikes, levees), has reduced sediment deposition on the waterfront. The beach substrate is primarily comprised of coarse-grained material such as coarse sand, gravel, and cobble (Department of Ecology, 2007, p. 34). As a result, sediment deposition along the beach does not influence SLR enough to have incorporated it into our analysis.

We know that trends in both SLR and vertical land movement processes (crustal deformation) vary over time. 50-year trends (1898-2000) of vertical land movement measured in Seattle fluctuate from uplifts of 1.04 mm/yr to 2.80 mm/yr (University of Washington Climate Impacts Group, 2008). Changes in annual and inter-annual (even decadal) rates of global SLR in combination with rates of local vertical land movement regulate these linear trends. Due to Puget Sound's inconsistent and scattered increases in vertical land movement, projecting an accurate elevation increase for the Edmonds region is challenging. One study predicts that Edmonds will rise 10 cm (4") by 2050 and 20 cm (8") by 2100 (Verdonck, 2006).

Atmospheric Circulation

Models that analyze atmospheric circulation variability and its association with local sea level utilize measurements of circulation change and ocean density. Mote et al. (2008) show that Washington's coast and estuaries are experiencing an increase in sea level of approximately 50 cm (20") in the wintertime, as compared to summertime sea levels. In addition, sea levels can rise as much as 30 cm (12") during an El Niño event, which can last for months at a time. University of Washington's Climate Impacts Group considered 30 examples from global climate predictions (Mote, Scenarios of Future Climate for the Pacific Northwest, 2008). On average, these predictions show that the mean differences in wintertime northward wind are insignificant with respect to Washington's coast. Nonetheless, there are also models which show increases in a wintertime northward wind that are predicted to cause an increase of the average sea level of up to 15 cm (6") from 2050-2099, compared to data retrieved from 1950-1999. Significant differences in location and physical characteristics generate considerable fluctuation in these predictions. As processes of climate change continue to develop, the spatial standard deviation of SLR increases (Intergovernmental Panel on Climate Change, n.d.).

Coastal Flooding

The effects of SLR will be noticeable in the severity of floods along the coast of the Salish Sea and at many coastal cities (EPA, www.epa.gov, 2016). Figure 1 illustrates the extent of the Salish Sea in North America (Freelan). Flooding occurs during seasonal high tides (King tides), which, combined with storms, will increase in severity (EPA, www.epa.gov, 2016). Figure 2 depicts how coastal flooding driven by climate change has increased in the Puget Sound (Central, Coastal Floods are Increasing, 2016). Floods topping 4 ft by 2050 and 5 ft by 2070 are projected (Strauss, 2017). These flood events, which are magnified by King tides, will pose a real threat to the City of Edmonds in coming years. An increase in coastal flooding can have effects on a city's storm water drainage capacity, lead to road closure, and damage infrastructure (NOAA, Sea Level Rise and Nuisance Flood Frequency, 2014) SLR will cause the City of Edmonds to face record floods in the coming century.

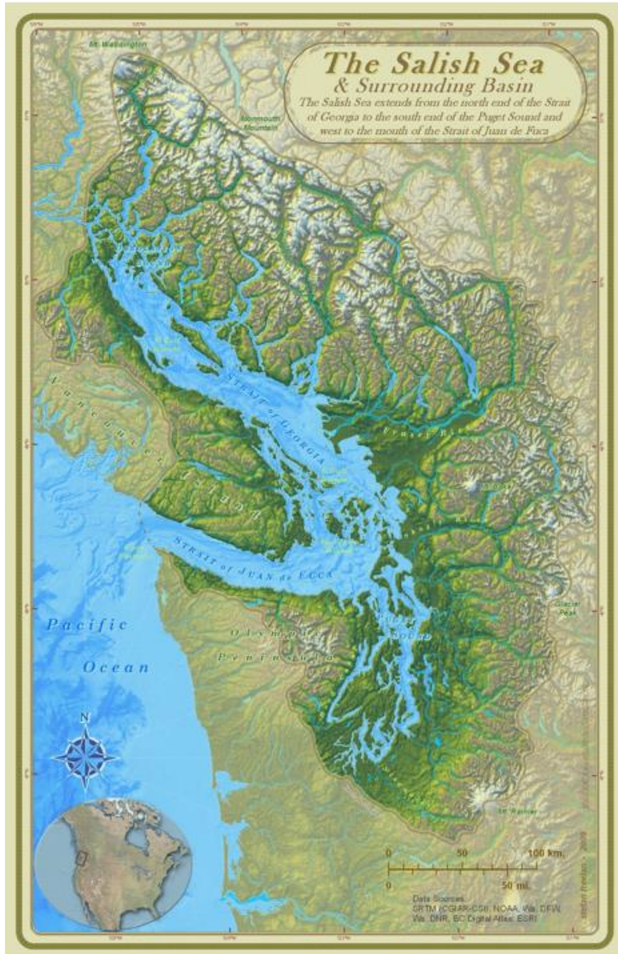

Figure 1. The Salish Sea and Surrounding Basin.
Stefan Freelan, 2009.

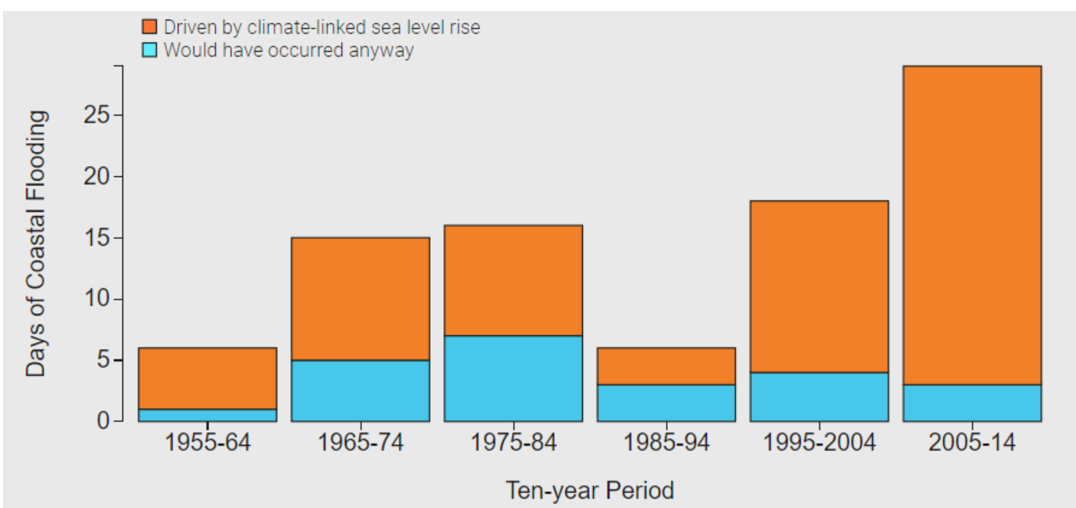

Figure 2. Climate change has increased the occurrence of coastal flooding

Modeling Coastal Flooding in Edmonds, WA

Coastal flooding is a dynamic environmental phenomenon involving climatic, hydrologic, and geologic elements, and intensifies as temperatures rise, ocean waters thermally expand, and polar ice caps and glaciers melt. While the causation of coastal flooding is complex and intensively studied, the rate of coastal flooding is variable around the globe.

