

A Proposal for Using Geonarratives in Hazard-Adaptive Planning:
Coastline Change in South Beach, Washington

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Abstract

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Indigenous peoples of the Pacific Northwest told stories to prepare future generations for environmental hazards. Facing a Cascadia Subduction Zone earthquake, tsunami, and sea level rise, non-indigenous communities today also tell stories using scientific models and maps. This thesis presents materials that can tell the story of one such community - South Beach, Washington. The materials include a narrative history of the region, a description of the community today, future hazards maps, and historical maps depicting coastal change. The future hazards maps are the product of three interacting hazards: a Cascadia Subduction Zone earthquake and coseismic subsidence, an earthquake-generated tsunami, and water level of the Pacific Ocean which accounts for both sea level rise and tidal fluctuations. A geonarrative using these materials is recommended for engagement efforts with South Beach stakeholders seeking to maintain community resilience in this dynamic environment.

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I would like to thank Lauren Stevens, again, in addition to Gillian Hagstrom who joined me in collecting and analyzing historical maps during the Winter 2021 Geospatial Analysis course taught by Marina Alberti. Carrie Garrison-Laney provided an extensive database of historical information that was the basis for this work.

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Table of Contents

List of Figures	6
List of Tables	10
Glossary of Abbreviations	11
Chapter 1: Introduction	13
1.1 Problem Identification	13
1.2 Purpose of Thesis	14
1.3 Related Research and Projects	15
1.4 Thesis Outline	16
1.5 Limitations	17
Chapter 2: Geonarratives as a Tool in Scenario Planning	17
2.1 Disaster Management, Communication, and Planning	17
2.2 Remembering as an Element of Resilience	19
2.3 Scenario Planning	24
2.4 Incorporating a Historical Perspective in Scenario Planning	29
2.5 Geonarratives as an Educational and Planning Tool	32
Chapter 3: A Case Study Background: South Beach, Washington	34
3.1 Overview of Environmental Hazards	35
3.1.1 Cascadia Subduction Zone Earthquakes	36
3.1.2 Cascadia Subduction Zone Tsunamis	38
3.1.3 Sea Level Rise	39
3.2 Narrative History of the Region	41
3.3 Current South Beach Community	46
3.4 Hazard Mitigation Planning in South Beach	49
3.5 Prior Engagement in South Beach	50
Chapter 4: Developing Maps for Geonarratives of South Beach, Washington	52
4.1 Future Coastline Change in South Beach	52
4.1.1 Methodology	58
4.1.2 Limitations and Assumptions	59

4.1.3 Findings	63
4.2 Framing Future Change Scenarios with Historical Maps	80
4.2.1 Methodology	80
4.2.2 Limitations and Assumptions	85
4.2.3 Findings	86
Chapter 5: Development and Use of Geonarratives and Other Engagement Materials	98
5.1 Geonarrative Development	98
5.1.1 Implications of Materials in a Geonarrative	98
5.1.2 Recommendations for Geonarrative Development	99
5.2 Different Uses of a Geonarrative	104
5.2.1 Enrichment of Existing Engagement	105
5.2.2 Geonarrative Development with Local Stakeholders	105
5.2.3 Scenario Planning Exercise	107
5.2.4 Remote Planning Exercise	110
5.3 Other Community Engagement Materials	110
5.3.1 Printed Materials	110
5.3.2 Digital Materials	111
5.3.3 Interactive Materials	115
5.3.4 Workshop	116
Chapter 6: Conclusion	117
Appendices	120
Appendix A. Tsunami Inundation Maps	120
Appendix B. Land Loss Maps	131
Appendix C. Digital Shoreline Analysis System Summary Report	140
References	144

List of Figures

- Figure 2.1 The shift in disaster management strategies
- Figure 2.2 A representation of the panarchy concept
- Figure 2.3 A representation of panarchical connections, revolt and remembering
- Figure 2.4 In the wake of earthquakes in Christchurch, the transitional rupture is fuzzy due to unclear readjustment strategies
- Figure 2.5 Single and multiple driver risk assessment for Snohomish Basin 2060 scenarios
- Figure 2.6 Length of time for select keystone processes to affect landscape change
- Figure 3.1 The Ring of Fire around the Pacific Ocean
- Figure 3.2 South Beach, Washington in the United States
- Figure 3.3 The focus of this thesis is in the Grays Harbor portion of South Beach, where the communities of Westport and Grayland are located
- Figure 3.4 Earthquake types in the Pacific Northwest
- Figure 3.5 Local sea level rise impacts
- Figure 3.6 Important features, assets, and infrastructure in the study area of South Beach
- Figure 3.7 Preparedness Expo Posters displaying hazards and impacts
- Figure 4.1 Histogram of the hourly tide gauge water level record in Westport, Washington between 2006 and April, 2021
- Figure 4.2 King tide in Westport, Washington on November 23, 2020
- Figure 4.3 Vertical crustal deformation fields of the suite of 15 CSZ earthquakes developed by Witter, et al. (2013) for 5 Size Classes expressed as T-shirt sizes and 3 Fault Geometry Classes labeled qualitatively with the relative depth of the fault
- Figure 4.4 Topography of South Beach at contemporary mean high water
- Figure 4.5 Today's pre-earthquake topography in South Beach
- Figure 4.6 Coseismic subsidence after an M1 earthquake event
- Figure 4.7 Coseismic subsidence after an L1 earthquake event

- Figure 4.8 Tsunami inundation after an M1 earthquake under each water level scenario
- Figure 4.9 Tsunami inundation after an L1 earthquake under each water level scenario
- Figure 4.10 Land loss after an M1 earthquake under each water level scenario.
- Figure 4.11 Land loss after an L1 earthquake under each water level scenario.
- Figure 4.12 T-sheet of Grays Harbor in 1860
- Figure 4.13 Topographic map of South Beach in 1989
- Figure 4.14 Vector of 1926 Westport shoreline downloaded from the Shoreline Data Explorer
- Figure 4.15 DSAS intersection parameter choice available to users
- Figure 4.16 All historical vector data used in the analysis
- Figure 4.17 2006 historic shoreline map
- Figure 4.18 1989 historic shoreline map
- Figure 4.19 1954 historic shoreline map
- Figure 4.20 1941 historic shoreline map
- Figure 4.21 1926 historic shoreline map
- Figure 4.22 1911 historic shoreline map
- Figure 4.23 1860 historic shoreline map
- Figure 4.24 Shoreline change transects
- Figure 4.25 Transect intersections along one transect near the south jetty in Westport
- Figure 5.1 South Beach low tide
- Figure 5.2 South Beach king tide
- Figure 5.3 South Beach low tide
- Figure 5.4 South Beach king tide
- Figure 5.5 Steps 1 to 4 of the scenario planning process, as described by Schwartz (1991) and visualized by Tenneson et al. (2013)
- Figure 5.6 Steps 5 to 8 of the scenario planning process, as described by Schwartz (1991) and visualized by Tenneson et al. (2013)

- Figure 5.7 3D visualization of snow pack in Vancouver’s Northshore mountains in 2000 and a 2100 scenario
- Figure 5.8 4D visualizations of sea level rise scenarios and strategies in South Delta, British Columbia
- Figure 5.9 Easy and Broad Streets, Nantucket under 3.25 feet sea level rise
- Figure 5.10 Easy and Broad Streets, Nantucket under 8.04 feet sea level rise
- Figure A.1 Tsunami inundation map for M1 earthquake scenario at background water level contemporary mean high water - 3 feet
- Figure A.2 Tsunami inundation map for M1 earthquake scenario at background water level contemporary mean high water
- Figure A.3 Tsunami inundation map for M1 earthquake scenario at background water level contemporary mean high water + 3 feet
- Figure A.4 Tsunami inundation map for M1 earthquake scenario at background water level contemporary mean high water + 5 feet
- Figure A.5 Tsunami inundation map for M1 earthquake scenario at background water level contemporary mean high water + 7 feet
- Figure A.6 Tsunami inundation map for L1 earthquake scenario at background water level contemporary mean high water - 3 feet
- Figure A.7 Tsunami inundation map for L1 earthquake scenario at background water level contemporary mean high water
- Figure A.8 Tsunami inundation map for L1 earthquake scenario at background water level contemporary mean high water + 3 feet
- Figure A.9 Tsunami inundation map for L1 earthquake scenario at background water level contemporary mean high water + 5 feet
- Figure A.10 Tsunami inundation map for L1 earthquake scenario at background water level contemporary mean high water +7 feet
- Figure B.1 Land loss map for M1 earthquake scenario at water level contemporary mean high water
- Figure B.2 Land loss map for M1 earthquake scenario at water level contemporary mean high water + 3 feet
- Figure B.3 Land loss map for M1 earthquake scenario at water level contemporary mean high water +5 feet

- Figure B.4 Land loss map for M1 earthquake scenario at water level contemporary mean high water + 7 feet
- Figure B.5 Land loss map for L1 earthquake scenario at water level contemporary mean high water
- Figure B.6 Land loss map for L1 earthquake scenario at water level contemporary mean high water + 3 feet
- Figure B.7 Land loss map for L1 earthquake scenario at water level contemporary mean high water + 5 feet
- Figure B.8 Land loss map for L1 earthquake scenario at water level contemporary mean high water + 7 feet

List of Tables

Table 4.1	Selected water level scenarios and historical frequency based on hourly water level record in Westport between 2005 and April, 2021
Table 4.2	Selected water level scenario likelihood under different sea level rise scenarios based on historical water level record in Westport
Table 4.3	Sea level rise likelihood of exceedance in the Lower Chehalis region of Grays Harbor County under a high greenhouse gas scenario (RCP 8.5)
Table 4.4	Areas of South Beach not impacted by tsunami inundation under each scenario
Table 4.5	Water level combinations depicted in maps representing topography after an M1 earthquake
Table 4.6	Water level combinations depicted in maps representing topography after an L1 earthquake
Table 4.7	Areas of South Beach at or above mean high water under each scenario compared to the area of South Beach currently at or above mean high water

Glossary of Abbreviations

Abbreviation	Phrase	Definition
ASCE	American Society of Civil Engineers	National authority on engineering designs, codes, and standards including tsunami resistant designs
BWL	Background water level	Water level relative to a fixed reference level selected for tsunami modeling
CoPe	Coastlines and People	National Science Foundation program for scientific research about complex coastal systems
CSZ	Cascadia Subduction Zone	Megathrust fault stretching from Vancouver Island to California
EAGER	Early-Concept Grants for Exploratory Research	National Science Foundation funding that supports exploratory work in its early stages
ESRI	Environmental Systems Research Institute	Company that supplies geographic information system software, web GIS, and geodatabase management applications
GIS	Geographic information systems	Framework for gathering, managing, and analyzing data
Mw	Moment magnitude	The most reliable estimate of earthquake size
M9	Magnitude 9 earthquake	High magnitude earthquake
MHT	Multi-hazard tournament	A condensed, accelerated version of Shared Vision Planning that couples serious gaming with collaborative decision-making for planning for multiple hazards ¹
MHW	Mean high water	The average of all the high water heights observed over the National Tidal Datum Epoch
MLLW	Mean lower low water	The average of the lower low water height of each tidal day observed over the National Tidal Datum Epoch
SLR	Sea level rise	An increase in ocean water levels over long periods of time such as decades or centuries

¹ Andrea Carson et al., “Serious Gaming for Participatory Planning of Multi-Hazard Mitigation,” *International Journal of River Basin Management* 16, no. 3 (2018): 379–91, <https://doi.org/10.1080/15715124.2018.1481079>.

UW	University of Washington	University located in western Washington State where this thesis was developed
VES	Vertical Evacuation Structure	A structure specially designed, constructed, and built to resist both tsunami and earthquake loads

Chapter 1: Introduction

1.1 Problem Identification

“Maybe the stories explain how to be resilient, how to outsmart disaster. Maybe they warn the children to warn their own children. The 2004 Indian Ocean earthquake that killed 200,000 people in the Indonesian province of Aceh, killed only seven of the 78,000 people living on the island of Simeulue because the Simeulueans had been telling stories for generations of what to do during tsunamis. That may well have been the case in the Pacific Northwest...”²

Ann Finkbeiner analyzed indigenous stories of great environmental changes in the Pacific Northwest - Cascadia Subduction Zone (CSZ) earthquakes and tsunamis.³ There is evidence that indigenous stories had been passed down through generations over the last 10,000-plus years that the region has been having these earthquakes. There is also evidence that stories have the ability to prepare communities for these threats, such as in Simeulue.⁴

Storytelling could be a very effective tool in pursuit of increasing the resilience of communities facing such environmental hazards.⁵ Coastal, non-indigenous communities today tell stories using scientific models and maps in the face of a CSZ earthquake, earthquake-generated tsunami, and sea level rise. Stories could be used in at least three related but separate community engagement efforts - public education, emergency planning, and long-term community planning. Relaying history can be a powerful tool. But in the face of climate change, our environmental challenges may be quite different in the future. Communities faced with multiple divergent, plausible futures can benefit from stories told using geonarratives.

A geonarrative, also known as a Story Map,⁶ is an online application that enables researchers, educators, public officials, and others to enhance interactive maps with text, figures, videos, photos, and more.⁷ Recent research has highlighted the potential of geonarratives for

² Ann Finkbeiner, “The Great Quake and the Great Drowning,” September 14, 2015, 4.

³ Finkbeiner.

⁴ Finkbeiner.

⁵ Bob Freitag et al., “Storytelling-Plots of Resilience, Learning, and Discovery in Emergency Management,” *Journal of Emergency Management* 18, no. 5 (October 2020): 363–71, <https://doi.org/10.5055/jem.2020.0485>.

⁶ Environmental Systems Research Institute, “Digital Storytelling with Maps | ArcGIS StoryMaps,” Esri, 2021, <https://www.esri.com/en-us/arcgis/products/arcgis-storymaps/overview>.

⁷ M. P. Cope et al., “Developing and Evaluating an ESRI Story Map as an Educational Tool,” *Natural Sciences Education* 47, no. 1 (2018): 180008, <https://doi.org/10.4195/nse2018.04.0008>.

communicating stories to non-expert audiences and engaging residents in community issues.⁸ Geonarratives are effective for communicating and visualizing complicated ideas and large amounts of information. Geonarratives could enhance spatial thinking,⁹ which could be useful in communities where the effects of multiple hazards can vary greatly across a landscape and time.

South Beach, Washington is one such region. South Beach is a cluster of communities located on the Pacific Coast of Washington which runs parallel to the Cascadia Subduction Zone (CSZ). The largest threat to South Beach is a CSZ magnitude 9 ‘mega-quake’ which will produce ground shaking, liquefaction, and other seismic-related hazards including a tsunami.¹⁰ The severity of a tsunami could be significantly impacted by climate change in regions with vulnerable coastlines,¹¹ such as South Beach. Sea level rise alone could also increase storm surge, flooding areas that traditionally experience little to no flooding,¹² or chronically inundate some areas.¹³

1.2 Purpose of Thesis

This thesis is guided by the desire to increase the resilience of the South Beach community. I aimed to develop materials that researchers can use to create a geonarrative depicting a compelling story about the future of the community in the face of interacting natural hazards that vary in their frequency, severity, suddenness, and cumulative impact.¹⁴ Due to time constraints and the COVID-19 pandemic I was unable to develop an actual geonarrative. However, in addition to producing geonarrative materials, I also outlined the process researchers may use to develop a geonarrative for South Beach engagement. Engagement purposes could range from public education, to emergency preparedness, to long-term, comprehensive community planning.

⁸ M. P. Cope et al., “Developing and Evaluating an ESRI Story Map as an Educational Tool,” *Natural Sciences Education* 47, no. 1 (2018): 180008, <https://doi.org/10.4195/nse2018.04.0008>.

⁹ Cope et al.

¹⁰ Bridgeview Consulting, “Grays Harbor County 2018 Multi-Jurisdiction Hazard Mitigation Plan Update Volume 1: Planning-Area-Wide Elements,” July 2018, https://cms5.revize.com/revize/graysharborcounty/Emergency%20Management/Planning/Grays%20Harbor%20County%20HMP_Plan_Final_2018.pdf.

¹¹ Bridgeview Consulting.

¹² Bridgeview Consulting.

¹³ Erika Spanger-Siegfried et al., *When Rising Seas Hit Home: Hard Choices Ahead for Hundreds of US Coastal Communities* (Union of Concerned Scientists, 2017), <https://www.ucsusa.org/sites/default/files/attach/2017/07/when-rising-seas-hit-home-full-report.pdf>.

¹⁴ Daniel Abramson et al., “Coastal Hazard Planning in Time Abstract” (National Science Foundation, 2019), https://www.nsf.gov/awardsearch/showAward?AWD_ID=1940024&HistoricalAwards=false.

In this thesis I explore the following statement:

- Providing both localized historical and probable future hazard information and maps in an accessible, interactive format will promote increased community understanding of hazards, improve emergency preparedness, and promote incorporation of relevant science in community planning, policy development, and infrastructure development.

In particular, I develop materials of this thesis were developed that can form the background for future empirical assessments to address the following questions:

- Providing coastal hazard science in an accessible, historically and locally expressive format will promote incorporation of relevant science into community planning and policy development.¹⁵
- Clearer communication of the evolving and multidisciplinary nature of Cascadia Subduction Zone hazards science can inform a more robust suite of strategies appropriate to scientific understanding of the impacts of various hazards, including sea level rise as well as seismic and co-seismic threats.¹⁶

1.3 Related Research and Projects

This thesis has benefited from numerous past projects, began with participation in a University of Washington (UW) studio, and has been developed in concert with the CoPe EAGER Coastal Hazard Planning in Time project. One of the first hazards planning partnerships between UW and South Beach communities was Project Safe Haven, a community focused and driven initiative tasked with identifying potential vertical evacuation structure locations in 2010-2011.¹⁷

In 2018, the City of Westport partnered with a UW College of Built Environments studio which expanded the community's planning for tsunami evacuation by exploring the integration of a wider range of hazard mitigation strategies with long-term development planning goals, and recommending updates in Westport's Comprehensive Plan.¹⁸ The studio was supported through

¹⁵ Daniel Abramson et al., "CoPe EAGER: Coastal Hazard Planning in Time" (National Science Foundation Award #1940024, 2019), Abstract available at https://www.nsf.gov/awardsearch/showAward?AWD_ID=1940024.

¹⁶ Daniel Abramson et al.

¹⁷ Grays Harbor County Emergency Management, "Project Safe Haven: Grays Harbor County," 2011, <https://mil.wa.gov/asset/5ba41ffb35f02>.

¹⁸ University of Washington Urban Design & Planning Studio "Community Engagement for Coastal Resilience," *Localizing Hazard Mitigation: Recommendations for Westport's Comprehensive Plan Update* (University of Washington, 2018), https://mitigate.be.uw.edu/wp-content/uploads/sites/70/2021/03/FullReport_WestportCoastalResiliencyReport_11.22.19.pdf. See also Helen Stanton, "Integrating Hazard Mitigation Strategies into the City of Westport's Comprehensive Plan Update," Thesis (M. Urban Plan.), University of Washington, 2019, <http://hdl.handle.net/1773/45278>

an NSF grant for Interdisciplinary Research in Hazards and Disasters (Hazards SEES) to develop and use Magnitude 9 Earthquake Scenarios - Probabilistic Modeling, Warnings, Response and Resilience in the Pacific Northwest (project “M9”); a Bullitt Foundation grant for Building Community Adaptive Capacity as part of the Foundation’s initiative in Thought Leadership and Innovation in Applied Urban Sustainability Research, Scholarship and Action; a TOMNET US Department of Transportation Tier 1 University Transportation Center grant for “Incorporating attitudes, values and perceptions into activity forecasting models”; and a Center for Safety Equity in Transportation (CSET) grant for coordination and context-sensitive transportation solutions that address the safety needs of rural, isolated, tribal and indigenous (RITI) communities.

This thesis also relied on findings from the 2018 studio, particularly shared community identity, values, and assets discussed during the engagement efforts. The thesis also relied on the Architectural League of New York’s American Roundtable initiative, which supported a profile of greater South Beach that highlighted significant environmental, geographic, social, and economic factors that contribute to regional community identity.¹⁹ In early 2021, an interdisciplinary studio consisting of architects, landscape architects, and urban planners envisioned interventions that might enhance the community’s resilience to tsunamis and sea level rise.²⁰ Material developed for this studio by myself and other students is weaved into this document.

Finally, the researchers involved with the CoPe EAGER Coastal Hazard Planning in Time project have been influential in the development of this research.²¹ The project aims to develop new communication tools for coastal resilience through use of three interactive geonarratives for public education, community planning, and emergency preparedness workshops. The materials developed for this thesis may inform the information presented in these geonarratives.

1.4 Thesis Outline

Chapter 2 reviews relevant literature on disaster management, communication, and planning; resilience theory; scenario planning; incorporating historical perspectives in scenario planning; and geonarratives as tools. Chapter 3 details the environmental hazards threatening South Beach, the history of the study area, the community today, prior engagement by the University of

¹⁹ Architectural League of New York, “American Roundtable: South Beach, Washington,” The Architectural League of New York, 2021, <https://archleague.org/article/south-beach-washington-coastal-ecology/>.

²⁰ ArcDR3, “ArcDR3 Regenerative Urbanism Studio ‘Water’ 2020-2021 Urban Design and Planning / Architecture @ The University of Washington,” ArcDR3, 2021, <https://xlab.aud.ucla.edu/irides-tohoku-arcdr3/studio/washington-seattle-the-university-of-washington/>.

²¹ Daniel Abramson et al., “CoPe EAGER: Coastal Hazard Planning in Time” (National Science Foundation Award #1940024, 2019), Abstract available at https://www.nsf.gov/awardsearch/showAward?AWD_ID=1940024.

Washington, and community engagement efforts during the Grays Harbor County Hazard Mitigation Plan effort. Chapter 4 includes the methodology, limitations, and results for future hazard maps and historical environmental change maps. Chapter 5 outlines proposals for some uses of the materials from the previous chapter as well as an overview of a broad range of potential tools for community engagement in South Beach. Finally, Chapter 6 contains a conclusion for this project.

1.5 Limitations

This thesis was developed over two terms, Winter and Spring 2021, and during the COVID-19 pandemic. Community input was limited to Kevin Goodrich, City of Westport Public Works Director, and John Shaw, Westport Maritime Museum Executive Director. COVID-19 protocols constrained community engagement efforts although information about the South Beach community, including values and assets, was available through previous engagement documentation which started in 2018. Testing of the hypotheses outlined in this thesis was not possible due to these restraints.

Chapter 2: Geonarratives as a Tool in Scenario Planning

2.1 Disaster Management, Communication, and Planning

Historically, disaster management in the United States has been conducted for the community, not with the community.²² In the 1990s, community members were becoming increasingly frustrated with being excluded from both community planning and disaster management planning. Since then, the disaster management process has increasingly included public participation.²³ Section 3.4 outlines the public participation process that was involved in the creation of the 2018 Grays Harbor County Hazard Mitigation Plan, where South Beach is located. It is evident public participation was a big component of this multi-hazard planning effort.

In Australia there seems to also be a shift in focus from response and recovery to mitigation efforts which also includes a role for public participation.²⁴ While a top-down approach is necessary, local-level policies are needed to implement mitigation strategies and a successful

²² Laurie Pearce, “Disaster Management and Community Planning, and Public Participation: How to Achieve Sustainable Hazard Mitigation,” *Natural Hazards* 28, no. 2 (March 1, 2003): 211–28, <https://doi.org/10.1023/A:1022917721797>.

²³ Pearce.

²⁴ Pearce.

disaster management operation. This transformation in the approach to disaster management was summarized in Figure 2.1.²⁵

From		To
· Hazards	→	· Vulnerability
· Reactive	→	· Proactive
· Single Agency	→	· Partnerships
· Science Driven	→	· Multidisciplinary Approach
· Response Management	→	· Risk Management
· Planning for Communities	→	· Planning with Communities
· Communicating to Communities	→	· Communicating with Communities

Figure 2.1. The shift in disaster management strategies.²⁶

This emerging approach does four novel things for disaster management planning:²⁷

1. Incorporates general vulnerabilities into the disaster management process as opposed to focusing on specific hazards.
2. Proactively puts the focus on community planning as opposed to response and recovery activities.
3. Brings together many interests from the community and creates partnerships.
4. Puts the obligation on disaster managers and community planners to involve the community.

As cataclysmic losses from disasters mount it is evident that previous disaster management strategies have been less than effective.²⁸ Pearce states that “change seems inevitable, and the trend is clear: ensure more community involvement, ensure basic responsibility at the local level and ensure that there are links between disaster management planning and community planning.”²⁹ This thesis aims to develop materials that can be integrated into a geonarrative for use in disaster communication in pursuit of disaster management, disaster planning, and community planning efforts in South Beach. Although it could not be tested during development of this thesis it is hypothesized that framed within a historical perspective, future maps of multiple hazards will enable stakeholders, including the general public, to create robust, innovative strategies to decrease hazard-related losses.

²⁵ Laurie Pearce, “Disaster Management and Community Planning, and Public Participation: How to Achieve Sustainable Hazard Mitigation,” *Natural Hazards* 28, no. 2 (March 1, 2003): 211–28, <https://doi.org/10.1023/A:1022917721797>.

²⁶ Pearce, 213.

²⁷ Pearce, 213.

²⁸ Pearce, 214.

²⁹ Pearce, 214.

2.2 Remembering as an Element of Resilience

Planners and ecologists today recognize the inextricably linked nature of human populations and the environments in which they exist. Communities exist within social-ecological systems, complex adaptive systems that can be altered by human activities such as infrastructure development and market changes as well as environmental changes such as fires and floods.³⁰ These triggers have the potential to devastate a social-ecological system. However, if the resilience of a system can be increased, the effects of such events can be lessened. The term resilience was originally used in the physical sciences and was adopted by the psychology and ecology fields in the 1970s. Holling began using the term in an ecological sense, stating resilience “is a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables”.³¹

"Panarchy is the term we use to describe a concept that explains the evolving nature of complex adaptive systems" such as those in South Beach.³² Panarchy is the hierarchical structure in which social-ecological systems "are interlinked in never-ending adaptive cycles of growth, accumulation, restructuring, and renewal".³³ According to Holling, if we understand the transformational cycles of systems at their various scales it could be possible to identify the points at which a system is capable of change which can be leveraged to foster resilience within a system.

The panarchic adaptive cycle proceeds through four phases: exploitation, conservation, release, and reorganization, as seen in Figure 2.2. During the exploitation to conservation phases connectedness and stability of a system increase and capital is accumulated.³⁴ Capital could take the form of nutrients in ecological systems or relationship networks in human systems, for instance. As the conservation phase continues, the system becomes tightly bound and highly connected and eventually becomes rigid. "It becomes an accident waiting to happen."³⁵ The accident, or trigger, can take many forms - a fire, disease, or an insect outbreak, for example.

Once this trigger disrupts the system, the system enters a period of rapid reorganization which is a period of unpredictability and high uncertainty. Opportunities abound and "the adaptive

³⁰ Lawrence J. Vale and Thomas J. Campanella, *The Resilient City: How Modern Cities Recover from Disaster* (Cary, UNITED STATES: Oxford University Press, Incorporated, 2005), <http://ebookcentral.proquest.com/lib/washington/detail.action?docID=273182>.

³¹ C. S. Holling, "Resilience and Stability of Ecological Systems," *Annual Review of Ecology and Systematics* 4 (1973): 1–23.

³² C. S. Holling, "Understanding the Complexity of Economic, Ecological, and Social Systems," *Ecosystems (New York)* 4, no. 5 (2001): 390–405, <https://doi.org/10.1007/s10021-001-0101-5>, 392

³³ Holling, 392.

³⁴ Holling, 394.

³⁵ Holling, 394.

cycle... embraces two opposites: growth and stability on the one hand, change and variety on the other"³⁶ The concepts of revolt and remembering are important before and after a release. Their effects can be seen in Figure 2.3. Revolt can cause a critical change that makes the system more vulnerable. This could eventually lead to a collapse. In a system that has legacies and memories "it is as if a connection draws on the accumulated wisdom and experiences of maturity; hence, the word 'remember'" which aids the system in its reorganization and recovery.³⁷ Once the reorganization phase is coming to an end, the exploitation phase begins yet again and connections and stability of the system increase.

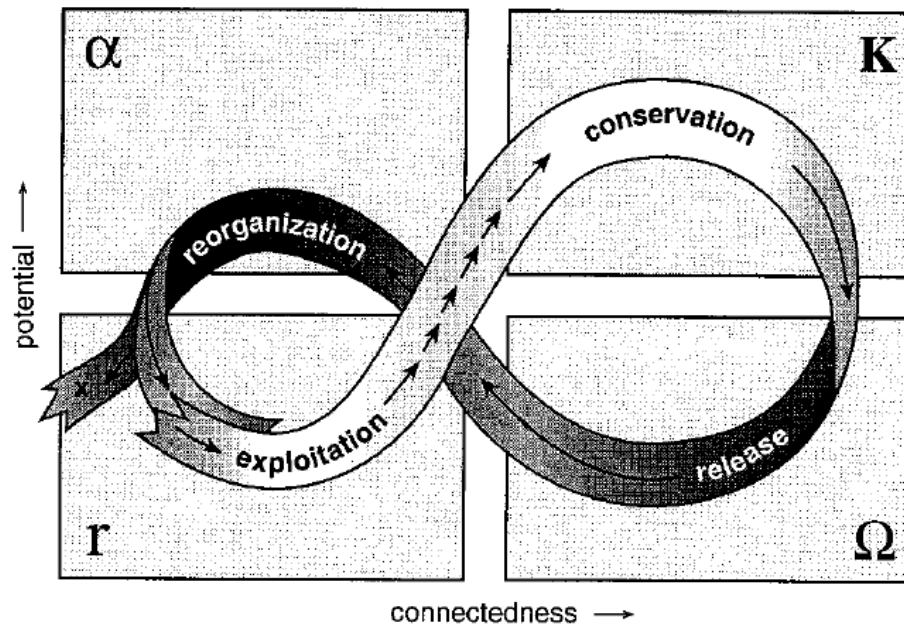


Figure 2.2. A representation of the panarchy concept.³⁸

³⁶ C. S. Holling, "Understanding the Complexity of Economic, Ecological, and Social Systems," *Ecosystems* (New York) 4, no. 5 (2001): 390–405, <https://doi.org/10.1007/s10021-001-0101-5>, 395.

³⁷ Holling, 398.

³⁸ Holling, 394.