Edmonds is a coastal, inland sea community of 39,709 people, situated on the shoreline of the Salish Sea in Washington State (U.S. Department of Commerce, 2010). Figure 3 provides a reference map of the City of Edmonds (City of Edmonds, 2011). The Edmonds community is made vulnerable to coastal flooding due to the interaction of ecological variables such as SLR, tidal variation, storm surge, and climatic oscillation events. This report utilizes the Geographic Information Science (GIS) applications ESRI ArcMap and the FEMA Hazus Plug-in to generate two predictive spatial analysis models that measure and visualize the extent of projected coastal flooding in the Edmonds community.

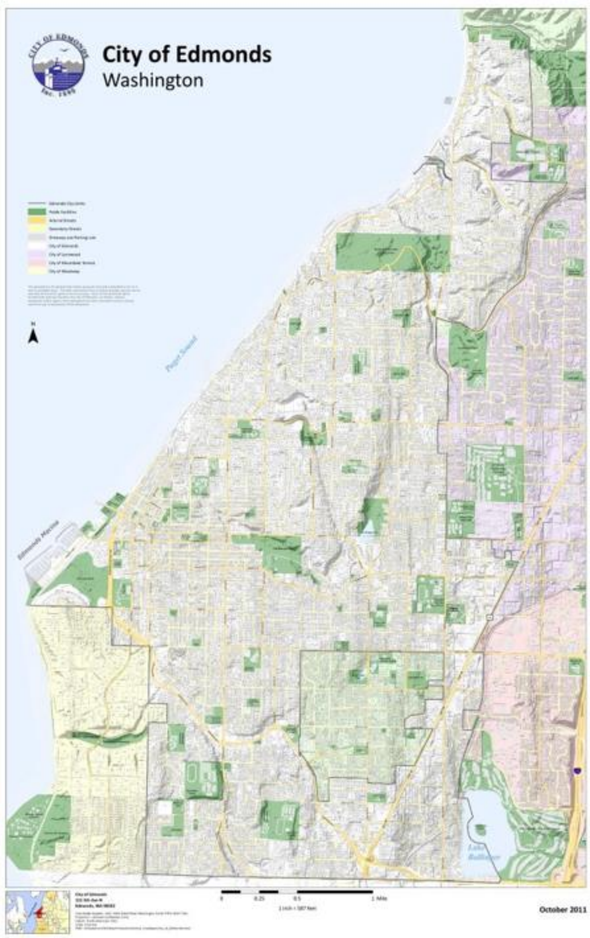

Figure 3 City of Edmonds, WA, locator map (City of Edmonds, 2011).

ESRI ArcMap Analysis

Environmental Systems Research Institute (ESRI) is a geo-spatial technology company which develops, analyzes, and distributes geo-spatial data and software across the globe. Using the ESRI software ArcMap, this analysis generates predictive scenarios of 'expected' and 'extreme' coastal flooding events in the year 2100 for the Edmonds community.

The following is a list of the data sources this report uses for analysis of coastal flooding in Edmonds, WA. Spatial analysis and cartography within this report are conducted using the NAD 1983 State Plane Washington North FIPS 4601, Feet, projected coordinate system.

Census Population Data

2010 Census population data is used to quantify how many people in Edmonds are vulnerable to displacement from coastal flooding. Figure 4 illustrates the 2010 Census Block Groups for the city.

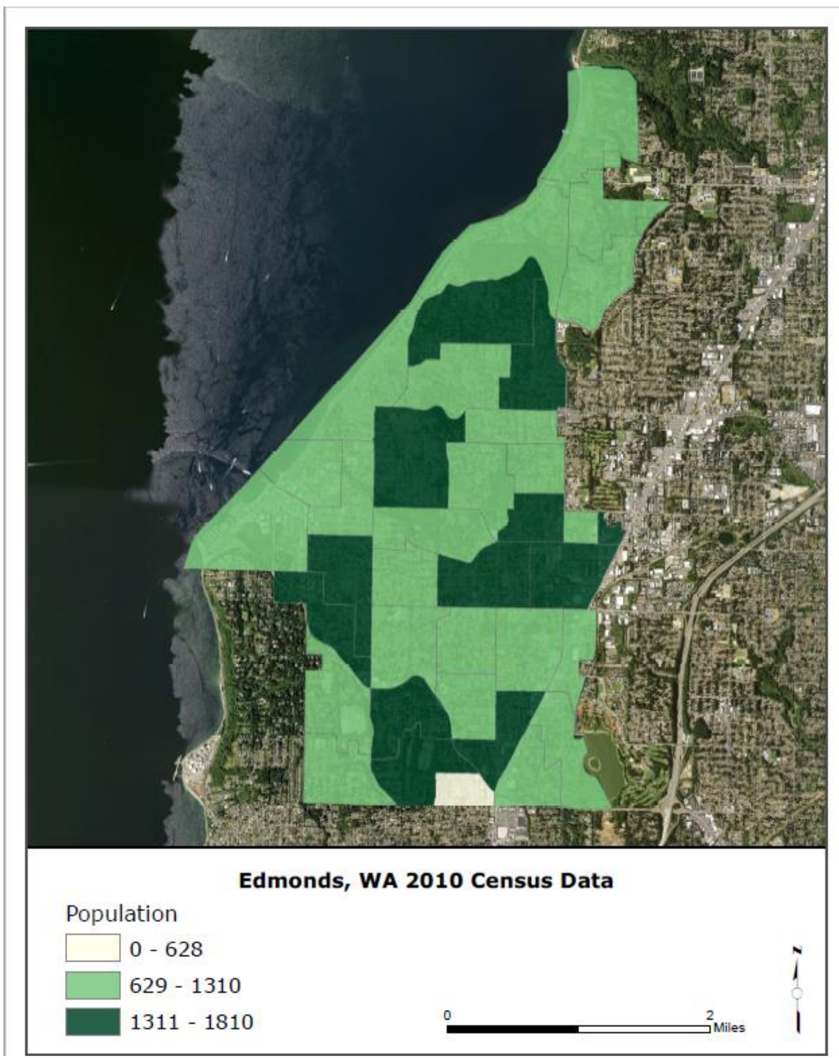

Figure 4. Reference map of the City of Edmonds, WA 2010 Census Block Groups (U.S. Department of Commerce, 2010)

Source: U.S. Department of Commerce, U.S. Census Bureau, Geography Division
2010 Census Block Groups, 2010 TIGER/Line Shapefile
Date: 01/01/2010
Format: Vector

Edmonds Parcel Data

Property parcel data provided by the Snohomish County Assessor's Office is used to identify the parcels, property owners, and taxpayers vulnerable to property loss or damage caused by coastal flooding inundation.