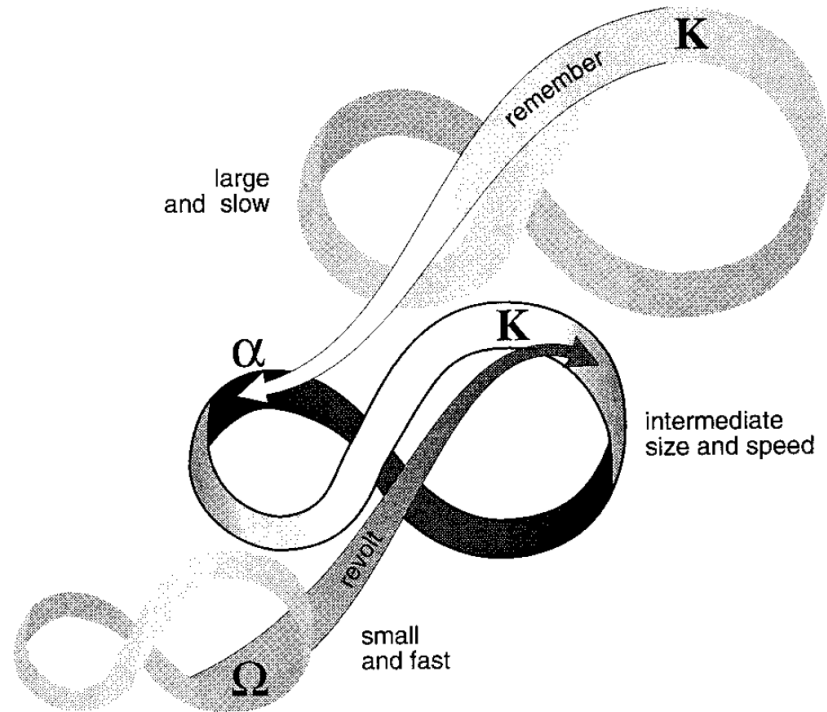


Figure 2.3. A representation of panarchical connections, revolt and remembering.³⁹

Coastal communities are particularly vulnerable. The Cascadia Subduction Zone (CSZ) along the west coast of North America is a prime example of a trigger. The last CSZ event changed the environmental conditions of the South Beach region significantly. In 1700 the earthquake caused a drop in land elevation which would have created a new shoreline.⁴⁰ The elevation change also dipped the coastal forest below the mean high water level, exposing trees to saltwater, killing them, and creating today's ghost forests.⁴¹

For native peoples, remembering seems to have been an important factor in survival during these great environmental shifts along the Washington coast. There are numerous recorded stories depicting large earthquakes and subsequent tsunamis flooding the land⁴² and lessons passed down. These stories prepared future generations for the evolving nature of the region. One such story has had repercussions even to today:

³⁹ C. S. Holling, "Understanding the Complexity of Economic, Ecological, and Social Systems," *Ecosystems* (New York) 4, no. 5 (2001): 390–405, <https://doi.org/10.1007/s10021-001-0101-5>, 398.

⁴⁰ Tullan Spitz, "How Scientists Know When the Last Big Cascadia Earthquake Happened," OPB FM, 2015, <https://www.opb.org/news/series/unprepared/jan-26-1700-how-scientists-know-when-the-last-big-earthquake-happened-here/>.

⁴¹ Spitz.

⁴² Finkbeiner, "The Great Quake and the Great Drowning."

“One night the land shook, and a big wave smashed into the beach, and the people who lived on the bay were all killed. But the people who lived on high ground, the water couldn’t reach them, and they came out of the tsunami alive... years later when the Huu-ay-aht were planning a community center, they first consulted their elders, then they built the center not down in the flats but up on high ground. Now they have to stock it with food and emergency gear and keep it stocked.”⁴³

Ghost forests are a visible reminder of the impacts the 1700 event had on the landscape in South Beach. However, these visible reminders of the volatile nature of the coast have no correlates in the memories and stories of non-indigenous settlers. The effect of community 'memory' on resilience is a relatively new area of study.⁴⁴ In 2012, Geoff Wilson explored the importance of social memory for community resilience pathways in Christchurch, New Zealand following earthquakes in 2010 and 2011. Before the 2010 earthquake and series of aftershocks, the author found that there had been very little social learning which resulted in a limited number of adaptations. The author notes that in Christchurch there was very little experience with high magnitude earthquakes, as opposed to other parts of New Zealand. This lack of experience, knowledge, and memory meant that the City and community were ill-prepared. For example, the city center had not been reopened nor had a plan been developed for the land use as of January 2012. The city did not have past experience to lean on such as earthquake-proof building codes and post-disaster decision making. Wilson argues that in the face of sudden, continual earthquakes residents' ability to cope, adapt, and plan for the future eroded as a result of being unprepared due to lack of social memory. The responses in Christchurch could not yet be portrayed along a resilience/vulnerability spectrum, seen in Figure 2.4 below. Elements of the social-ecological system in Christchurch showed both raised and lowered resilience, suggesting the see-saw pattern in the figure. “Predictions for future resilience pathways are, therefore, impossible to make”.⁴⁵

⁴³ Ann Finkbeiner, “The Great Quake and the Great Drowning,” September 14, 2015, 5.

⁴⁴ Geoff A. Wilson, “Community Resilience, Social Memory and the Post-2010 Christchurch (New Zealand) Earthquakes,” *Area (London 1969)* 45, no. 2 (2013): 207–15, <https://doi.org/10.1111/area.12012>.

⁴⁵ Wilson, 214.

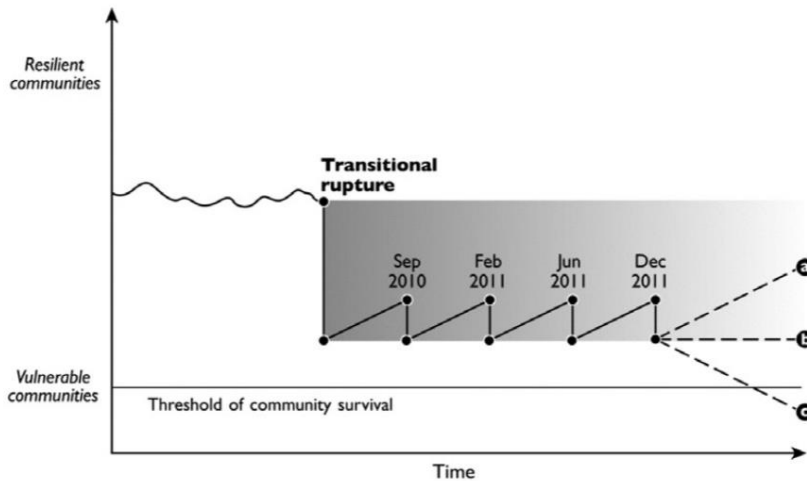


Figure 5 The Christchurch earthquakes since 2010 as a fuzzy transitional rupture with unclear readjustment strategies
Source: author

Figure 2.4. In the wake of earthquakes in Christchurch, the transitional rupture is fuzzy due to unclear readjustment strategies. A represents 'rapid readjustment and recovery'. B represents 'slow readjustment and recovery'. C represents 'inadequate readjustment and recovery'.⁴⁶

In 2017 researchers used a case study in Southwest England to argue that social and cultural memory of floods plays a key role in response to flood events and fostering resilience.⁴⁷ The concept of 'sustainable flood memory' is framed as a future-oriented, community-focused, archival, experience-integrated, intra-personal, and inter-personal approach to memory work. The sustainable memory creates and supports its continuance, "with strong attention to knowledge exchange and social learning, and to using associated lay expertise in delivering on future resilience needs".⁴⁸ In Southwest England, oral narratives, folk memories, and archives of previous floods are integrated in local heritage and culture. In interviews it was evident that during a 2007 flood, the memories of residents that had experienced previous floods played a big role in the transmission of flood memory for resilience for new residents. Additionally, media such as photos and videos as well as flood marks integrated into the architecture of previous floods play a key role in collective memory. Researchers were able to determine that a rural village with an established community is the most resilient to floods. In the village "the 1947 flood experience is passed down from father to son, knowledge of ancient flood banks (with rumour or legend that monks constructed them), and memories of the three different types of flood defence systems since the 1970s".⁴⁹ The authors found that without prior flood experience

⁴⁶ Geoff A. Wilson, "Community Resilience, Social Memory and the Post-2010 Christchurch (New Zealand) Earthquakes," *Area (London 1969)* 45, no. 2 (2013): 207–15, <https://doi.org/10.1111/area.12012>. 212-213.

⁴⁷ Joanne Garde-Hansen et al., "Sustainable Flood Memory: Remembering as Resilience," *Memory Studies* 10, no. 4 (2017): 384–405, <https://doi.org/10.1177/1750698016667453>.

⁴⁸ Garde-Hansen et al., 386.

⁴⁹ Garde-Hansen et al., 398.

it is challenging to compel people to take any action, even with policies. Therefore, it is suggested that a more proactive, participatory process involving communities, academics, and policy makers be developed to increase sustainable flood memory. The authors intend to work with the local environmental regulator to "explore the role of digital and social media for producing more sustainable flood memories through personalised and networked digital storytelling and web-based applications".⁵⁰ In South Beach there is no living memory of CSZ events, because the last event was in 1700, and there is no living memory of climate-change driven sea level rise, because this is a new phenomenon. This thesis intends to provide materials that will allow the South Beach community, academic researchers, and policy makers to develop stories about the future of the region using a geonarrative that includes spatial information about both historic and possible future coastline change.

The future of the social-ecological systems in South Beach, Washington is certainly unknown when environmental changes caused by events such as a CSZ earthquake and sea level rise are considered. There are multiple potential futures that may or may not be approaching triggers that could send South Beach into a reorganization phase. However, managed systems can be adjusted to be more resilient.

In addition to increasing the resilience of the social-ecological system, communities such as South Beach can view future social-ecological changes as opportunities.⁵¹ Outside forces such as a CSZ event or sea level rise can threaten residents' ways of life, however, these events could also encourage innovative thinking. New or expanded economic opportunities may emerge; relationships may form between the Shoalwater Bay tribe and other South Beach communities, for example; inadequate housing may be replaced; or a whole new community may be developed upland. Resilience thinking, therefore, includes increasing the resilience of a system prior to a potential event as well as capitalizing on changes as they occur. This research aims to develop materials and media that will increase the resilience of South Beach through remembering as well as anticipating.

2.3 Scenario Planning

Complex interactions among uncertain human and ecological drivers make planning for social-ecological systems particularly challenging. Traditional approaches are being challenged by rapid environmental and social change and the increasing complexity of social-ecological systems. Traditional approaches to planning and management of these systems rely on

⁵⁰ Joanne Garde-Hansen et al., "Sustainable Flood Memory: Remembering as Resilience," *Memory Studies* 10, no. 4 (2017): 384–405, <https://doi.org/10.1177/1750698016667453>. 402.

⁵¹ Brian Walker, David Salt, and Walter Reid, *Resilience Thinking: Sustaining Ecosystems and People in a Changing World* (Washington, UNITED STATES: Island Press, 2006), <http://ebookcentral.proquest.com/lib/washington/detail.action?docID=3317645>.

predictions of probable futures based on past trends.⁵² However, past trends do not necessarily provide a reliable guide to future environmental changes; many systems, particularly coupled social-ecological systems, are complex and nonlinear. The driving forces influencing the trajectory of the system may behave differently than expected and may generate conditions outside of probability distributions. This has enormous consequences on policy outcomes and how we assess resilience. Policies are dependent on our ability to account for the complexities and dynamism of interdependent systems. Scenario planning is emerging as a tool to address rapid environmental change shifting our attention “from a single probable future toward a range of plausible ones”.⁵³ Alternative future scenarios expand the boundary conditions of predictive models by acknowledging the uncertainty associated with identified driving forces. “A fundamental objective of scenario planning is to explore the interactions between multiple critical uncertainties, thus entertaining potential future conditions that might otherwise be overlooked.”⁵⁴

A scenario planning exercise depicts scenarios, possible future trajectories of a system, with the intention of articulating multiple, alternative futures that account for critical uncertainties.⁵⁵ These exercises use both qualitative and quantitative methods to depict scenarios. In recent years, scenario planning has been used in a wide variety of applications from biodiversity assessments to climate change planning to land degradation. Scenario planning exercises are meant to support decision making and therefore have implications for a wide variety of stakeholders. Due to the influence of these decisions, it is important that scenario planning is participatory. Participatory scenario planning can result in empowering stakeholders, stimulating innovation, mitigating conflicts, learning, and integrating a variety of perspectives in discussions of future effects of drivers and the system(s). Participatory scenario planning can result in an increase in adaptive capacity,⁵⁶ which is one of the objectives of disaster management in a complex system such as South Beach.

In a recent analysis of 23 case studies of participatory scenario planning in place-based social-ecological research, Elisa Oteros-Rosaz et al. analyzed seven aspects of case studies: the context, the original motivations and objectives, the methodological approach, the process, the content of the scenario, the outputs of the research, and the monitoring and evaluation of the process.⁵⁷ They found that of the 23 case studies, 12 cases included background information collected from

⁵² M. Marina Alberti, *Cities That Think like Planets: Complexity, Resilience, and Innovation in Hybrid Ecosystems* (Seattle: University of Washington Press, 2016), 53.

⁵³ Alberti, 196-197.

⁵⁴ Alberti, 206.

⁵⁵ Elisa Oteros-Rozas et al., “Participatory Scenario Planning in Place-Based Social-Ecological Research: Insights and Experiences from 23 Case Studies,” *Ecology and Society* 20, no. 4 (2015), <https://www.jstor.org/stable/26270296>, 1.

⁵⁶ Oteros-Rozas et al, 2.

⁵⁷ Oteros-Rozas et al, 1.

workshops or focus groups while the remaining 13 relied on desk research and 14 of the cases included stakeholders in their scenario development. 21 of the exercises used a projected year but the majority (14 cases) only projected out 10 to 20 years. Four scenarios were developed for 15 of the cases in order to ensure manageable discussions. Scenarios were factors or two drivers for eight of the cases, seven cases included 3 main factors, and another seven cases involved mixes of four or more factors in scenario development. All cases involved trade-offs between different social-ecological components of systems and 21 of the 23 cases centered around biodiversity topics and human well-being.

The majority of cases included input from the local community, local policy makers, natural resource management agencies, and non-governmental organizations. Policy makers, academics, and representatives from the business and recreation sector were included as well.⁵⁸ These exercises were supported by a wide variety of tools and techniques. These included group discussions, individual reflections, drawings, recording ideas on cards, mental models, quantitative models or data about climate change or land use change, ranking issues, interviews, maps, collages, diagrams, timelines, fictional headlines, and storytelling.

Two of the most widespread strengths found were engagement of stakeholders in the research process and the technical and methodological advantages of participatory workshops in exploration of plausible futures. The most common weakness was technical development of the processes and quality of the results. Researchers found that participatory scenario planning can produce new knowledge for environmental decision making and enhance the ability of decision making to engage with the complexity of systems. The four biggest challenges of the approach were found to be the tension between exploratory versus normative analysis, handling conflict amongst unequal stakeholders, communicating to a diverse group, and assessing the impact of the process. Particularly relevant for this research, the authors suggest different scenario outputs varying from technical reports to posters, drawings, or videos. Art was found to effectively communicate results as well as facilitate discussions.⁵⁹

Schwartz (1991) pointed out that scenarios are not predictions.⁶⁰ Scenarios aim to characterize the uncertainty of complex interactions that can influence future conditions. Scenarios are tools to help decision-makers to identify robust strategies by highlighting the risk and opportunities that can arise under alternative plausible futures. Traditional approaches to planning and management rely on predictive models of probable futures from past trends.⁶¹ Models must rely

⁵⁸ Elisa Oteros-Rozas et al., "Participatory Scenario Planning in Place-Based Social-Ecological Research: Insights and Experiences from 23 Case Studies," *Ecology and Society* 20, no. 4 (2015), <https://www.jstor.org/stable/26270296>, 1.

⁵⁹ Oteros-Rozas et al, 12.

⁶⁰ Peter Schwartz, *The Art of the Long View*, First edition. (New York: Doubleday/Currency, 1991).

⁶¹ M. Marina Alberti, *Cities That Think like Planets: Complexity, Resilience, and Innovation in Hybrid Ecosystems* (Seattle: University of Washington Press, 2016), 53.

on accurate, historic data and scientists must have a comprehensive understanding of the system and how it functions.⁶² Predictive models are designed to accurately assess future conditions, but these models can only account for some of the interactions between highly uncertain drivers.⁶³ These models generate probabilities based on historically observed dynamics which predict with a certain level of confidence the trajectory of each variable. However, we cannot predict unexpected interactions or tipping points, since the probability distribution of any interactions is unknown.”⁶⁴

Scenario modeling exercises for multiple, interacting natural hazards are relatively rare in the literature, particularly those that integrate models of sea level rise, earthquakes, and tsunamis. Most integrated hazard modeling exercises are probabilistic exercises intended to assist emergency management services and local governments.⁶⁵ One example is the probabilistic multi-hazard approach to earthquake-generated tsunamis, storm events, and sea level rise was conducted for New South Wales, Australia. 36 earthquake-generated tsunami models combined three annual probabilities of occurrence, 2 source locations, 6 sea level states, and tide and surge. The outputs of this exercise included tsunami wave amplitude, inundation extent of the forecast area, and estimates of maximum water level and flow velocity. The exposure of buildings and infrastructure was also included for review. Finally, probabilistic storm surge hazards were compared to the tsunami hazards under the same water level conditions. The researchers found that exposure to the earthquake-generated tsunamis is relatively low, but as sea levels rise exposure would increase significantly.⁶⁶

One benefit of integrating probabilistic modeling and scenario planning is the ability to compare different hazards predictions under alternative plausible futures by expanding the boundary conditions of predictive models. Although different methods were used to develop a 1/100 storm surge event model of total land area and number of buildings inundated in New South Wales, the effects of a storm event exceeds that of all simulated tsunamis under the same initial sea level conditions.⁶⁷ Researchers note this is due to the fact that storm surges have a much higher

⁶² M. Marina Alberti, *Cities That Think like Planets: Complexity, Resilience, and Innovation in Hybrid Ecosystems* (Seattle: University of Washington Press, 2016).

⁶³ Karis Tenneson, Michal Russo, and Marina Alberti, *Snohomish Basin 2060 Scenarios: Adapting to an Uncertain Future*, 2013, <https://doi.org/10.13140/RG.2.2.14535.39844>.

⁶⁴ Tenneson, Russo, and Alberti, 54.

⁶⁵ F. Dall’Osso et al., “The Exposure of Sydney (Australia) to Earthquake-Generated Tsunamis, Storms and Sea Level Rise: A Probabilistic Multi-Hazard Approach,” *Scientific Reports* 4, no. 1 (May 2015): 7401, <https://doi.org/10.1038/srep07401>.

⁶⁶ Elisa Oteros-Rozas et al., “Participatory Scenario Planning in Place-Based Social-Ecological Research: Insights and Experiences from 23 Case Studies,” *Ecology and Society* 20, no. 4 (2015), <https://www.jstor.org/stable/26270296>.

⁶⁷ Oteros-Rozas et al.

frequency than tsunamis in the region. This information is particularly useful for cost-benefit analyses and simplifies the conversation surrounding allocation of resources.⁶⁸

While the multi-hazard modeling in New South Wales depicted alternative futures, a scenario planning exercise would further expand the conditions of the social-ecological system that is explored. Planning generally focuses on low impact, high probability events, such as a king tide. Scenario planning takes these events into account while also exploring high impact, low probability events of uncertain drivers. It is important to account for outliers in planning exercises, because if we knew which of the many plausible future scenarios was correct we could prepare accordingly. However, the consequences of not exploring expanded boundary conditions could lead to a revolt or collapse of the system.

Scenarios become powerful when coupled with predictive modeling, expanding boundary conditions and creating an integrated framework with multiple models. Once divergent scenarios have created expanded boundaries, integrated models can generate futures that are unpredictable by predictive models.⁶⁹

Alternative future conditions may be caused by complex interactions among drivers of change, such as earthquake-generated tsunamis and sea level rise explored in this thesis. Uncertain drivers become significantly more complex when considered with other uncertain drivers, as depicted in Figure 2.5.⁷⁰ Exploring the uncertain endpoints associated with both drivers can create scenario conditions that would challenge long-term planning actions, creating policies that would function across a wider range of scenario conditions. Policies and regulations developed under highly alternative, divergent futures will be robust. In other words, they will perform well under a wider range of scenario conditions but may not be optimal for any one plausible future.⁷¹ Scenarios, therefore, can aid in creating robust policies that create a more resilient social-ecological system.

⁶⁸ F. Dall’Osso et al., “The Exposure of Sydney (Australia) to Earthquake-Generated Tsunamis, Storms and Sea Level Rise: A Probabilistic Multi-Hazard Approach,” *Scientific Reports* 4, no. 1 (May 2015): 7401, <https://doi.org/10.1038/srep07401>.

⁶⁹ M. Marina Alberti, *Cities That Think like Planets: Complexity, Resilience, and Innovation in Hybrid Ecosystems* (Seattle: University of Washington Press, 2016).

⁷⁰ Karis Tenneson, Michal Russo, and Marina Alberti, *Snohomish Basin 2060 Scenarios: Adapting to an Uncertain Future*, 2013, <https://doi.org/10.13140/RG.2.2.14535.39844>.

⁷¹ M. Marina Alberti, *Cities That Think like Planets: Complexity, Resilience, and Innovation in Hybrid Ecosystems* (Seattle: University of Washington Press, 2016).

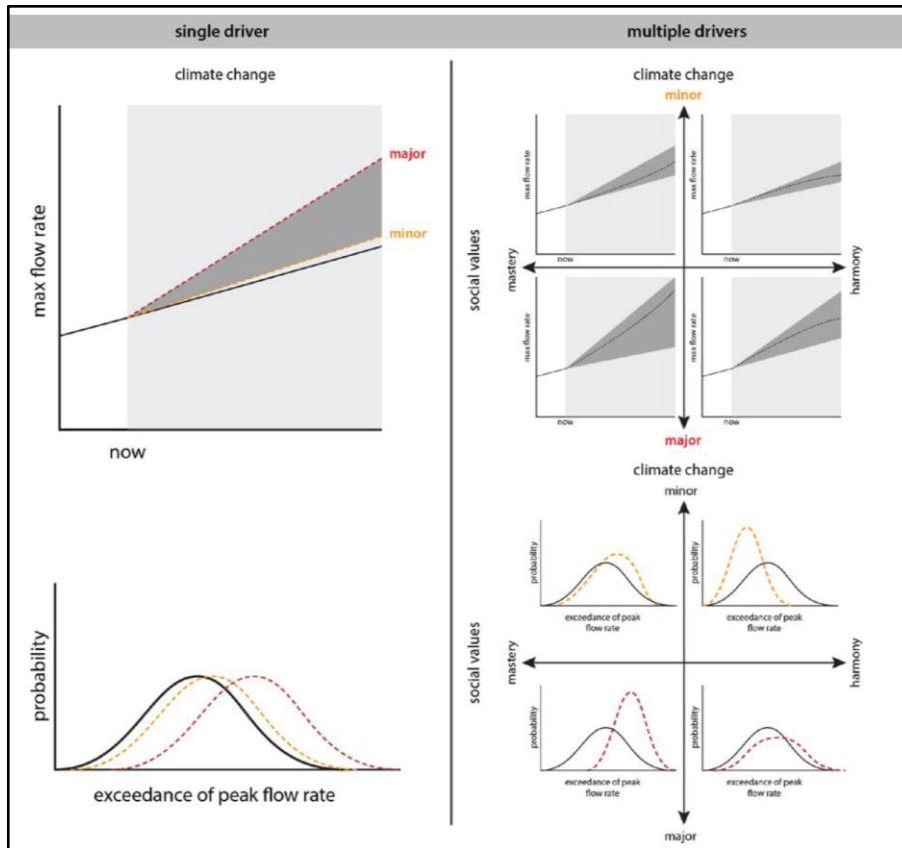


Figure 2.5. Single and multiple driver risk assessment for Snohomish Basin 2060 scenarios.^{72,73}

It is important to note that scenario planning differs from future scenarios that were used to develop future hazard maps in Chapter 4. In the case of maps, possible future conditions of multiple hazards were combined to create ‘future scenarios’.

2.4 Incorporating a Historical Perspective in Scenario Planning

One of the first pushes to include a historical perspective in the planning profession was in the 1920s.⁷⁴ Benton MacKaye was urging regional planners to undertake 100 century histories as early as 1928. MacKaye stated that the “environment is the product of history” and outlined a landscape history that would later be improved upon by Marcucci.⁷⁵ The planning method was

⁷² Karis Tenneson, Michal Russo, and Marina Alberti, *Snohomish Basin 2060 Scenarios: Adapting to an Uncertain Future*, 2013, <https://doi.org/10.13140/RG.2.2.14535.39844>. 64.

⁷³ Marina Alberti, *Advances in Urban Ecology: Integrating Humans and Ecological Processes in Urban Ecosystems*, 1. Aufl. (New York, NY: Springer-Verlag, 2008), <https://doi.org/10.1007/978-0-387-75510-6>.

⁷⁴ Daniel J Marcucci, “Landscape History as a Planning Tool,” *Landscape and Urban Planning* 49, no. 1 (May 25, 2000): 67–81, [https://doi.org/10.1016/S0169-2046\(00\)00054-2](https://doi.org/10.1016/S0169-2046(00)00054-2).

⁷⁵ Marcucci. 69.

not widely used as planning efforts focused on short-term socio-economic goals over the next few decades.⁷⁶

Including the environment in planning efforts began to grow in the United States in the 1960s.⁷⁷ Planners began to understand that change and evolution were part of the landscape and therefore the planning process. However, land-use history was largely used for suitability analysis and land-use decisions, or for documentation of historic resources.⁷⁸ In the 1970s Brian Hackett argued that large-scale landscape change was the responsibility of landscape planners.⁷⁹ Hackett developed four landscape planning techniques, one of which involved studying landscape evolution.⁸⁰

In 1989, Carl Abbott & Sy Adler stated that the use of historical analysis by planning practitioners will improve functionality of planners and their organizations.⁸¹ Programs and policies cannot be picked up and implemented in different regions, thus place based history is important. The authors state that "historical thinking involves special attention to time and context".⁸² Context is the result of analyzing the past. Understanding of long-term history can prevent overreaction to short-term fluctuations which could lead to valuing short-term results over long-term payoffs. The authors state that "historical analysis lacks the predictive precision that is usually claimed by quantitative or social science models. What it offers instead is a systematic way to understand the changing context of organizations, communities, and policies".⁸³ History makes us aware of the interrelationships of technical, economic, social, cultural, and political factors which have dramatic effects on communities. These same elements can be used to create future scenarios which "in one sense is history in reverse."⁸⁴ These elements of a geonarrative may inspire long-term planning that recreates the creativity and forward-thinking nature with which the community approached problems in the past, even as new science, respect for core cultural values, and uniqueness of place are incorporated.

⁷⁶ Daniel J Marcucci, "Landscape History as a Planning Tool," *Landscape and Urban Planning* 49, no. 1 (May 25, 2000): 67–81, [https://doi.org/10.1016/S0169-2046\(00\)00054-2](https://doi.org/10.1016/S0169-2046(00)00054-2).

⁷⁷ Marcucci, 70.

⁷⁸ Marcucci, 70.

⁷⁹ Brian. Hackett, *Landscape Planning: An Introduction to Theory and Practice*. (Newcastle upon Tyne: Oriel, 1971), <https://catalog.hathitrust.org/Record/001130311>.

⁸⁰ Hackett.

⁸¹ Carl Abbott and Sy Adler, "Historical Analysis as a Planning Tool," *Journal of the American Planning Association* 55, no. 4 (December 31, 1989): 467–73, <https://doi.org/10.1080/01944368908975435>.

⁸² Abbott and Adler, 471.

⁸³ Abbott and Adler, 472.

⁸⁴ Abbott and Adler., 472.

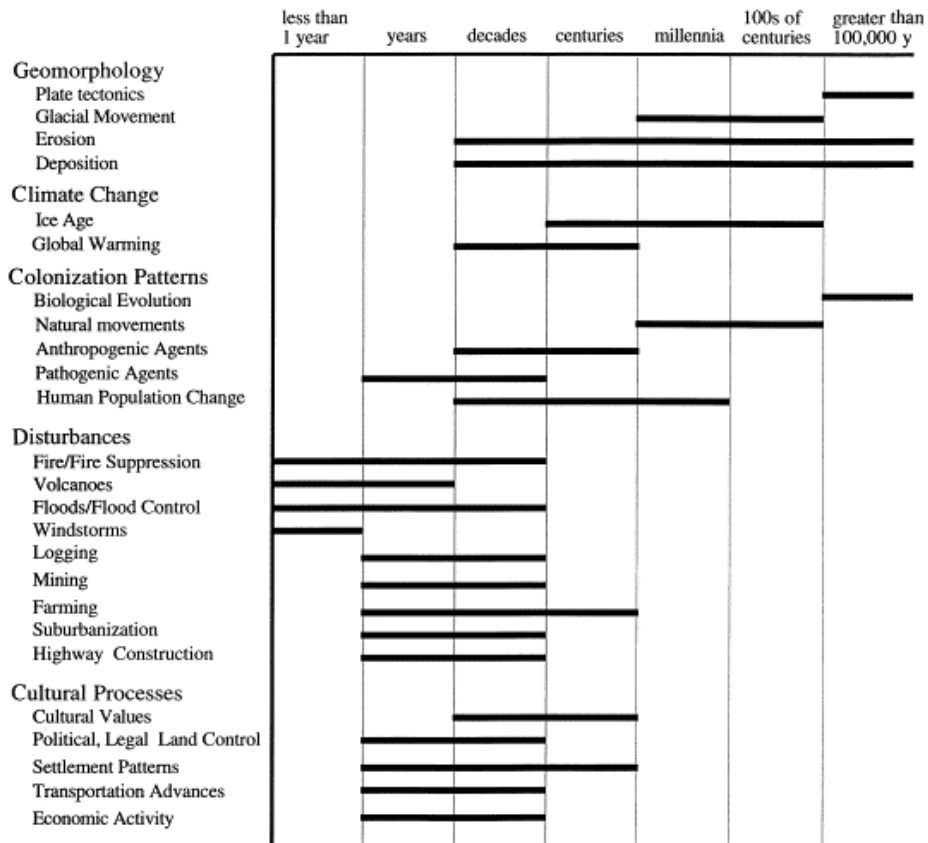


Figure 2.6. Length of time for select keystone processes to affect landscape change.⁸⁵

Marcucci argues that the history of a particular landscape is unique and complicated, existing with spatial, temporal, geographic, and historic contexts.⁸⁶ Landscapes are a function of historic conditions and the future condition of the same landscape will be the legacy of today's elements and processes. Marcucci states that "without an accurate long-term history of the landscape and without an understanding of the processes which are guiding its evolutionary path, we are unable to envision future landscape changes".⁸⁷

Marcucci lays out three benefits to the historical landscape model outlined in the article. First, understanding the source of conflicting values and beliefs will assist in finding common interest during conflict resolution.⁸⁸ Second, a large scale land history forces consideration of potential issues and problems that threaten long-term landscape resilience. Third, keystone processes allow change agents from outside the landscape to be recognized. For example, a water authority project in a distant city may have a drastic impact on the study landscape. Marcucci argues that

⁸⁵ Daniel J Marcucci, "Landscape History as a Planning Tool," *Landscape and Urban Planning* 49, no. 1 (May 25, 2000): 67–81, [https://doi.org/10.1016/S0169-2046\(00\)00054-2](https://doi.org/10.1016/S0169-2046(00)00054-2).

⁸⁶ Marcucci, 68.

⁸⁷ Marcucci, 68.

⁸⁸ Marcucci, 77.

history complements the total planning process. Through this process potential landscape change can be determined to be desirable or undesirable. The planning actions taken in response to landscape change can be informed by history in the landscape which will ultimately be a legacy seen by future generations.⁸⁹

Marcucci aimed to develop a system that would describe and predict the patterns and causes of evolution and change in the landscape. The three elements of a landscape history according to the author include a specific geography, a holistic system, and keystone processes that shape the landscape over multiple time frames. Marcucci states that a logarithmic timeline, as seen in Figure 2.6, is the most useful graphic device for depicting landscape history. The sections of this thesis focused on history and historical coastal change in South Beach are one of many elements that could be integrated into a larger, longer historical timeline. That timeline could, in turn, become part of a geonarrative that incorporates both the history of past socio-ecological adaptation and scenarios of adaptation to multiple plausible future changes.