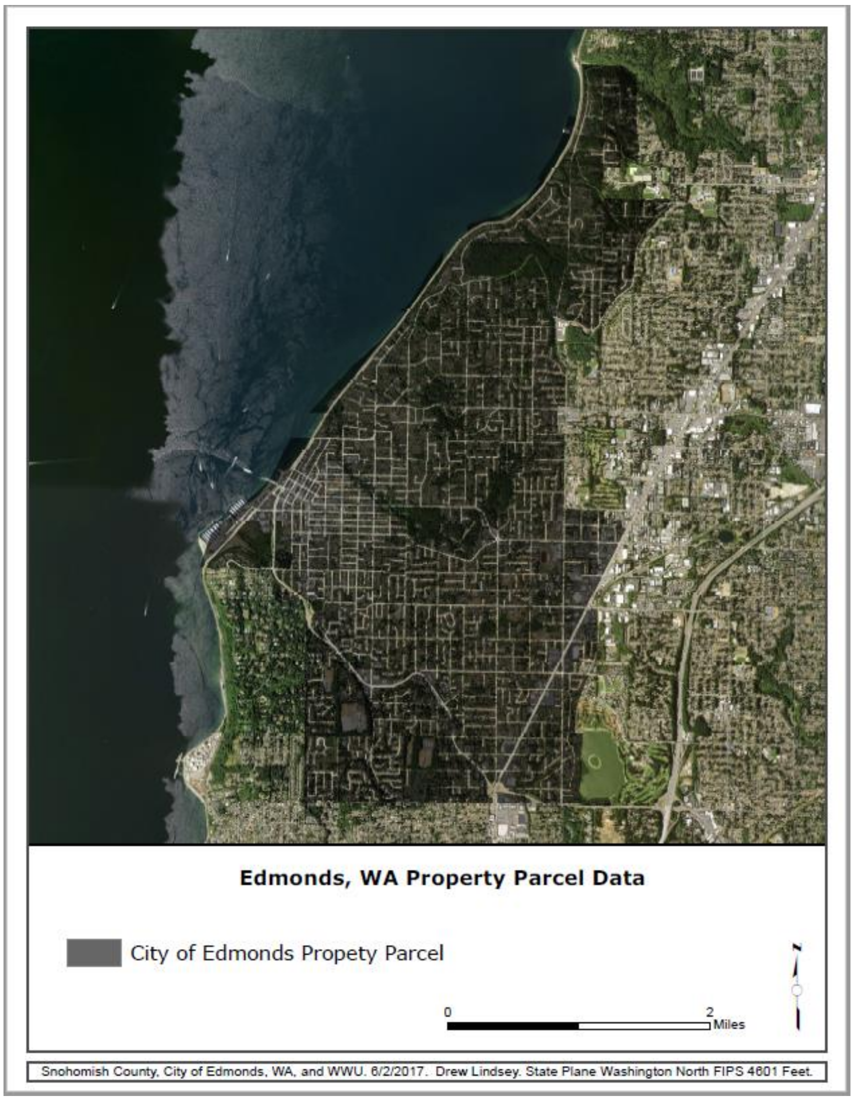

Figure 5. Reference map of the City of Edmonds, WA property parcels (Snohomish County Assessor, 2003).

Source: GIS Data Administrator, Snohomish County Assessor
3000 Rockefeller Ave, MS 510
Everett, WA 98201
Date: 01/12/2003
Format: Vector

2015 Washington NAIP Digital Ortho Photo Imagery

The National Agriculture Imagery Program (NAIP) provides ortho photo imagery to display a high resolution, aerial perspective of Edmonds, WA.

Source: National Oceanic and Atmospheric Administration (NOAA)
https://coast.noaa.gov/dataviewer/#/imagery/search/
Format: raster, .tif
Output Resolution: 1.0 meters

Edmonds Elevation, Infrastructure, Boundary, and Hydrological Data

A digital elevation model (DEM), or a polygon representing the boundary of the City of Edmonds, and hydrological feature polygons found within the City of Edmonds, is included in this analysis.

Source: City of Edmonds FTP website
Format: raster (DEM), vector (infrastructure, boundary, and hydrological points and polygons)
Output Resolution: 3.0 feet (DEM)

ESRI ArcMap Methodology

Prior research indicated a need for spatial analysis representing an 'expected' and an 'extreme' event of coastal flooding projections for the Edmonds community. SLR in the Salish Sea is projected to reach between two and four feet in the year 2100. Additionally, in order to quantify and visualize coastal flooding inundation in Edmonds, it can be projected that tidal variation from storm surge and the ENSO may contribute to a three foot increase in sea level (National Research Council , 2012; Mote, Petersen, Reeder, Shipman, & Whitely Binder, 2008). Figure 6 represents a workflow diagram of methods used in the ESRI ArcMap analysis.

Coastal Flooding Simulation

'Raster Calculator' is a geoprocessing tool that spatially analyzes raster data sets. 'Raster Calculator' is utilized to simulate the interaction and contribution of SLR, tidal variation, and climatic variation to coastal flooding in the Edmonds community based on a current elevation dataset represented by a digital elevation model (DEM).

Areal Interpolation

Areal Interpolation is a recombination or rescaling of spatial data in order to provide a predictive analysis of proportional areas and is specifically helpful in the analysis of demographic and areal data. Areal interpolation is calculated by dividing the volume of an original area by the volume of

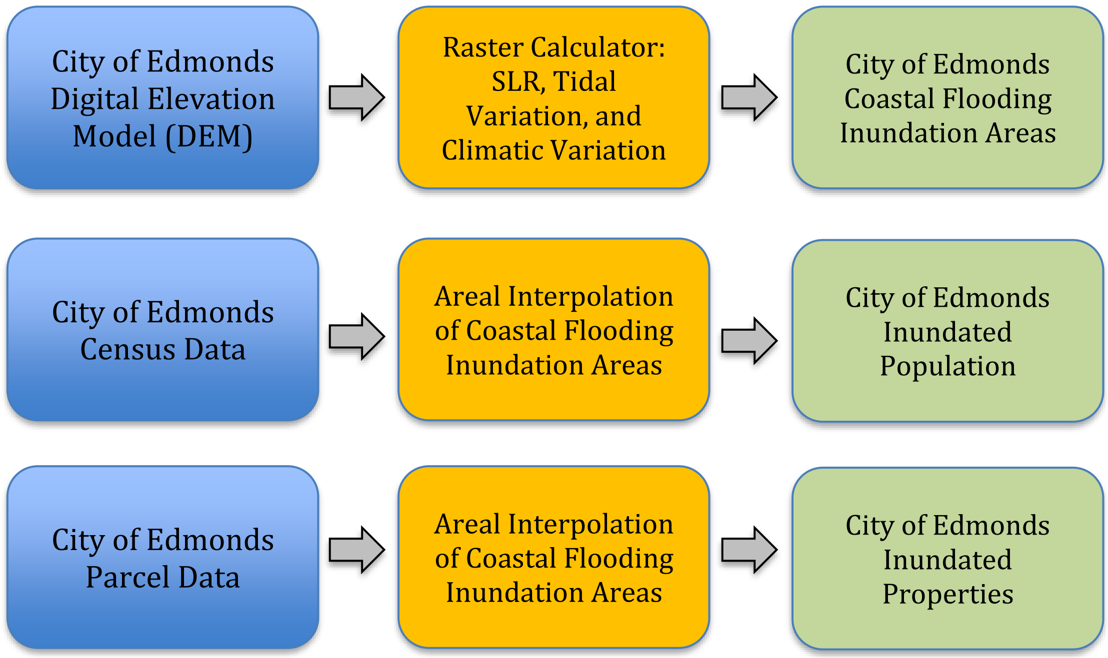

Figure 6. Workflow diagram visualizing data inputs, geoprocessing tools, and results of inundated population and parcels due to coastal flooding for the city of Edmonds, WA.

a newly defined area. Areal interpolation is used within this report to redistribute and estimate populations and parcel areas affected by coastal flooding within the Edmonds community.

Swiss Hillshade

Swiss Hillshade is a technique useful for simulating a three-dimensional elevation profile utilizing a digital elevation model (DEM). This technique refines shading and irregularities by using geoprocessing tools such as 'Hillshade', 'Focal Statistics', and 'Raster Calculator', in order to further differentiate between elevations while emphasizing major geographic features, in the creation of an elevation profile. The Swiss Hillshade technique was used to produce an aesthetic elevation profile for Edmonds, WA.