2.5 Geonarratives as an Educational and Planning Tool

A geonarrative extends traditional geospatial information systems (GIS) capabilities and can be used to develop contextualized visual narratives which can be helpful in the analysis and interpretation of narrative materials.⁹⁰ “Geo-narratives have transcended conventional geovisualization of scientific data by providing a narrative complement to geospatial analytics and prioritizing socio-ecological context (place) over mere spatial structure or organization”.⁹¹ A common platform for developing this tool is ESRI’s Story Map. Through use of this platform and similar platforms, geonarratives can be adapted to specific uses and can be enriched with content such as videos, audio, photos, interviews, interactive maps, slideshows, guided tours, and links to other resources specific to the users’ needs.⁹² There is limited literature analyzing the use of geonarratives in a disaster education, communication engagement, or planning tool.

One of the most recent and relevant studies took place in Germany. Vollstedt et al. began their work by recognizing that coastal adaptation required information to be communicated to the general public regarding the risks associated with sea level rise.⁹³ However, simultaneously the

⁸⁹ Daniel J Marcucci, “Landscape History as a Planning Tool,” *Landscape and Urban Planning* 49, no. 1 (May 25, 2000): 67–81, [https://doi.org/10.1016/S0169-2046\(00\)00054-2](https://doi.org/10.1016/S0169-2046(00)00054-2).

⁹⁰ Mei-Po Kwan and Guoxiang Ding, “Geo-Narrative: Extending Geographic Information Systems for Narrative Analysis in Qualitative and Mixed-Method Research*,” *The Professional Geographer* 60, no. 4 (September 16, 2008), <https://doi.org/10.1080/00330120802211752>.

⁹¹ Daniel Abramson et al., “CoPe EAGER: Coastal Hazard Planning in Time” (National Science Foundation Award #1940024, 2019), Abstract available at https://www.nsf.gov/awardsearch/showAward?AWD_ID=1940024.

⁹² Environmental Systems Research Institute, “Digital Storytelling with Maps | ArcGIS StoryMaps.”

⁹³ Bente Vollstedt et al., “Co-Production of Climate Services: A Story Map for Future Coastal Flooding for the City of Flensburg,” *Climate Services* 22 (April 1, 2021): 100225, <https://doi.org/10.1016/j.cliser.2021.100225>.

team recognized there are significant barriers to public understanding of coastal risks and complexities. The use of geonarratives to depict climate change and adaptation had not previously been widely explored, yet an accessible communication tool was needed in order to increase awareness of the impacts of climate change. An interdisciplinary team consisting of social scientists, coastal experts, city partners, a journalist, a web designer, and users produced a geonarrative depicting sea level rise in the coastal town of Flensburg, Germany. The team created different visual forms of depicting data including figures, photographs, and maps. The goal of the project was to increase understanding and usability of the data, therefore the team included questionnaire results and workshop feedback from users before the product was finalized. Users were particularly helpful with respect to how floods were depicted in maps. Coordination with local partners proved to be valuable for identifying local assets and using accessible language. The authors state that other learning techniques could be coupled with the geonarrative such as conferences, workshops, training programs, and field visits.⁹⁴ The materials in this thesis are designed to be included in a geonarrative similar to that created for Flensburg residents. One other pertinent example of the use of geonarratives to communicate scientific data to the general public was a study done with university students.

A Clemson University study developed a story map that would later be used to teach an introductory soil science course.⁹⁵ The authors note that paper or digital maps have long provided visual aid for soil science, however, they are often difficult to read and interpret. Multiple studies support the idea that students are more engaged in and understand soil science better by narrative-based learning which includes objectives. The geonarrative was developed according to Environmental Systems Research Institute's (ESRI) five principles of effective storytelling. The effectiveness of the story map was tested through a quiz of the users. Users scored well on the quiz, indicating positive teaching outcomes and retention of material. Assessment of the effectiveness of this storytelling method by students revealed that most students rated the method as 'excellent'. In fact, students rated the geonarrative method higher than a presentation on the same topic. Participants also stated that the geonarrative would be useful as a stand-alone teaching tool or in combination with a presentation.⁹⁶ Teaching about the history of South Beach and the multiple hazards facing residents using a geonarrative could return similarly positive results.

⁹⁴ Vollstedt et al.

⁹⁵ Cope et al., "Developing and Evaluating an ESRI Story Map as an Educational Tool."

⁹⁶ Cope et al, 6.

Chapter 3: A Case Study Background: South Beach, Washington

The Ring of Fire is a path along the Pacific Ocean characterized by earthquakes and active volcanoes. Following boundaries between tectonic plates, ninety percent of earthquakes occur along its path.^{97,98} The west coast of the United States consists of California to the south, Oregon, Washington, and Alaska to the north. The focus of this thesis is South Beach, Washington. South Beach is approximately 100 miles and 3 hours by car from Seattle, Washington.

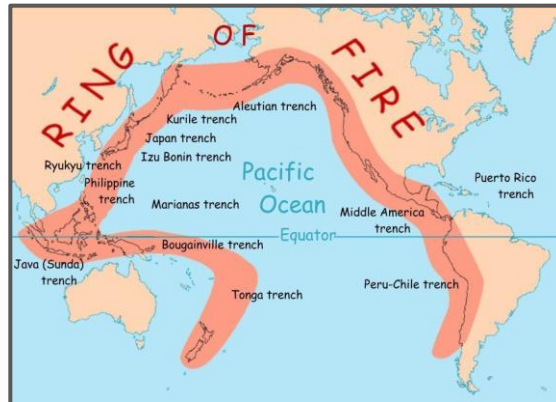


Figure 3.1. The Ring of Fire around the Pacific Ocean.⁹⁹

South Beach is a region that straddles two county lines, Grays Harbor County to the north and Pacific County to the south. Westport, located in Grays Harbor County is the only incorporated city in the region although there are other community clusters including Grayland and the Shoalwater Bay Tribe in Pacific County along Willapa Bay. This thesis is centered around the northern part of South Beach, extending to the county border.

⁹⁷ Linda Lawrance Noson, Anthony Qamar, and Gerald W. Thorsen, *Washington State Earthquake Hazards* (Washington Division of Geology and Earth Resources, 1988),

https://file.dnr.wa.gov/publications/ger_ic85_earthquake_hazards_wa.pdf.

⁹⁸ National Geographic Society, "Plate Tectonics and the Ring of Fire," National Geographic Society, January 6, 2015, <http://www.nationalgeographic.org/article/plate-tectonics-ring-fire/>.

⁹⁹ National Geographic Society.



Figure 3.2 (left). South Beach, Washington in the United States. Reproduced with permission from Jordan Sliz.

Figure 3.3 (right). The focus of this thesis is in the Grays Harbor portion of South Beach, where the communities of Westport and Grayland are located.

3.1 Overview of Environmental Hazards

South Beach is faced with different hazards that vary in their frequency, severity, warning time, and cumulative impact, but they also interact.¹⁰⁰ Depending on the severity and sequence of changing environmental conditions, the combined effects of sea level rise and a Cascadia Subduction Zone (CSZ) earthquake can vary greatly. For example, uplift may negate some or all of the sea level rise in South Beach until rapid subsidence occurs due to an earthquake. Sea level rise will also generally exacerbate the impacts of a tsunami resulting from an earthquake.

¹⁰⁰ Abramson et al., “Coastal Hazard Planning in Time Abstract.”

Subsidence of the coast during an earthquake event could cause sudden and drastic relative sea level rise that locally exacerbates climate-driven sea level changes.¹⁰¹

3.1.1 Cascadia Subduction Zone Earthquakes

An earthquake can deform the earth's crust following the release of energy by a sudden dislocation or a volcanic eruption.¹⁰² The epicenter of an earthquake is the location on the surface directly above the nucleation point, or hypocenter, of an earthquake; the associated geographic coordinates focal depth locate the earthquake in space. Oftentimes, these events occur along a fault, a fracture in the earth's crust. In the Pacific Northwest, more than ninety percent of earthquakes occur along the boundary between the North American plate and the Juan de Fuca plate called the Cascadia Subduction Zone (CSZ).^{103,104} See Figure 3.4.

¹⁰¹ Abramson et al.

¹⁰² Bridgeview Consulting, "Grays Harbor County 2018 Multi-Jurisdiction Hazard Mitigation Plan Update Volume 1: Planning-Area-Wide Elements," July 2018, https://cms5.revize.com/revize/graysharborcounty/Emergency%20Management/Planning/Grays%20Harbor%20County%20HMP_Plan_Final_2018.pdf, 7-1.

¹⁰³ Linda Lawrance Noson, Anthony Qamar, and Gerald W. Thorsen, *Washington State Earthquake Hazards* (Washington Division of Geology and Earth Resources, 1988), https://file.dnr.wa.gov/publications/ger_ic85_earthquake_hazards_wa.pdf.

¹⁰⁴ Bridgeview Consulting, "Grays Harbor County 2018 Multi-Jurisdiction Hazard Mitigation Plan Update Volume 1: Planning-Area-Wide Elements," July 2018, https://cms5.revize.com/revize/graysharborcounty/Emergency%20Management/Planning/Grays%20Harbor%20County%20HMP_Plan_Final_2018.pdf, 7-1.

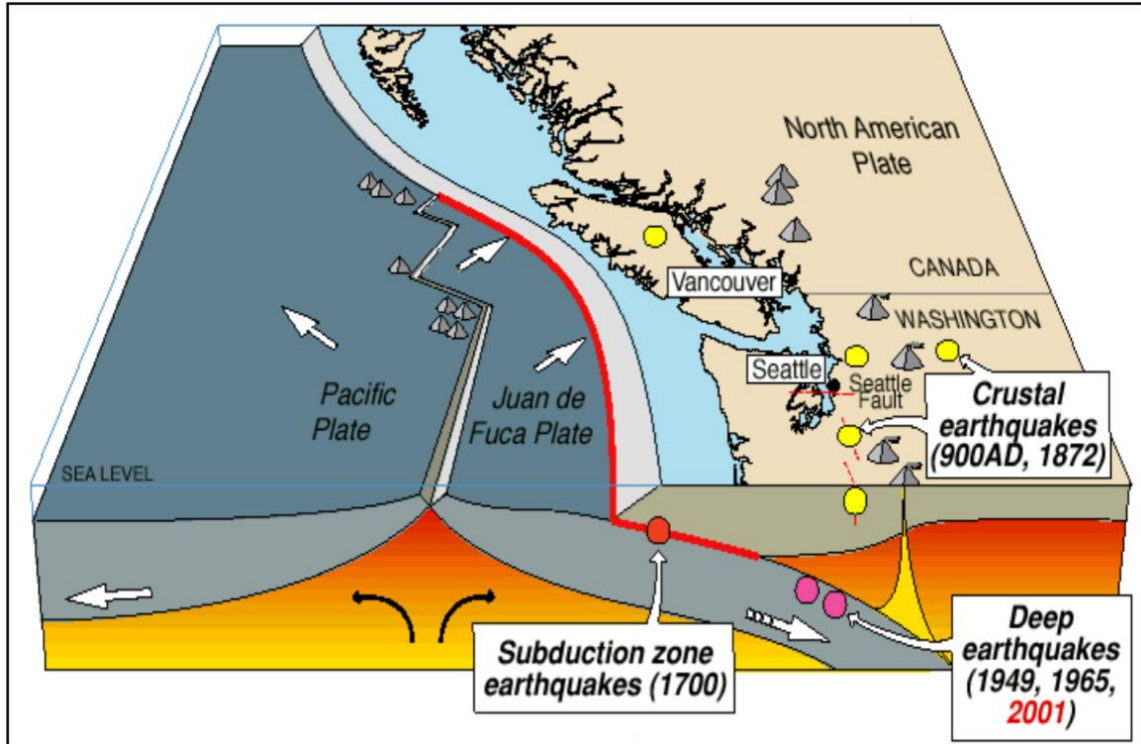


Figure 3.4. Earthquake types in the Pacific Northwest.¹⁰⁵

Generally, the strongest ground motions resulting from an earthquake will occur near the epicenter and the intensity of ground motions will diminish with increasing distance from the epicenter.¹⁰⁶ Shaking at any point depends on four main factors: earthquake magnitude, distance from the earthquake epicenter, earthquake depth, and crustal properties along the energy propagation path. Earthquake magnitude is a measure of the amount of energy released from an earthquake and is expressed by a variety of scales, such as the Richter Scale.¹⁰⁷ More frequently, however, the moment magnitude scale, Mw, is used because it is more reliable and consistent up to very large energy levels.¹⁰⁸ A magnitude 8.0 Mw earthquake or higher is commonly classified as 'great'.¹⁰⁹ These earthquakes can cause major damage over wide geographic areas. A

¹⁰⁵ Bridgeview Consulting, 7-2.

¹⁰⁶ Bridgeview Consulting, "Grays Harbor County 2018 Multi-Jurisdiction Hazard Mitigation Plan Update Volume 1: Planning-Area-Wide Elements," July 2018, https://cms5.revize.com/revize/graysharborcounty/Emergency%20Management/Planning/Grays%20Harbor%20County%20HMP_Plan_Final_2018.pdf, 7-2.

¹⁰⁷ Bridgeview Consulting.

¹⁰⁸ U.S. Geological Survey, "Moment Magnitude, Richter Scale - What Are the Different Magnitude Scales, and Why Are There so Many?," Moment magnitude, Richter scale - what are the different magnitude scales, and why are there so many?, 2021, https://www.usgs.gov/faqs/moment-magnitude-richter-scale-what-are-different-magnitude-scales-and-why-are-there-so-many?qt-news_science_products=3#qt-news_science_products.

¹⁰⁹ Bridgeview Consulting, "Grays Harbor County 2018 Multi-Jurisdiction Hazard Mitigation Plan Update Volume 1: Planning-Area-Wide Elements," July 2018, https://cms5.revize.com/revize/graysharborcounty/Emergency%20Management/Planning/Grays%20Harbor%20County%20HMP_Plan_Final_2018.pdf.

magnitude 9 (M9) 'mega-quake' on the CSZ, the largest threat to South Beach, could affect the entire Pacific Northwest with the highest damage occurring along the Pacific coast.¹¹⁰

The impact of a CSZ earthquake in South Beach will largely be a function of distance from the epicenter and its depth, which will induce ground shaking, liquefaction, and other seismic-related hazards including landslides and tsunamis.¹¹¹ An earthquake may also trigger fires, dam failure, release of hazardous materials, falling objects and debris, damaged buildings, and disruption of utilities including electric, gas, sewer, and water.

Paleoseismologists have identified forty-one CSZ interface earthquakes that have occurred over the past 10,000 years, corresponding to one earthquake about every 250 years.¹¹² Approximately half of these events were M9.0 or greater indicating a full rupture of the fault from Northern California to British Columbia. The remaining earthquakes were M8+, indicating a partial rupture along the southern portion of the subduction zone. Scientists currently estimate that an M9 event in the CSZ occurs approximately once every 500 years while an M8 event occurs about every 250 years.

Evidence suggests the most recent rupture occurred on January 26, 1700. Physical evidence includes abrupt subsidence along the Copalis River which caused a spruce and cedar forest to drown.¹¹³ This ghost forest can still be seen today just north of South Beach. Researchers predict there is a 10 to 14 percent chance that a CSZ earthquake could occur in the next 50 years.¹¹⁴ The 321 years since the last major CSZ earthquake is longer than the average M8 occurrence and shorter than some of the intervals between M9 earthquakes.¹¹⁵

3.1.2 Cascadia Subduction Zone Tsunamis

A tsunami is a series of waves radiating from a disturbance such as an earthquake.¹¹⁶ The characteristics of tsunamis are much more extreme than normal ocean waves. The wavelength of normal ocean waves is around 300 feet whereas tsunamis have much longer wavelengths of up to 300 miles. The deep water speed of tsunamis is also much greater than normal ocean waves. As a tsunami approaches a coast, its speed and wavelength decrease and its height greatly increases.

¹¹⁰ Bridgeview Consulting, 7-6.

¹¹¹ Bridgeview Consulting, 7-8.

¹¹² Bridgeview Consulting, 7-21.

¹¹³ Bridgeview Consulting, "Grays Harbor County 2018 Multi-Jurisdiction Hazard Mitigation Plan Update Volume 1: Planning-Area-Wide Elements," July 2018, https://cms5.revize.com/revize/graysharborcounty/Emergency%20Management/Planning/Grays%20Harbor%20County%20HMP_Plan_Final_2018.pdf.

¹¹⁴ Bridgeview Consulting, 7-18.

¹¹⁵ Bridgeview Consulting, 7-21.

¹¹⁶ Bridgeview Consulting, 12-1.

The first tsunami wave is generally not the largest. Larger, more destructive waves often follow the first wave. The destructiveness of a tsunami is affected primarily by the structure of the coastline, the bathymetry of the ocean floor, and the characteristics of the waves.¹¹⁷

The first indication of a tsunami approaching land may be drawdown of the water or may be a rise in the water level.¹¹⁸ A trough, or dramatic drawdown of the water, exposes normally submerged areas. Rapid drawdown can create strong currents in harbors and channels that can severely damage coastal infrastructure. Piers can be damaged by boats pulling or breaking their mooring lines, boats can overturn or sink in the strong currents, collision of objects can cause damage, and the harbor bottom can be impacted. Drawdown is followed by the crest of the first tsunami wave which can catch observers off guard. Alternatively, advancing tsunamis may resemble a strong surge but the tsunami surge rises faster than normal and does not stop at the shoreline. Even small wave heights of 3 to 6 feet can be deadly due to their strength. Surges at waist height can cause strong currents that float cars and other small structures. These structures are often carried inland and are left grounded when water recedes.¹¹⁹

The CSZ will produce Washington state's largest tsunami.¹²⁰ Portions of South Beach can expect waves to reach them within approximately 25-30 minutes of a CSZ earthquake. This rapid succession could result in high loss of life due to residents' inability to evacuate quickly to high ground. A CSZ earthquake followed by a CSZ tsunami could also result in severe economic and environmental impacts throughout Washington's coastal communities, including South Beach.¹²¹

3.1.3 Sea Level Rise

Sea level rise (SLR) is an increase in ocean water levels over long periods of time such as decades or centuries.¹²² Large increases in sea level are expected by the end of this century.¹²³ Future SLR depends on how much and how quickly atmospheric greenhouse gases cause warming of the earth systems in addition to the sensitivity of each process contributing to SLR.¹²⁴ Human behavior and decisions will dictate future greenhouse gas emissions, therefore,

¹¹⁷ Bridgeview Consulting, 12-2.

¹¹⁸ Bridgeview Consulting, 12-3.

¹¹⁹ Bridgeview Consulting, 12-3.

¹²⁰ Bridgeview Consulting, 12-20.

¹²¹ Bridgeview Consulting, 12-35.

¹²² Washington Coastal Network, "About Sea Level Rise," *Washington Coastal Hazards Resilience Network* (blog), October 19, 2020, <https://wacoastalnetwork.com/chrn/research/about-slr/>.

¹²³ Washington Coastal Network.

¹²⁴ I Miller et al., "Projected Sea Level Rise for Washington State - A 2018 Assessment" (Washington Coastal Resilience Project, July 2019).

there is no reliable way to estimate the probability of following any particular emission trajectory.¹²⁵

Components of SLR include melting land-based glaciers, ice caps and ice sheets, and ocean processes including thermal expansion and shifts in ocean currents.¹²⁶ Sea level changes are also influenced by ‘sea level fingerprinting’, changes in gravitational pull as glaciers and ice sheets shrink. Non-climate change related factors include reservoirs, groundwater extraction, and even changes in the Earth's crust due to the last ice age.¹²⁷

The rate and magnitude of future ice melt from Antarctica and, to a lesser extent, Greenland create a large amount of uncertainty in the modeled response of SLR to climate change.¹²⁸ Even for a single greenhouse gas scenario there is often a wide range among projections, reflecting this uncertainty.¹²⁹ Uncertainties also stem from the unpredictability of human emission, natural climate variability, and limitations of models.¹³⁰

Many Washington coastal communities will need to consider local conditions such as vertical land movement that will affect local variations in water levels.¹³¹ Relative SLR in South Beach is projected to be relatively lower than other parts of Washington due to estimated inter-seismic uplift which raises the level of the land as the level of the water also increases. In the event of coseismic subsidence resulting from a CSZ earthquake, relative SLR will be higher. For example, the Tohoku Earthquake in 2011, a magnitude 9.0 earthquake, caused coseismic subsidence of 1.2 meters or 3.9 feet in Oshika, Japan.¹³² Therefore, relative sea level changes influencing a community reflect both change in vertical land movement and in the absolute sea level.¹³³

¹²⁵ Miller et al, 10.

¹²⁶ Miller et al, 15-16.

¹²⁷ Miller et al, 16.

¹²⁸ Miller et al, 7.

¹²⁹ Miller et al, 7.

¹³⁰ I Miller et al., “Appendix B: Global and Regional Sea Level Rise: A Review of the Science,” in *Projected Sea Level Rise for Washington State - A 2018 Assessment* (Washington Coastal Resilience Project, 2019).

¹³¹ Miller et al., “Projected Sea Level Rise for Washington State - A 2018 Assessment.”

¹³² Tetsuro Imakiire and Mamoru Koarai, “Wide-Area Land Subsidence Caused by ‘the 2011 Off the Pacific Coast of Tohoku Earthquake,’” *Soils and Foundations* 52 (October 1, 2012), <https://doi.org/10.1016/j.sandf.2012.11.007>.

¹³³ Miller et al., “Projected Sea Level Rise for Washington State - A 2018 Assessment.”

Coastal flooding already affects South Beach¹³⁴ and the frequency and magnitude of coastal flooding will increase as sea level rises.¹³⁵ Daily tides will reach higher on the shoreline due to SLR and higher water levels will damage infrastructure, affect coastal ecosystems, and increase the impacts from other coastal hazards, as seen in the diagram below.¹³⁶

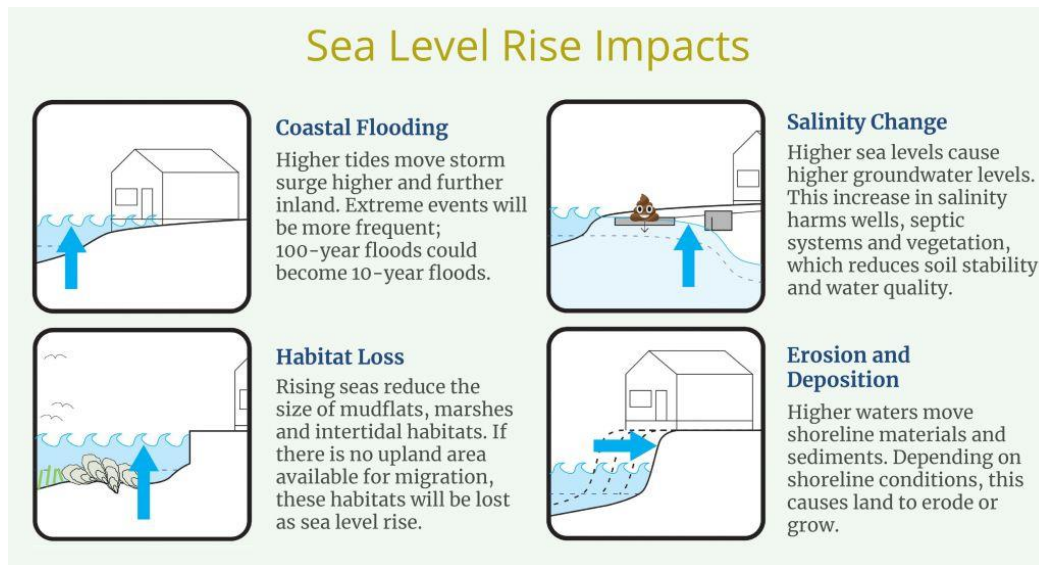


Figure 3.5. Local sea level rise impacts.¹³⁷

3.2 Narrative History of the Region

Today South Beach straddles the county line between Grays Harbor County and Pacific County. South Beach is also encompassed within two watersheds, the Lower Chehalis and the Willapa watersheds. South Beach has been shaped by regional environmental processes. Grays Harbor in the Lower Chehalis watershed was once open to the ocean.¹³⁸ Sediment from the Columbia River was brought north by littoral drift, replenishing the outer beaches and dunes of Grays Harbor. This sediment transport merged with material-laden flows of the lower Chehalis River as fresh

¹³⁴ Ryan Sparks, "Storm Surge Causes Minor Flooding in Westport Marina District," *The Daily World*, November 16, 2020, <https://www.thedailyworld.com/news/storm-surge-causes-minor-flooding-in-westport-marina-district/>.

¹³⁵ I.M. Miller et al., "Extreme Coastal Water Level in Washington State: Guidance to Support Sea Level Rise Planning," *Extreme Coastal Water Level in Washington State: Guidance to Support Sea Level Rise Planning* (A collaboration of Washington Sea Grant, University of Washington Climate Impacts Group, Oregon State University, University of Washington, Pacific Northwest National Laboratory and U.S. Geological Survey. Prepared for the Washington Coastal Resilience Project., 2019), <http://pubs.er.usgs.gov/publication/70205780>.

¹³⁶ Washington Coastal Network, "About Sea Level Rise," *Washington Coastal Hazards Resilience Network* (blog), October 19, 2020, <https://wacoastalnetwork.com/chrn/research/about-slr/>.

¹³⁷ Washington Coastal Network, "About Sea Level Rise," *Washington Coastal Hazards Resilience Network* (blog), October 19, 2020, <https://wacoastalnetwork.com/chrn/research/about-slr/>.

¹³⁸ Katherine L Arntzen, "Ocosta-by-the-Sea: A Boomtown in Three Narratives," August 1, 2009, 170.

water and salt water mixed in the estuary. As these waters mixed, they slowed and sediment dropped from the water column - creating mudflats, bars, islands, and other landforms.¹³⁹

Each watershed is associated with different indigenous histories. The Chehalis watershed portion of South Beach roughly extends to the county boundary. This area was home to the Coast Salish and Chehalis indigenous peoples.¹⁴⁰ Descendants of the lower Chehalis peoples are members of today's Quinault Indian Nation, Confederated Tribes of the Chehalis, and the Shoalwater Bay Tribe.¹⁴¹ Archaeological findings of shell middens and fishing weirs show that there were fishing and camping sites all around Grays Harbor. Pre-European lifestyles here exhibited close connections to the water, with shellfish and salmon as major food sources. The dense forests of the area provided wood supply which fueled extremely skilled woodworking. Local western red cedar trees were used to construct longhouses, which reflected deep connections with water through an open doorway facing the water for easy salmon collection.¹⁴²

Geologic research, aided by indigenous stories, has shown that indigenous populations have lived with catastrophic earthquakes and tsunamis for centuries.¹⁴³ Archaeological records show that despite these catastrophic events sites along the Washington coast were reoccupied afterward.¹⁴⁴ After assessing indigenous stories, archaeology, and geology related to hazards of the region, Ann Finkbeiner stated that "The Pacific Northwest turns out to be, in the long run, a place conducive to resilience."¹⁴⁵ This resilient nature applies to the greater region and one common identified link is storytelling. The earth shaking and rising water is frequently described in stories as acts of supernatural beings often in the form of animals.¹⁴⁶ In the northern Washington region the struggle between Thunderbird and Whale is cited to be the cause.¹⁴⁷ "Thunderbird and Whale had a terrible fight, making the mountains shake and uprooting the trees, said the Quileute and the Hoh people; they said the ocean rose up and covered the whole land."¹⁴⁸

The story of the Thunderbird and the Whale and many other stories were passed down generation to generation. This beautiful, bountiful, and hazardous region has always been home to resilient people that have found a way to instill preparedness in the next generation. The

¹³⁹ Arntzen, 3.

¹⁴⁰ Arntzen.

¹⁴¹ Jackson Blalock, "Shifting Shorelines: A Process-Based Approach to Sea Level Rise Resilience in Grays Harbor Estuary," 2017, <https://digital.lib.washington.edu/researchworks/handle/1773/40214>.

¹⁴² Katherine L Arntzen, "Ocosta-by-the-Sea: A Boomtown in Three Narratives," August 1, 2009.

¹⁴³ Ann Finkbeiner, "The Great Quake and the Great Drowning," September 14, 2015.

¹⁴⁴ Finkbeiner.

¹⁴⁵ Finkbeiner.

¹⁴⁶ Ruth Ludwin, "Dating the 1700 Cascadia Earthquake: The Great Coastal Earthquake in Native Stories," *Seismological Research Letters* 76, no. 2 (2005).

¹⁴⁷ Ludwin, 142.

¹⁴⁸ Finkbeiner, "The Great Quake and the Great Drowning."

resilient nature of the region's peoples has continued to this day.

European contact was first made in Grays Harbor on May 7, 1792¹⁴⁹ by the American fur trader Robert Gray.¹⁵⁰ The first Western permanent resident didn't arrive until more than 50 years later.¹⁵¹ More Euro-American settlers began to arrive in Grays Harbor during the 1850s after the passage of the 1850 and 1853 Donation Acts, and the 1862 Homestead Act.¹⁵² The first business on the peninsula was a sawmill which proved useful for the development of permanent structures and boat building.¹⁵³

While white settlers began to put down roots, European smallpox took a devastating toll on native peoples.¹⁵⁴ A smallpox outbreak originating from a boat in Neah Bay in 1853 was referred to as the Big Sick.¹⁵⁵ Thousands of Chehalis died on Point Chehalis,¹⁵⁶ and the village was all but abandoned.¹⁵⁷ In the same year, 1853, Washington territory was created.¹⁵⁸ Soon after the US Government asked the Quinault, Queets, Cowlitz, Shoalwater, and Chehalis tribes to cede rights to their land and settle onto a reservation.¹⁵⁹

In 1891 the former Point Chehalis was named Westport.¹⁶⁰ In the late 1800s and early 1900s two significant infrastructure projects were constructed in Westport to ensure safe passage of ships through Grays Harbor.¹⁶¹ In 1897 a lifesaving station was opened.¹⁶² The next year, light and fog signals were added to what we know today as the Grays Harbor lighthouse.¹⁶³ Construction began on the south jetty in Westport in 1898 and the 12,000 foot long jetty was completed in 1902.¹⁶⁴ The jetty provided an excellent barrier to the littoral drifts that had carried sediment

¹⁴⁹ Arntzen, "Ocosta-by-the-Sea: A Boomtown in Three Narratives," August 1, 2009.

¹⁵⁰ Ruth McCausland, *Washington's Westport* (Virginia Beach, VA: Donning Co, 1998).

¹⁵¹ McCausland.

¹⁵² Blalock, "Shifting Shorelines: A Process-Based Approach to Sea Level Rise Resilience in Grays Harbor Estuary."

¹⁵³ Ruth McCausland, *Washington's Westport* (Virginia Beach, VA: Donning Co, 1998), 19.

¹⁵⁴ Blalock, "Shifting Shorelines: A Process-Based Approach to Sea Level Rise Resilience in Grays Harbor Estuary."

¹⁵⁵ Ruth McCausland, *Washington's Westport* (Virginia Beach, VA: Donning Co, 1998), 18.

¹⁵⁶ Blalock, "Shifting Shorelines: A Process-Based Approach to Sea Level Rise Resilience in Grays Harbor Estuary."

¹⁵⁷ Ruth McCausland, *Washington's Westport* (Virginia Beach, VA: Donning Co, 1998), 18.

¹⁵⁸ Blalock, "Shifting Shorelines: A Process-Based Approach to Sea Level Rise Resilience in Grays Harbor Estuary."

¹⁵⁹ Ruth McCausland, *Washington's Westport* (Virginia Beach, VA: Donning Co, 1998), 21.

¹⁶⁰ Ruth McCausland, "History of the South Beach," 2021, <http://westportgrayland-chamber.org/history.php>.

¹⁶¹ McCausland.

¹⁶² Ruth McCausland, *Washington's Westport* (Virginia Beach, VA: Donning Co, 1998), 41.