ESRI ArcMap Results

The ESRI ArcMap analysis simulates an 'expected' coastal flooding event at ***5 ft*** of saltwater inundation and an 'extreme' coastal flooding event at ***7 ft*** of saltwater inundation in the year 2100 (Mote, Petersen, Reeder, Shipman, & Whitely Binder, 2008; National Research Council , 2012).

"Expected" Coastal Flooding Projection in 2100 for Edmonds, WA

A projection of 'expected' coastal flooding of 5 ft resulted in no conclusive or quantifiable data. The results of this analysis indicate that a 5 ft coastal flooding event in Edmonds will not displace Edmonds community members or completely inundate property parcels. Although the ESRI ArcMap spatial model was not able to provide conclusive evidence of displacement or damage, it is important to understand that coastal flooding to this extent will produce vast changes to coastline ecosystems and human development in the Edmonds area.

"Extreme" Coastal Flooding Projection in 2100 for Edmonds, WA

An 'extreme' coastal flooding event at 7 ft in the year 2100 is expected to result in substantial human displacement and property parcel degradation. The results of the 'extreme' flooding analysis indicate that a 7 ft flooding event will affect five census blocks, potentially displacing over 1,300 Edmonds community members, while inundating at least 164 property parcels, covering approximately 150 acres of shoreline. Figure 7 demonstrates an 'extreme' coastal flooding event in the City of Edmonds in the year 2100. Of the potentially displaced community members, 91% identify as Euro-American, according to the U.S. Census Bureau. The effected property parcels consist of both private and publicly held lands, including the Port of Edmonds, the Washington State Ferry Terminal, recreational areas, and ecological habitats.

Figure 7. Simulation of a 7 ft saltwater inundation on the Edmonds, WA coastline. Inundation of this magnitude will affect 150 acres, or 2.3%, of total land area in Edmonds, WA.

HAZUS-MH: Level 2 Coastal Flood Analysis

HAZUS is a regional multi-hazard loss estimation model that was developed by the Federal Emergency Management Agency (FEMA) and the National Institute of Building Sciences (NIBS). The primary purpose of HAZUS is to provide a methodology and software application to estimate multi-hazard losses at a regional scale. These loss estimates would be used primarily by local, state, and regional officials to plan and simulate efforts to reduce risks from multi-hazards, and to prepare for emergency response and recovery. The flood loss estimates provided below are reported for the Edmonds municipal limits, a 9 square mile area that contains 485 census blocks. The city contains over 17,000 households and has a total population of 39,709 (2010 Census Bureau data). There are an estimated 14,071 buildings in the region with a total replacement value (excluding contents) of $5.142 billion (2010 dollars). Approximately 91.83% of the buildings (and 83.72% of the building value) are associated with residential housing.

Data

FEMA provides data for the U.S. which is downloaded at the state level. FEMA data includes:

- General Building Stock. To accurately model the impacts of natural hazards, it is critical to know what type of buildings exist in a region, and where. The more information known regarding existing infrastructure, the more accurately damages and recovery can be modeled and understood. General building stock includes variables such as square footage, building count, valuation parameters, dollar exposure, replacement value, depreciation parameters, depreciated exposure, general occupancy, and first floor elevations.
- Essential Facilities. Essential facilities are important to post-event response and recovery. It is important to know the capacities and capabilities of surrounding hospitals, fire stations, and police states. Similarly, it is important to know where temporary shelters can be located and what schools are available to temporarily house families, groups, and other individuals.
- High Potential Loss Facilities. These facilities include dams, levees, nuclear power plants, and military installations. These facilities have the potential to create a technological disaster following a natural one, and need to be properly inventoried to model potential failures and/or vulnerabilities.
- Transportation Systems. These include interstates, highways, bridges, overpasses, railroads, airports, sea ports, ferry systems, etc. These systems are critical for post-event response and recovery. It is important to know what infrastructure exists, and what infrastructure is vulnerable to natural hazards.
- Utility Systems. These include power lines, power generation and distribution centers, water and sewage treatment plants, etc. These systems are critical in post-event response and long-term recovery.
- Demographics. Demographics use U.S. Census data to show where people are located throughout the region. Attributes regarding race, sex, age, and income can be used to determine who is living in vulnerable areas. Demographic data is useful to show structural injustice and oppression in a visual way.
- Agricultural Products. In areas with high agricultural activity, agricultural data is used to show projected economic losses based on flood depth, time of year, and type of crop.

- Vehicles. HAZUS-MH has the ability to show damages caused to vehicles in a study region. Data exists to show damages based on time-of-day and whether people are at home or at work.

Methodology

FEMA provides the majority of the data needed to run a HAZUS level 2 analysis. Level 2 analysis utilizes FEMA's default recommended damage functions and other parameters. First, the user must define a study region. This region can be at the state, county, census tract, or census block level. For this model, the City of Edmonds is the area of interest. To create this region, Snohomish County is first selected, and the City of Edmonds is then defined using census tracts. Next, digital elevation models (DEMs) are imported and used to define topography and create a hill shade for cartographic purposes. Once the topography is defined, the watershed boundaries can be established and the floodplain can be delineated. A scenario is created after the topography, watershed, and floodplain are defined. First, the shoreline is selected and segmented into smaller areas. Next, the Stillwater elevation can be entered and manipulated for 10, 50, 100, and 500 year floods. This automatically generates significant wave height. Once the scenario is defined, the analysis is ready to run. HAZUS-MH automatically generates a series of reports after each run of the model. Following is additional detail regarding methodology.

1. Specify Region. Starting at the state level, Washington is selected. Next, Snohomish County is selected. The City of Edmonds is selected by selecting census tracts which make up the city boundaries. Census tracts 53061050200, 53061050300, 53061050401, 53061050402, 53061050500, 53061050600, 53061050700, 53061050800, 53061050900, 53061051000, 53061051500, and 53061051601 are selected to create a region that encompasses the city.
2. Define Topography. HAZUS-MH provides an interface where DEMs can be located, downloaded, and unzipped within the program. After the DEMs are downloaded, HAZUS automatically generates a symbolized DEM and overlays a hill shade. Derived topographic data is used to delineate floodplain.
3. Define Scenario. As a level 2 analysis, the default parameters for the scenario are suggested to produce the most accurate flood boundaries. Damage functions are defined for buildings, essential facilities, transportation facilities, utilities, and vehicles. Similarly, restoration functions and parameters regarding debris, casualties, and agriculture are defined in this step of analysis.
4. Segment Shoreline. The city's shoreline is selected from a shoreline feature that encompasses the entire coast of the Salish Sea. The targeted shoreline segment begins at census tract 53061050500, continues through 53061050300, and ends on the north end of 53061050200. To further break down the large dataset, the shoreline is then segmented into five equal parts.
5. Identify 100-year Floor Elevation. For this analysis, the 100 year Stillwater elevation was the manipulated variable. The HAZUS-MH coastal flood model requires the user to set the 100-year elevation and autogenerates numbers for significant wave heights for 10, 50, and 500 year event projections. For this analysis, one run of the model was set at 10 feet elevation; another was set at 15 feet elevation.

6. Calculate Hazard. Once all variables and parameters are set, analysis can be performed. This process takes several hours, as well as a computer with substantial processing power. To ensure the program doesn't crash, it's critical to close all programs other than HAZUS-MH.

HAZUS-MH Results

The primary area of concern is the coastline of census tract 53061050500 near the Port of Edmonds. Though level 2 analysis is not comprehensive and does not produce loss estimation data, the flood boundaries show levels of projected inundation that will be substantial. To gain a better understanding of the hazard and a complete loss-estimation model, damage functions and other variable parameters need to be developed to more accurately represent the City of Edmonds and the Salish Sea as a whole. Figure 8 represents the impacted zone based on a projected 100-year, 10-foot Stillwater elevation. Figure 9 represents the impacted zone based on a projected 100-year, 15-foot Stillwater elevation.

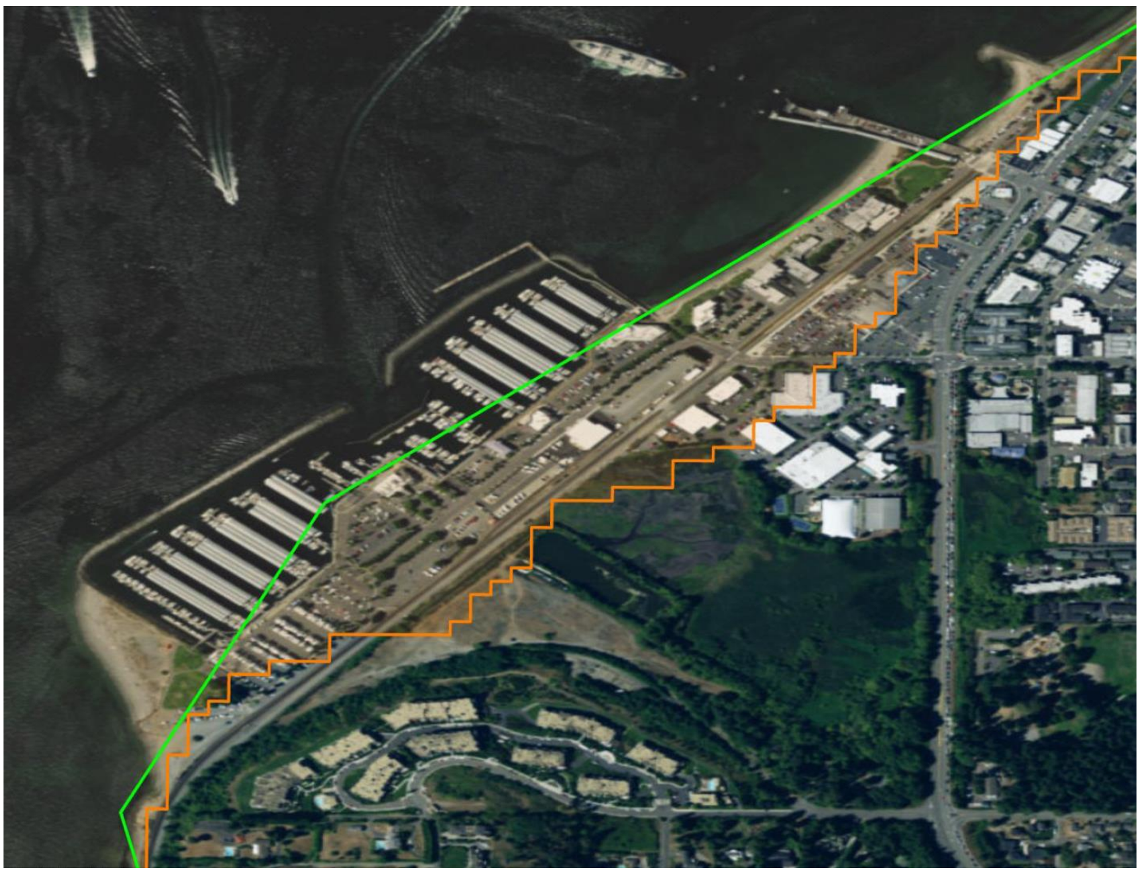

Figure 8. Impact zone, 10-foot Stillwater elevation, 100-year flood

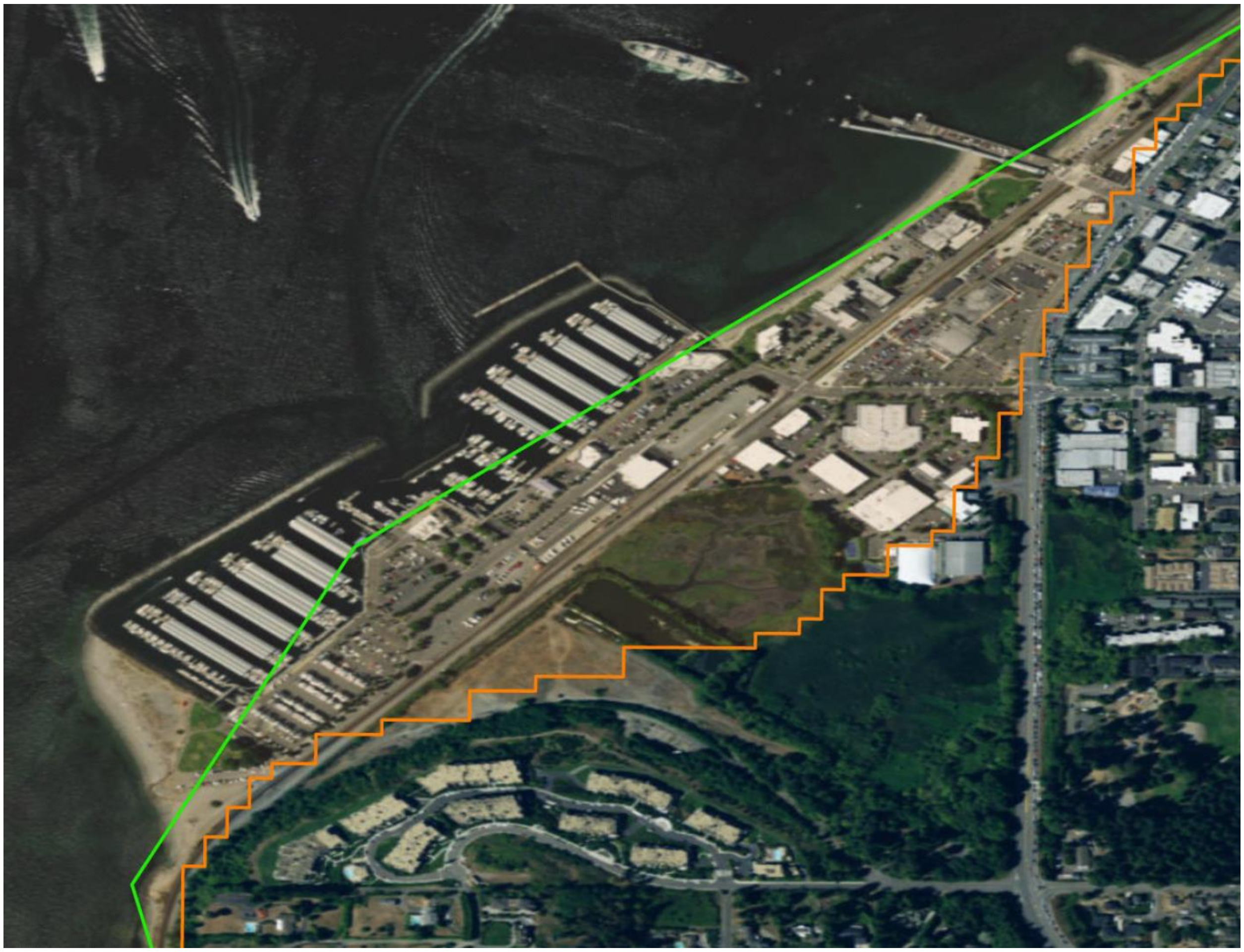

Figure 9. Impact zone, 15-foot Stillwater elevation, 100-year flood

Limitations of Spatial Analysis

The ESRI ArcMap and HAZUS-MH: Level 2 coastal flooding models revealed limitations in utilizing spatial data for analysis of coastal flooding.