¹⁶³ McCausland, 44.

¹⁶⁴ James Phipps and John Smith, "Pacific Ocean Beaches Erosion and Accretion Report," July 1978, <https://www.govinfo.gov/content/pkg/CZIC-gb454-b3-p5-1978/html/CZIC-gb454-b3-p5-1978.htm>.

north along the Washington coast.¹⁶⁵ Two years after construction was completed the area behind the jetty had accreted 3,000 feet west.¹⁶⁶

At the turn of the century, Westport was being recognized as a summer recreation destination.¹⁶⁷ More land was platted and hotels were built.¹⁶⁸ In 1902 “the inhabitants of Westport [were] preparing to entertain a larger number of visitors [that] season than ever before. Already the season [had] opened, and every boat [unloaded] health and pleasure-seekers”, said the Seattle Times.¹⁶⁹

Westport continued to grow and people continued to invest. In 1912 a road was completed from Aberdeen to South Beach coastal communities.¹⁷⁰ By 1913 a total of 133 buildings had been built in Westport. The next year, in 1914, residents voted to incorporate.¹⁷¹ By this point, Westport was a busy, though small center for fishing, shellfish harvesting, seafood processing and tourism.¹⁷²

Commercial fishing started in the 1920s in Westport with the introduction of gas and diesel engines.¹⁷³ Fishing was a huge industry in the beginning of the century.¹⁷⁴ Canneries expanded the industry.¹⁷⁵ After World War II, the cove was dredged, breakwaters were installed, and improvements to the Westport Marina brought commercial and sport fishing vessels.¹⁷⁶ By the end of the 1940s their business proved strong enough to maintain two stores, two fish-packing plants, a tavern, and a restaurant.¹⁷⁷ In the 1950s, Westport was dubbed the “Salmon Fishing Capital of the World.”¹⁷⁸

In the early 1900s desire for hydroelectric power was growing in the Pacific Northwest.¹⁷⁹ The Columbia River between Washington and Oregon was targeted for dams that would serve

¹⁶⁵ Phipps and Smith.

¹⁶⁶ Phipps and Smith.

¹⁶⁷ Ruth McCausland, *Washington’s Westport* (Virginia Beach, VA: Donning Co, 1998).

¹⁶⁸ McCausland, “History of the South Beach.”

¹⁶⁹ Kershner, “HistoryLink.Org Essay 10723.”

¹⁷⁰ Arntzen, “Ocosta-by-the-Sea: A Boomtown in Three Narratives”, 28.

¹⁷¹ McCausland, “History of the South Beach.”

¹⁷² Experience Westport, “History of Westport, Washington,” Experience Westport, Washington, 2021, <https://www.experiencwestport.com/history-of-westport-washington>.

¹⁷³ McCausland, “History of the South Beach.”

¹⁷⁴ Ruth McCausland, *Washington’s Westport* (Virginia Beach, VA: Donning Co, 1998).

¹⁷⁵ McCausland, “History of the South Beach.”

¹⁷⁶ McCausland, “History of the South Beach.”

¹⁷⁷ Ruth McCausland, *Washington’s Westport* (Virginia Beach, VA: Donning Co, 1998), 65.

¹⁷⁸ Mark Yuasa, “Washington Town Highlights Its Salmon Fishing History | The Spokesman-Review,” July 10, 2014, <https://www.spokesman.com/stories/2014/jul/10/washington-town-highlights-its-salmon-fishing/>.

¹⁷⁹ Northwest Power and Conservation Council, “Dams: History and Purpose,” 2021, <https://www.nwcouncil.org/reports/columbia-river-history/damshistory>.

multiple purposes. The Bonneville and Grand Coulee dams on the Columbia were completed in the 1930s and 1940s.¹⁸⁰ Since their construction the dams sediment flow from the Columbia River has decreased.¹⁸¹ Simultaneously, there has been significant coastal change in the South Beach region.¹⁸² Multiple jetty rehabilitation projects have taken place since the Bonneville dam construction in 1933.^{183,184}

From the 1960s to the late 1970s, the height of salmon fishing occurred in Westport.¹⁸⁵ The town then was home to about 200 charter boats luring more than 250,000 anglers during good seasons.¹⁸⁶ The Boldt Decision in 1974 hit Westport's economy hard.¹⁸⁷ Upon recognition of treaty tribes' rights to half the annual fish catch, restrictions were put into place for other fishermen. The shorter fishing season, two-fish-a-day limit, and declining salmon stock challenged non-indigenous fishermen. In the 1980s, Grays Harbor County was one of only three Washington counties that lost population.¹⁸⁸ In the 1990s conditions worsened for Westport fishermen when a ban on ocean salmon fishing took place for a year in response to declining salmon numbers.¹⁸⁹ Westport scrambled to find an economic replacement for the hard-hit fishing industry.

Westport has found alternative economic solutions since the Boldt Decision. Westport Shipyard, Inc. pivoted from manufacturing salmon and crab boats to recreational boats and luxury yachts. Tourism has also diversified with surfers and wildlife enthusiasts.¹⁹⁰ During the COVID-19 pandemic Westport saw a significant increase in tourists during the 2020 summer months.¹⁹¹

¹⁸⁰ Northwest Power and Conservation Council.

¹⁸¹ Jeremy FiveCrows, "Changing Ecosystem: Reservoir Sedimentation," CRITFC, October 6, 2015, <https://www.critfc.org/blog/2015/10/05/changing-ecosystem-reservoir-sedimentation/>.

¹⁸² FiveCrows.

¹⁸³ FiveCrows.

¹⁸⁴ Phipps and Smith, "Pacific Ocean Beaches Erosion and Accretion Report."

¹⁸⁵ Yuasa, "Washington Town Highlights Its Salmon Fishing History | The Spokesman-Review."

¹⁸⁶ Yuasa.

¹⁸⁷ Ruth McCausland, *Washington's Westport* (Virginia Beach, VA: Donning Co, 1998), 145.

¹⁸⁸ McCausland.

¹⁸⁹ McCausland, 148.

¹⁹⁰ McCausland.

¹⁹¹ Shelby Miller, "Westport Businesses Thriving during COVID-19 Pandemic," KIRO 7 News Seattle, accessed March 17, 2021, <https://www.kiro7.com/news/local/westport-businesses-thriving-during-covid-19-pandemic/CMBLVXVQWZAUJCF7L67QERE3UE/>.

3.3 Current South Beach Community

Westport is the largest community in South Beach with a population of approximately 2,000 residents.¹⁹² The larger community of South Beach, which generally follows the boundaries of the Ocosta School District, has a total population of 7,500 people.¹⁹³ South Beach residents can be generally described as aging and low-income. 44% of the population is over the age of 50 years old and the population is expected to be relatively stagnant for the foreseeable future with an expected growth of only 6%, the majority of which is expected to occur in Westport.^{194,195} The median annual household income in South Beach is slightly more than \$45,000 which is approximately three-fifths the median household income in Washington.¹⁹⁶

South Beach's economy is centered around water. The sizable Westport marina supports commercial fishing, charter boats for visitors, and pleasure boating. Commercial fishing provides a sizable economic impact to the area as the largest marina in Washington for commercial fishing vessels.¹⁹⁷ The area around the marina hosts warehouses and cold storage used for storing and processing fish in preparation of distribution.¹⁹⁸ The region also produces other food products such as oysters, clams, and cranberries. Although cranberries are being threatened by salt-water intrusion and erosion.¹⁹⁹ Similarly, oyster production is threatened by environmental change such as altered food chains and changing pH of ocean waters.²⁰⁰ Tourism is a major part of the economy during summer months and Westport intends on drawing tourists year-round in the future. Popular tourist activities include surfing, fishing, beach walking, camping, biking, wildlife viewing, storm watching, and festivals.²⁰¹

¹⁹² United States Census Bureau, "City of Westport: Age and Sex," American Community Survey, accessed April 15, 2021, <https://data.census.gov/cedsci/table?q=westport,%20washington&d=ACS%205-Year%20Estimates%20Data%20Profiles&tid=ACSDP5Y2019.DP05&hidePreview=false>.

¹⁹³ Census Reporter, "Census Profile: Ocosta School District, WA," Census Reporter, accessed April 17, 2021, <http://censusreporter.org/profiles/97000US5306090-ocosta-school-district-wa/>.

¹⁹⁴ Census Reporter.

¹⁹⁵ Washington State: Office of Financial Management, "Growth Management Act Population Projections for Counties: 2000 to 2030," Office of Financial Management, 2007, <https://ofm.wa.gov/washington-data-research/population-demographics/population-forecasts-and-projections/growth-management-act-county-projections/growth-management-act-population-projections-counties-2000-2030>.

¹⁹⁶ Census Reporter, "Census Profile."

¹⁹⁷ Port of Grays Harbor, "Westport Marina," Port of Grays Harbor, 2021, <https://www.portofgraysharbor.com/westport-marina>.

¹⁹⁸ University of Washington Urban Design & Planning Studio "Community Engagement for Coastal Resilience," *Localizing Hazard Mitigation: Recommendations for Westport's Comprehensive Plan Update* (University of Washington, 2018), https://mitigate.be.uw.edu/wp-content/uploads/sites/70/2021/03/FullReport_WestportCoastalResiliencyReport_11.22.19.pdf.

¹⁹⁹ "Livelihoods: Looking to the Horizon Line," in *The Architectural League of New York: South Beach, Washington*, accessed April 17, 2021, <https://archleague.org/article/south-beach-washington-livelihoods/>.

²⁰⁰ "Livelihoods."

²⁰¹ City of Westport, "City of Westport Comprehensive Park and Recreation Plan 2018 – 2023," 2018, 91.

During two community resilience workshops in 2018 community members identified values and assets that contribute to making South Beach a unique place to live. Residents stated that they value the resilient, hard-working, self-sufficient nature of the people.²⁰² The community values affordable housing and are proud of their heritage and the community's history. The tight social bonds in the community are enabled by people meeting regularly at the docks, school events, church gatherings, or in their neighborhoods. Community members help one another and have a strong sense of belonging. The rural character of the community ensures the area does not feel crowded and provides clean air and water. State parks, local parks, ocean beaches, and forests allow residents easy access to recreational opportunities such as hiking, running, sightseeing, and surfing. Oceans and forests provide naturally-available foods such as fresh seafood, elk, deer, berries, and mushrooms for which the community fish, hunt, and forage. The community also values built structures, including the marina, library, Ocosta school, Grays Harbor lighthouse, and Westport Maritime Museum.²⁰³

²⁰² University of Washington Urban Design & Planning Studio "Community Engagement for Coastal Resilience," *Localizing Hazard Mitigation: Recommendations for Westport's Comprehensive Plan Update*.

²⁰³ University of Washington Urban Design & Planning Studio "Community Engagement for Coastal Resilience."



Figure 3.6. Important features, assets, and infrastructure in the study area of South Beach. More detailed information about values and assets can be found in the report from the 2018 studio entitled “Localizing Hazard Mitigation Recommendations for Westport’s Comprehensive Plan Update”.²⁰⁴

²⁰⁴ University of Washington Urban Design & Planning Studio “Community Engagement for Coastal Resilience,” *Localizing Hazard Mitigation: Recommendations for Westport’s Comprehensive Plan Update* (University of

3.4 Hazard Mitigation Planning in South Beach

South Beach stakeholders interested in reducing the effects of natural hazards and helping protect life, property, and the economy have participated in the wider Grays Harbor County's hazard planning workshops.²⁰⁵ The 2018 Grays Harbor County Hazard Mitigation Plan is an update to the 2011 Plan that was the first of its kind in the County. The County had determined there was an urgent need to increase public awareness of hazards and the associated risks.

Public involvement in the planning process was varied and included multiple types of media to reach individuals and agencies.²⁰⁶ In order to secure increased involvement the County and planning partners paired meetings with existing council meetings and commission meetings, hosted online meetings, and organized conference calls. The public outreach strategy included a questionnaire about general perceptions of risk and support for hazard mitigation, newsletter articles about mitigation efforts, recordings of meetings, and local radio segments. The questionnaire also allowed for public comments throughout the process which were incorporated where appropriate. A website was also developed to update the public throughout the process and solicit input. Hazard maps were also available on the website. The website was designed to remain active after the plan was finalized in order to post about successful mitigation projects and future plan updates.²⁰⁷

Invitations were extended to the general public to learn about emergency management where risk data and hazard maps were presented, as seen in Figure 3.7 below.²⁰⁸ There were various meeting formats which encouraged attendees to analyze maps and handouts. Posters included hazards of concern, areas of impact, specific structure loss data, and general hazard mitigation planning data. Presentations were available both on PowerPoint and in hard copy for review. Handouts included overviews of risk, maps, and disaster history data in Grays Harbor County. One event in particular was held at the Ocosta School District's vertical evacuation site where attendees could tour the facility and learn about earthquake and tsunami hazards.²⁰⁹

Washington, 2018), https://mitigate.be.uw.edu/wp-content/uploads/sites/70/2021/03/FullReport_WestportCoastalResiliencyReport_11.22.19.pdf.

²⁰⁵ Bridgeview Consulting, "Grays Harbor County 2018 Multi-Jurisdiction Hazard Mitigation Plan Update Volume 1: Planning-Area-Wide Elements."

²⁰⁶ Bridgeview Consulting.

²⁰⁷ Bridgeview Consulting.

²⁰⁸ Bridgeview Consulting, 2-5.

²⁰⁹ Bridgeview Consulting, "Grays Harbor County 2018 Multi-Jurisdiction Hazard Mitigation Plan Update Volume 1: Planning-Area-Wide Elements," July 2018, https://cms5.revize.com/revize/graysharborcounty/Emergency%20Management/Planning/Grays%20Harbor%20County%20HMP_Plan_Final_2018.pdf, 2-19.



Figure 3.7. Preparedness Expo Posters displaying hazards and impacts.²¹⁰

The 2018 Grays Harbor County Hazard Mitigation Plan attempted to engage as many citizens as possible using multiple formats, which they note is important given the geographically remote areas in the county.²¹¹ A geonarrative has the ability to support many if not all of these functions, including hosting a questionnaire, as done in the soil science course,²¹² audio recordings, maps, posters, handouts, and more. A geonarrative would be particularly useful for distributing information about emergency management, risk data, and hazard maps for individuals not able to attend in-person public meetings. A geonarrative could be a centralized way for stakeholders to engage with the same materials but in an interactive format and on their own time.

3.5 Prior Engagement in South Beach

At the time the first Grays Harbor Hazard Mitigation Plan was finalized, the relationship between the University of Washington and the community of South Beach was beginning. Today, there is an established relationship. There have been multiple projects related to hazard mitigation planning that have involved the community in the decision making process. This thesis builds on the work of these projects.

²¹⁰ Bridgeview Consulting, 2-20.

²¹¹ Bridgeview Consulting, 2-8.

²¹² M. P. Cope et al., “Developing and Evaluating an ESRI Story Map as an Educational Tool,” *Natural Sciences Education* 47, no. 1 (2018): 180008, <https://doi.org/10.4195/nse2018.04.0008>.

Led by the Washington State Emergency Management Division, Project Safe Haven is a community focused and driven initiative.²¹³ Collaborating with the Washington State Department of Natural Resources and the University of Washington’s Institute for Hazard Mitigation Planning and Research, the project used a public process to identify locations for potential vertical evacuation structures. In 2011 a report was produced outlining recommended tsunami vertical evacuation structure locations for the City of Westport.²¹⁴

In the fall of 2018 the City of Westport partnered with the University of Washington’s Department of Urban Design and Planning for a studio. The multi-disciplinary studio reviewed the long-term planning goals for the community and curated strategies for the Westport Comprehensive Plan.²¹⁵ Through community partner and public workshops, and coordination with visiting Tohoku scholars, the studio produced a report of community values, assets and recommendations for the Comprehensive Plan Update.²¹⁶ This studio built on Project Safe Haven by inviting community members to consider not only how to evacuate from a tsunami, but also how to shape community development so that it would be less vulnerable to a tsunami in the first place and be able to recover and rebuild, given permanent changes in the coastline after either co-seismic subsidence or sea level rise. This thesis builds on this studio by integrating coseismic subsidence with sea level rise, and presents that information in a way that can correspond with different time horizons for planning.