This report utilized 2010 Census Block Groups to determine the displaced population in the Edmonds community. Census Block Groups are roughly comparable to neighborhoods. Areal interpolation is not an exact quantification; hence, error is present in the assessment that 1,300 Edmonds community members may be displaced. Updated census data in 2020 will enable a more comprehensive calculation of Edmonds community members vulnerable to coastal flooding.

The Snohomish County property parcel data used in this report is dated 2003. Utilizing updated and comprehensive property parcel data will reveal more at-risk stakeholders. Furthermore, this spatial analysis has identified the property parcels that lie in the 'extreme' scenario saltwater inundation, including the addresses, owners, and taxpayers. The next step is to inform and cooperate with the identified stakeholders vulnerable to coastal flooding events.

The HAZUS-MH: Flood Global Risk Report (Appendix A) states that there are zero economic losses for the built Edmonds scenario. This illustrates the limitations associated with running a level 2 HAZUS-MH analysis. Running a level 2 analysis and utilizing default parameters and damage functions provides a strong baseline analysis for any given region. As previously illustrated in the literature review, the Salish Sea does not follow national trends and presents a unique situation. The projected flood boundaries derived from the analysis are a good starting point, but a full loss estimation should be conducted to fully understand the impacts of coastal flooding in the City of Edmonds.

Interestingly, and fortunately, an "expected" coastal flooding event in Edmonds will not severely displace community members or destroy property parcels. However, the ESRI ArcMap and the FEMA HAZUS models indicate that while an "expected" flooding event will be manageable, an "extreme" (yet realistic) coastal flooding event in 2100 will produce dire consequences. Most importantly, the census and property parcel data are readily available to identify and assess the people and properties most vulnerable to coastal flooding events in the Edmonds community.

Recommended Actions

Tidal Station

Tidal stations are an effective way to measure water level variations near the coast. NOAA manages tidal stations across the US, which are usually located in areas which are sheltered, allowing them to effectively measure Stillwater (NOAA, Measuring Storm Surge, 2016). The City of Edmonds would benefit from installing a tidal station, as it would provide data in real time. The data gathered can be used when preparing for extreme weather events.

Additional Modeling of Impacts

Modeling coastal flooding and salt-water inundation is an important practice for natural resource managers and land-use planners in assessing the vulnerability of coastal habitats and communities. Knowledge and visualization of potentially vulnerable habitat and infrastructure allows decision-makers the ability to evaluate and prioritize mitigation techniques to reduce risks posed by coastal flooding and salt-water inundation. The following models are examples of readily available, comprehensive tools to predict and quantify impacts of coastal flooding and saltwater inundation, specifically in the Salish Sea (Reder, 2011).

SimCLIM

SimCLIM is a computer-based software application capable of analyzing spatial and temporal relationships between ecological and socio-economic variations. SimCLIM contains a 'scenario generator' that creates predictive, site-specific analyses. SimCLIM allows users to input site-specific data in conjunction with six global emission and 22 General Circulation (GCM) patterns, producing low, medium, and high local-impact estimates. SimCLIM is applicable on a local, regional, and global scale, is commercially licensed, and competitively priced for student, government, and non-profit entities. The island nations of Vanuatu and the Philippines recently utilized SimCLIM software to generate locally specific SLR scenarios, lending insight to effectively understand, manage, and mitigate saltwater inundation (Reder, 2011).

Developer: CLIMsystems; http://www.climsystems.com/

Location: Hamilton, New Zealand
Contact: Peter Urich; peter@climsystems.com
Tool Type: software
Cost Estimate: $500 – $20,000

Coastal Adaptation to Sea Level Rise Tool (COAST)

COAST is a software application capable of modeling distinct scenarios of SLR and storm surge, calculating the value of infrastructure and assets vulnerable to flooding, and assessing the long-term economic value of coastal flooding mitigation actions. The COAST program is primarily valuable in assessing and three-dimensionally visualizing economic impacts of climate change, considering decision-makers rely heavily on economic feasibility to justify development and mitigation strategies. COAST is not yet a standalone GIS application, requiring entities to work directly with Sam Merrill and the COAST development team. York County, ME, employed COAST to produce a cost-benefit analysis comparing economic damages from SLR to mitigation-actions costs. COAST availability and pricing is dependent on the size of the interested jurisdiction (Reder, 2011).

Developer: New England Environmental Finance Center, http://efc.muskie.usm.maine.edu/
Location: Portland, Maine
Contact: Sam Merrill; smerrill@usm.maine.edu
Tool Type: adaptation assessment tool
Cost Estimate: $30,000 – $200,000

Sea Level Affecting Marshes Model (SLAMM)

SLAMM is a predictive, geospatial model geared toward assessing the impacts of SLR on coastal habitats. While SLAMM cannot generate exact projections of future ecosystem conversion due to saltwater inundation, SLAMM can generate multiple habitat outcomes utilizing a range of coastal flooding variables and scenarios. While SLAMM is better suited for local and regional use, SLAMM is a valuable tool in assessing habitat change due to SLR. The National Wildlife Federation recently utilized the SLAMM program to model risk scenarios of potential impacts of saltwater in the Pacific Northwest, which yielded predictions of dramatic losses to coastal and estuary habitats (Reder, 2011).

Developer: Warren Pinnacle Consulting, Inc.; http://www.warrenpinnacle.com/prof/SLAMM/
Location: Warren, Vermont
Contact: Jonathan Clough; jclough@warrenpinnacle.com
Tool Type: model of SLR, habitat conversion, and shoreline modification
Cost Estimate: free

HAZUS Level 3 Analysis

HAZUS-MH: Coastal Flood modeling is a very powerful tool when the full spectrum of its capabilities is utilized. While the modeling completed for this report shows a clear delineation of projected inundation zones, the detailed quantitative impact data is missing. A level 3 analysis could be completed to generate a complete loss estimation report.

The City of Edmonds needs to augment the FEMA data with greater resolution parcel data and update any errors in the provided data. Similarly, the city needs to build a scenario with damage functions that accurately represent the region and the predicted damage level based on inundation. Overall, a level 2 analysis is a starting point which visually represents the problem. It is clear that a level 3 analysis would provide the city with a tool to mitigate against and respond to future events.

Concluding Thoughts

As sea level rises and causes disturbances to coastal erosion processes, human intervention with the natural environment will become more frequent. Such intervention is particularly likely to take place in an economically sound community such as Edmonds. Coastal communities and property owners will be prompted to implement new tidal barriers, seawalls, and dikes in order to protect their invested infrastructure. The development of such physical mitigation methods will sequentially lead to the loss of natural coastal ecosystems. The transformation and decrease in size of these coastal habitats will affect the species that they support. The Department of Ecology predicts that some coastal species will be able to relocate to different habitats and transition to different food sources, while others will not.

SLR projections in the Salish Sea are lower than the global average. Vertical land movement from isostatic rebound and tectonic activity causes coastal areas along the Salish Sea to rise approximately one inch per decade, counteracting the effects of SLR. (National Research Council , 2012).   But the highly anticipated Cascadia earthquake, of magnitude 8 or greater, would cause a sudden 3- to 7-foot drop in land elevation, which would be effectively equivalent to a similar degree of SLR above the predictive modeling (National Research Council , 2012).

Oceanic circulation patterns play a crucial role in the dynamics of SLR and coastal flooding. The El Niño-Southern Oscillation influences bodies of irregularly warm Pacific Ocean waters to coalesce on the coasts of Washington, Oregon, and California, contributing to increased SLR, storm surge, and coastal flooding. Conversely, research shows that the counterpart to ENSO, La Niña Southern Oscillation, lowers the average sea level along the West coast of the United States.

It is important for the City of Edmonds to make an effort to disseminate this information within the community in order to develop mitigation strategies as soon as possible. The sooner such strategies are implemented, the less of a toll they will take on the physical and biological environment.

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APPENDIX A

HAZUS-MH: Flood Global Risk Report

Region Name: City of Edmonds

Flood Scenario: Edmonds_15

Print Date: Monday, May 29, 2017

FEMA

RiskMAP
Increasing Resilience Together

Disclaimer:

This version of HAZUS utilizes 2010 Census Data.
Totals only reflect data for those census tracts/blocks included in the user's study region.

The estimates of social and economic impacts contained in this report were produced using HAZUS loss estimation methodology software which is based on current scientific and engineering knowledge. There are uncertainties inherent in any loss estimation technique. Therefore, there may be significant differences between the modeled results contained in this report and the actual social and economic losses following a specific Flood. These results can be improved by using enhanced inventory data and flood hazard information.

Table of Contents

General Description of the Region

HAZUS is a regional multi-hazard loss estimation model that was developed by the Federal Emergency Management Agency (FEMA) and the National Institute of Building Sciences (NIBS). The primary purpose of HAZUS is to provide a methodology and software application to develop multi-hazard losses at a regional scale. These loss estimates would be used primarily by local, state and regional officials to plan and stimulate efforts to reduce risks from multi-hazards and to prepare for emergency response and recovery.
The flood loss estimates provided in this report were based on a region that included 1 county(ies) from the following state(s):

- Washington

Note:
Appendix A contains a complete listing of the counties contained in the region.

The geographical size of the region is 9 square miles and contains 485 census blocks. The region contains over 17 thousand households and has a total population of 39,709 people (2010 Census Bureau data). The distribution of population by State and County for the study region is provided in Appendix B.

There are an estimated 14,071 buildings in the region with a total building replacement value (excluding contents) of 5,142 million dollars (2010 dollars). Approximately 91.83% of the buildings (and 83.72% of the building value) are associated with residential housing.

Building Inventory

General Building Stock

HAZUS estimates that there are 14,071 buildings in the region which have an aggregate total replacement value of 5,142 million (2014 dollars). Table 1 and Table 2 present the relative distribution of the value with respect to the general occupancies by Study Region and Scenario respectively. Appendix B provides a general distribution of the building value by State and County.

Table 1

Building Exposure by Occupancy Type for the Study Region

Occupancy	Exposure ($1000)	Percent of Total
Residential	4,305,159	83.7%
Commercial	658,657	2.8%
Industrial	59,301	1.2%

Agricultural	9,083	0.2%
Religion	68,200	1.3%
Government	9,968	.2%
Education	31,869	0.6%
Total	**5,142,237**	**100.0%**

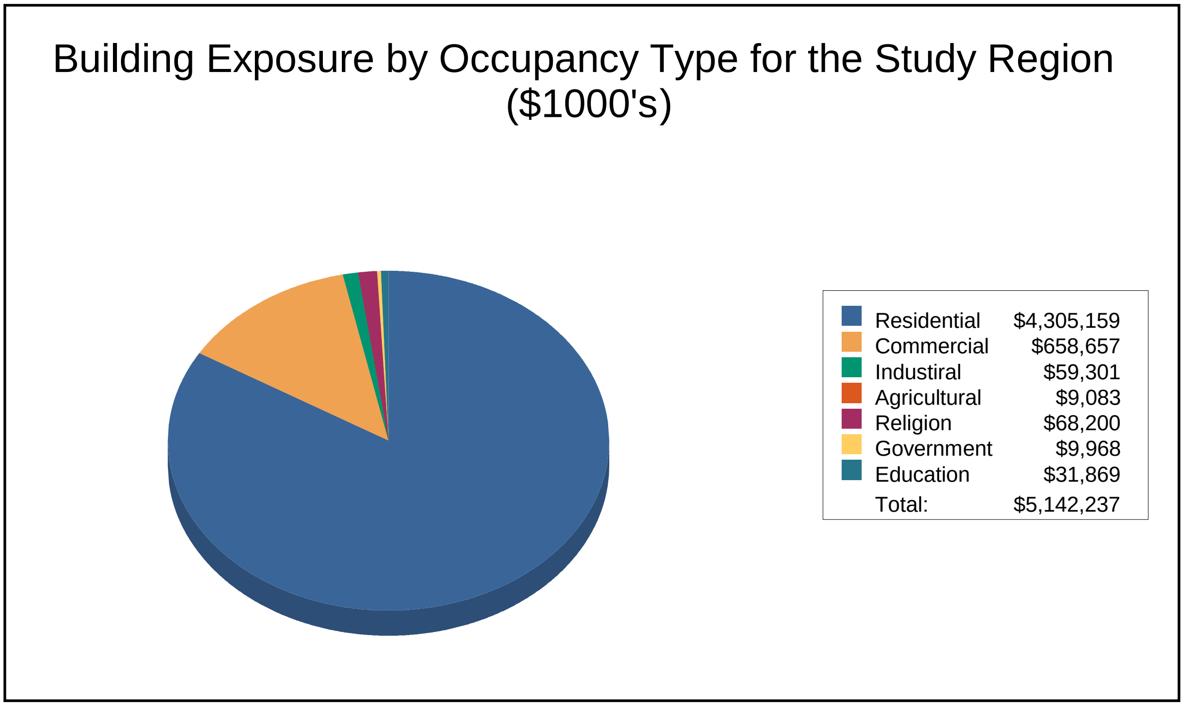
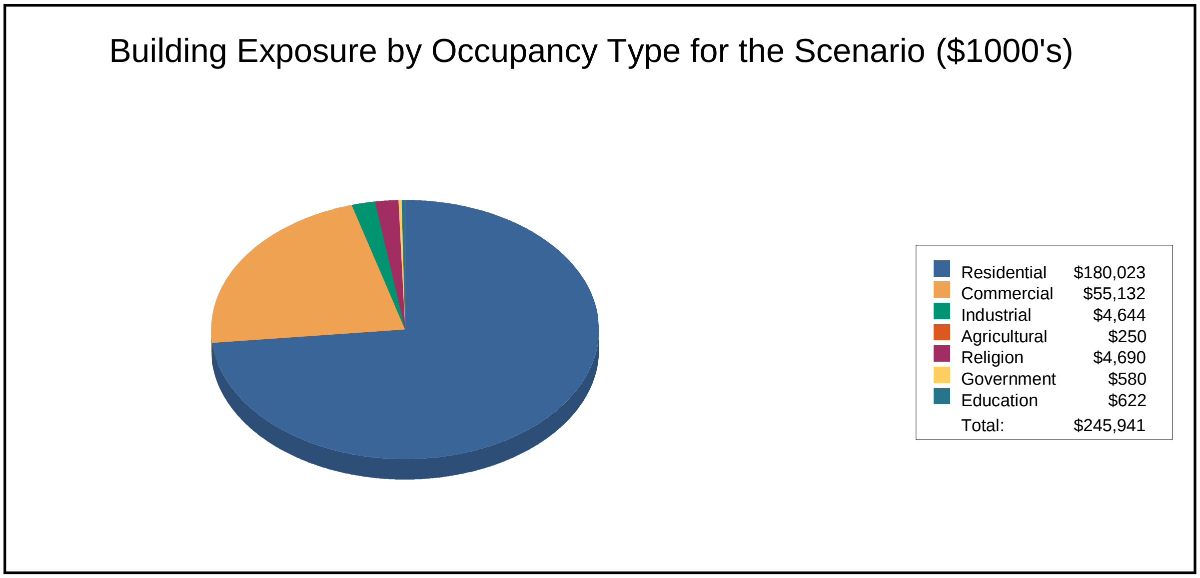


Table 2

Building Exposure by Occupancy Type for the Scenario

Occupancy	**Exposure ($1000)**	**Percent of Total**
Residential	180,023	73.2%
Government	580	0.2%
Education	622	0.3%
Commercial	55,132	22.4%
Industrial	4,644	1.9%
Agricultural	250	0.1%
Religion	4,690	1.9%

Total	245,941	100.0%



Flood Scenario Parameters

HAZUS used the following set of information to define the flood parameters for the flood loss estimate provided in this report.

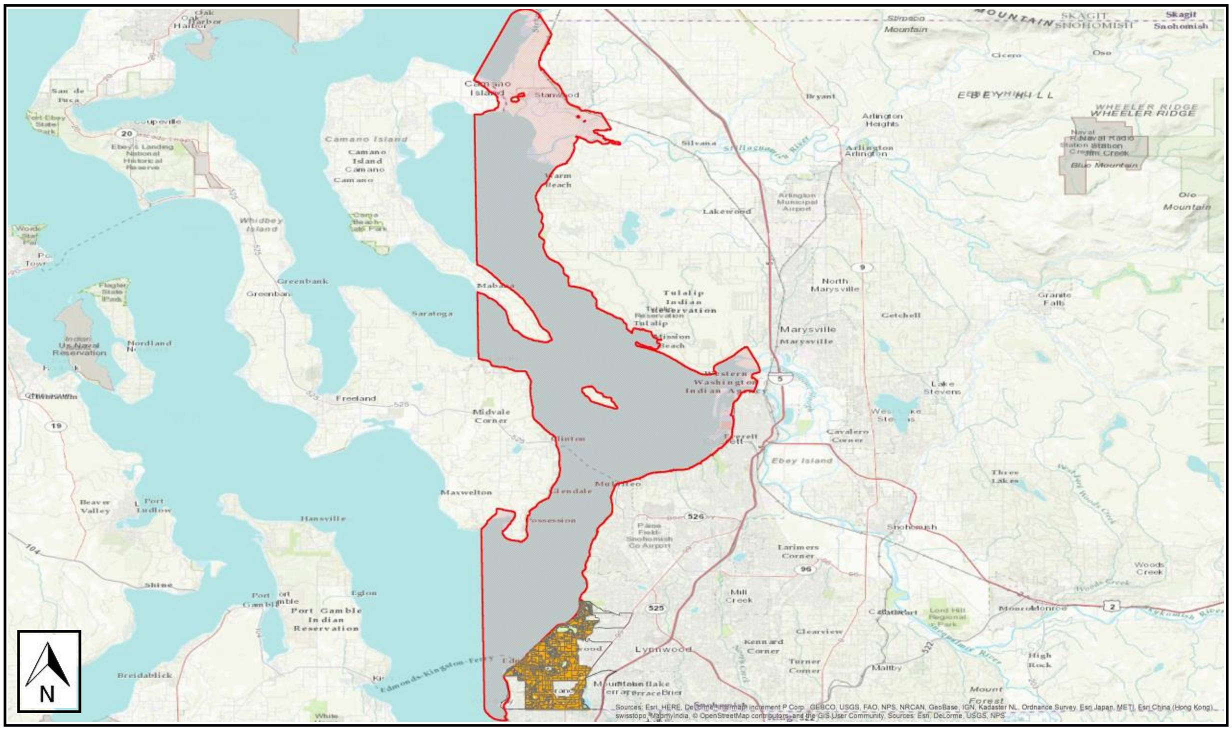
Study Region Name:	City of Edmonds
Scenario Name:	Edmonds_15
Return Period Analyzed:	100
Analysis Options Analyzed:	No What-Ifs

Essential Facility Inventory

For essential facilities, there are 1 hospitals in the region with a total bed capacity of 124 beds. There are 29 schools, 1 fire station, 2 police stations and no emergency operation centers.

Study Region Overview Map

Illustrating scenario flood extent, as well as exposed essential facilities and total exposure



Building Damage

General Building Stock Damage

Analysis has not been performed for this Scenario.

Table 3: Expected Building Damage by Occupancy

	1-10		11-20		21-30		31-40		41-50		Substantially	
Occupancy	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)

Analysis has not been performed for this Scenario.

Table 4: Expected Building Damage by Building Type

Building Type	1-10 Count	1-10 (%)	11-20 Count	11-20 (%)	21-30 Count	21-30 (%)	31-40 Count	31-40 (%)	41-50 Count	41-50 (%)	Substantially Count	Substantially (%)
Analysis has not been performed for this Scenario.												

Essential Facility Damage

Before the flood analyzed in this scenario, the region had 124 hospital beds available for use. On the day of the scenario flood event, the model estimates that 124 hospital beds are available in the region.

Table 5: Expected Damage to Essential Facilities

Classification	Total	# Facilities: At Least Moderate	# Facilities: At Least Substantial	# Facilities: Loss of Use
Fire Stations	1	0	0	0
Hospitals	1	0	0	0
Police Stations	2	0	0	0
Schools	29	0	0	0

If this report displays all zeros or is blank, two possibilities can explain this.

(1) None of your facilities were flooded. This can be checked by mapping the inventory data on the depth grid.

(2) The analysis was not run. This can be tested by checking the run box on the Analysis Menu and seeing if a message box asks you to replace the existing results.

Induced Flood Damage

Debris Generation

HAZUS estimates the amount of debris that will be generated by the flood. The model breaks debris into three general categories: 1) Finishes (dry wall, insulation, etc.), 2) Structural (wood, brick, etc.) and 3) Foundations (concrete slab, concrete block, rebar, etc.). This distinction is made because of the different types of material handling equipment required to handle the debris.

Analysis has not been performed for this Scenario.

Social Impact

Shelter Requirements

Analysis has not been performed for this Scenario.

Economic Loss

Analysis has not been performed for this Scenario.

Building-Related Losses

The building losses are broken into two categories: direct building losses and business interruption losses. The direct building losses are the estimated costs to repair or replace the damage caused to the building and its contents. The business interruption losses are the losses associated with inability to operate a business because of the damage sustained during the flood. Business interruption losses also include the temporary living expenses for those people displaced from their homes because of the flood.

Analysis has not been performed for this Scenario.

Table 6: Building-Related Economic Loss Estimates

(Millions of dollars)

Category	Area	Residential	Commercial	Industrial	Others	Total

Analysis has not been performed for this Scenario.