The American Roundtable project in South Beach advanced the work of the 2018 studio by presenting environmental change historically.²¹⁷ The American Roundtable was an initiative by the Architectural League of New York to pursue on-the-ground perspectives. The American Roundtable Project accepts proposals for community specific reports on the dynamics of community and its relationship to the environment. Led by Dr. Daniel Abramson and Robert Hutchison, a report on the greater South Beach area was produced in 2020²¹⁸ and served as a foundational element for a 2021 studio as a point of intimate understanding of place and identity for the community of Westport and South Beach. The American Roundtable project provided a foundation found this thesis which generated maps of historic coastline change that can be

²¹³ Grays Harbor County Emergency Management, “Project Safe Haven: Grays Harbor County,” 2011, <https://mil.wa.gov/asset/5ba41ffb35f02>.

²¹⁴ Grays Harbor County Emergency Management.

²¹⁵ University of Washington Urban Design & Planning Studio “Community Engagement for Coastal Resilience,” *Localizing Hazard Mitigation: Recommendations for Westport’s Comprehensive Plan Update* (University of Washington, 2018), https://mitigate.be.uw.edu/wp-content/uploads/sites/70/2021/03/FullReport_WestportCoastalResiliencyReport_11.22.19.pdf.

²¹⁶ University of Washington Urban Design & Planning Studio.

²¹⁷ Architectural League of New York, “American Roundtable: South Beach, Washington,” The Architectural League of New York, 2021, <https://archleague.org/article/south-beach-washington-coastal-ecology/>.

²¹⁸ Architectural League of New York, “American Roundtable: South Beach, Washington,” The Architectural League of New York, 2021, <https://archleague.org/article/south-beach-washington-coastal-ecology/>.

overlaid with the maps of future coastline change in a set of unified backward- and forward-looking geonarratives.

This thesis originated from a studio that took place at the beginning of 2021 which focused on future environmental changes in the South Beach community.²¹⁹ Students proposed design and programmatic interventions for the South Beach community that would increase resilience in the face of earthquakes, tsunamis, and sea level rise. Students approached the natural hazards facing the community from architectural, landscape, and planning perspectives.²²⁰ This thesis takes the planning perspective a step farther, by proposing the use of these materials in a workshop employing geonarratives.

Awarded by the National Science Foundation in 2019 and sponsored by the University of Washington, Dr. Daniel Abramson is currently leading a project called CoPe EAGER: Coastal Hazard Planning in Time.²²¹ The project aims to develop new communication tools for coastal resilience. Through the application of scientific consensus and investigation in partner communities, the research team hopes to produce a tool in the form of an interactive geonarrative for public education, community planning, and emergency preparedness workshops. The project focuses on subduction hazard and risk along the Cascadia Subduction Zone.²²² This thesis contributes to the information that will be presented to the community in one of three geonarratives.

Chapter 4: Developing Maps for Geonarratives of South Beach, Washington

4.1 Future Coastline Change in South Beach

Future environmental hazard maps for South Beach used models of the same types of hazards that were discussed in previous engagements with the community, starting in 2018. The hazards modeled include coseismic subsidence, earthquake-generated tsunami inundation, and sea level rise. In 2018, public workshop participants analyzed and discussed three sets of hazard scenarios: several sea level rise scenarios with varying probabilities and time horizons, and two CSZ earthquake scenarios, the “M1” and “L1”, both of which caused coseismic subsidence and

²¹⁹ ArcDR3, “ArcDR3 Regenerative Urbanism Studio ‘Water’ 2020-2021 Urban Design and Planning / Architecture @ The University of Washington,” ArcDR3, 2021, <https://xlab.aud.ucla.edu/irides-tohoku-arcdr3/studio/washington-seattle-the-university-of-washington/>

²²⁰ ArcDR3.

²²¹ Daniel Abramson et al., “CoPe EAGER: Coastal Hazard Planning in Time” (National Science Foundation Award #1940024, 2019), Abstract available at https://www.nsf.gov/awardsearch/showAward?AWD_ID=1940024.

²²² Daniel Abramson et al.

tsunami inundation. The M1 earthquake scenario, a moderately severe magnitude 8.9 event, is similar to the most recent CSZ earthquake in 1700 and has an average recurrence interval of 500 years.^{223,224} The L1 earthquake scenario, a more severe “maximum considered” 9.0 event with an average recurrence interval of 2,500 years.²²⁵ The L1 scenario is currently the basis for Washington’s tsunami inundation maps, evacuation planning, and critical facilities structural design.²²⁶ The information in this thesis is intended for use with South Beach residents. Therefore, this research has used the same hazards to develop future scenarios that were used in previous engagements with South Beach residents in the 2018-2019 City of Westport’s Comprehensive Plan update: an M1 earthquake, an L1 earthquake, the resultant subsidence and tsunami inundations, and several sea level rise cases.

Three kinds of coastline change that considered these hazards were mapped in this section. The first depicts tidal flooding under today’s conditions, seen in Figure 4.5. King tides affect South Beach seasonally and while they recur frequently these visual representations of tidal fluctuation are very predictable and not very severe. Future tsunami inundation maps depict temporary but severe inundation following a CSZ earthquake. Tsunami inundation shown in Figures 4.8 and 4.9 is extremely rare, occurring on the timescale of centuries. The onset of such inundation is unpredictable until an earthquake occurs, at which time South Beach will be inundated less than 30 minutes later. This severe flooding will retreat, unlike sea level rise. Sea level rise is much more predictable than a tsunami or king tide and as it rises will continue to affect South Beach over a much longer timescale. Sea level rise will also suddenly become much more severe in South Beach due to coseismic subsidence following a CSZ earthquake. Land loss, depicted in maps in Figures 4.10 and 4.11, will be a long-term reality for residents.

The water level at any time in South Beach is typically a function of astronomical tides and weather-driven storm surge operating on a mean local sea level.²²⁷ The fluctuation of the tide in Westport since 2005 can be seen in Figure 4.1 below.²²⁸ This histogram depicts the fluctuation in reference to today’s mean high water (MHW) level, seen here as “0 feet”, which is a tidal datum

²²³ University of Washington Urban Design & Planning Studio “Community Engagement for Coastal Resilience,” *Localizing Hazard Mitigation: Recommendations for Westport’s Comprehensive Plan Update* (University of Washington, 2018), https://mitigate.be.uw.edu/wp-content/uploads/sites/70/2021/03/FullReport_WestportCoastalResiliencyReport_11.22.19.pdf.

²²⁴ Robert C. Witter et al., “Simulated Tsunami Inundation for a Range of Cascadia Megathrust Earthquake Scenarios at Bandon, Oregon, USA,” *Geosphere (Boulder, Colo.)* 9, no. 6 (2013): 1783–1803, <https://doi.org/10.1130/GES00899.1>.

²²⁵ D.W. Eungard et al., “Tsunami Hazard Maps of Southwest Washington — Model Results from a ~2,500-Year Cascadia Subduction Zone Earthquake Scenario: Washington Geological Survey Map Series 2018-01,” March 2018.

²²⁶ University of Washington Urban Design & Planning Studio “Community Engagement for Coastal Resilience.”

²²⁷ National Oceanic and Atmospheric Administration, “Extreme Water Levels,” NOAA Tides & Currents, accessed June 16, 2021, <https://tidesandcurrents.noaa.gov/est/>.

²²⁸ National Oceanic and Atmospheric Administration, “Water Levels - NOAA Tides & Currents,” 2021, <https://tidesandcurrents.noaa.gov/waterlevels.html?id=9441102&units=metric&bdate=20200101&edate=20201231&timezone=LST/LDT&datum=MHHW&interval=h&action=>.

representing the average daily high water heights for the National Tidal Datum Epoch.²²⁹ The highest water level on record in Westport, dating back to 2005, is 4.25 feet above MHW. Peaks in the predicted high tide are the highest of the year, known as perigean spring tides or king tides.²³⁰ King tides bring unusually high water levels which cause local flooding in South Beach and adjacent areas (Figure 4.2). As sea level rises, peak water levels driven by tides and storm surge will increase. As a result, high tides will reach higher levels and flood further inland than in the past.²³¹ Today’s king tides are therefore a glimpse of future everyday water levels with sea level rise.²³²

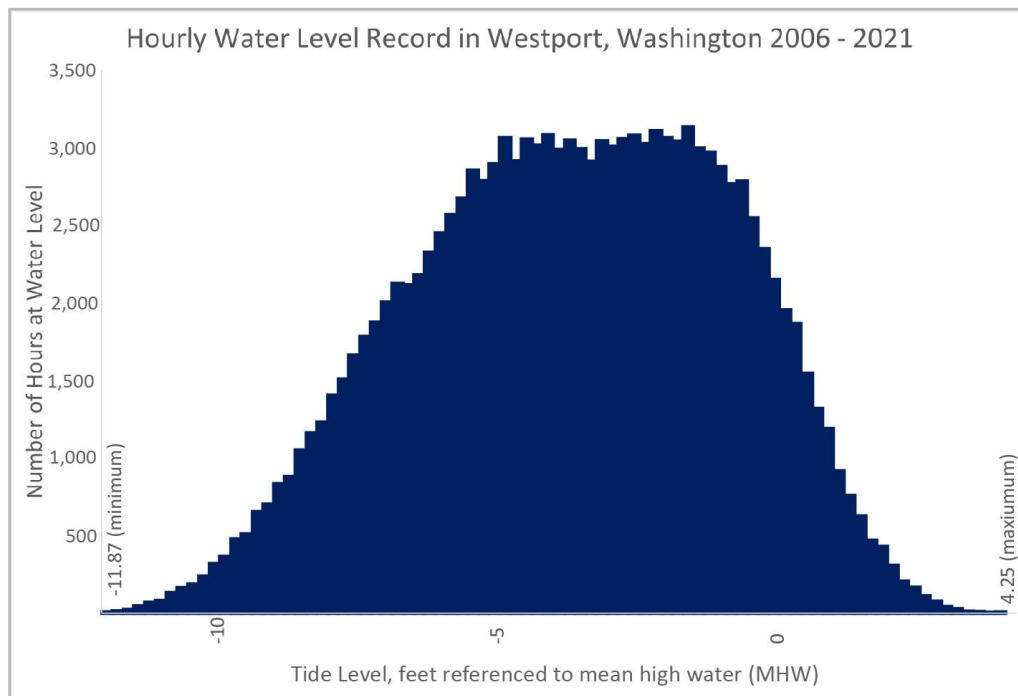


Figure 4.1. Histogram of the hourly tide gauge water level record in Westport, Washington between 2006 and April, 2021. Data reproduced from NOAA’s Tides and Currents Station 9441102 Westport, WA.²³³

²²⁹ National Oceanic and Atmospheric Administration, “Glossary - NOAA Shoreline Website,” accessed May 12, 2021, <https://shoreline.noaa.gov/glossary.html>.

²³⁰ United States Environmental Protection Agency, “King Tides and Climate Change,” Overviews and Factsheets, US EPA, March 21, 2014, <https://www.epa.gov/cre/king-tides-and-climate-change>.

²³¹ United States Environmental Protection Agency.

²³² United States Environmental Protection Agency.

²³³ National Oceanic and Atmospheric Administration, “Water Levels - NOAA Tides & Currents,” 2021, <https://tidesandcurrents.noaa.gov/waterlevels.html?id=9441102&units=metric&bdate=20200101&edate=20201231&timezone=LST/LDT&datum=MHHW&interval=h&action=>



Figure 4.2. King tide in Westport, Washington on November 23, 2020.²³⁴

Given the multi-hazard focus of this analysis, and the long-standing use of MHW as a reference datum for tsunami hazard assessment modeling and mapping, water level scenarios used in this analysis are described in reference to the local MHW tidal datum. Water level scenarios are coupled with sea level rise projections (Miller et al 2018) to describe both their contemporary and future likelihood of occurrence. For example, the highest value selected, MHW + 7 feet, has never been experienced in Westport, as indicated in Table 4.1. However, towards the end of the century as sea level rises, this water level may be experienced relatively frequently, as seen in Table 4.2. On the other end of the spectrum, the lowest value selected, MHW - 3 feet, is a frequent tide level today. Between 2005 and 2021, 10.7% of the time the tide has been 3 feet below MHW, as seen in Table 4.1. This tide level will become less common as sea level rises, as seen in Table 4.2. The scenario MHW + 5 feet is 0.75 feet higher than the highest recorded water level on record in Westport since 2005, what residents may refer to as a king tide event or storm surge. The specific water level scenarios were selected with input from Ian Miller, Frank Gonzalez, Randy LeVeque, and two local stakeholders, Kevin Goodrich, City of Westport Public Works Director, and John Shaw, South Beach Historical Society Executive Director. From a historical perspective, John Shaw noted that while king tide events have short durations, historically they have caused the most damage. The water level MHW + 5 feet was included with this in mind. From a future perspective, Kevin Goodrich noted that higher water level scenarios would be helpful for infrastructure planning. A particularly high water level, MHW + 7 feet, was included with this in mind.

²³⁴ “King Tides in Westport,” Experience Westport, Washington, accessed May 12, 2021, <https://www.experiencwestport.com/westport-blog/king-tides-in-westport>.

The water levels selected are each combined with the M1 and L1 earthquake scenarios to create a total of ten scenarios:

- M1 CSZ earthquake; water level MHW - 3 feet
- M1 CSZ earthquake; water level MHW + 0 feet
- M1 CSZ earthquake; water level MHW + 3 feet
- M1 CSZ earthquake; water level MHW + 5 feet
- M1 CSZ earthquake; water level MHW + 7 feet
- L1 CSZ earthquake; water level MHW - 3 feet
- L1 CSZ earthquake; water level MHW + 0 feet
- L1 CSZ earthquake; water level MHW + 3 feet
- L1 CSZ earthquake; water level MHW + 5 feet
- L1 CSZ earthquake; water level MHW + 7 feet

The probability of these water levels occurring is a function of four factors: vertical land movement, astronomical tidal fluctuations, storm surges, and sea level rise. The probability of sea level rise under a high greenhouse gas scenario can be seen in Table 4.3. Vertical land movement in South Beach is the result of the CSZ. Currently, South Beach is experiencing uplift, however, during a CSZ earthquake South Beach will first subside then, very slowly over decades to centuries, undergo uplift again.^{235,236} The amount of subsidence will vary across the landscape, depending on details of the earthquake deformation, as discussed in section 4.1.3.

Water Level Scenario	Historic Occurrence (%)
MHW + 7 ft	0.0
MHW + 5 ft	0.0
MHW + 3 ft	0.2
MHW + 0 ft	7.7
MHW - 3 ft	10.7

Table 4.1. Selected water level scenarios and historical frequency based on hourly water level record in Westport between 2005 and April, 2021. Reproduced by permission of Ian Miller.

²³⁵ Miller et al.

²³⁶ Pacific Northwest Seismic Network, “Land Level Change,” Pacific Northwest Seismic Network, accessed June 16, 2021, <https://pnsn.org/outreach/earthquakesources/csz/landlevelchange>.

Water Level Scenario Likelihood (%)	After 1 ft SLR	After 2 ft SLR	After 3 ft SLR	After 4 ft SLR	After 5 ft SLR	After 6 ft SLR	After 7 ft SLR
MHW + 7 ft	0.0	0.0	0.0	0.2	1.3	3.9	7.7
MHW + 5 ft	0.0	0.2	1.3	3.9	7.7	10.2	10.8
MHW + 3 ft	1.3	3.9	7.7	10.2	10.8	10.7	10.7
MHW + 0 ft	10.2	10.8	10.7	10.7	10.2	8.4	6.7
MHW - 3 ft	10.7	10.2	8.4	6.7	4.5	2.4	1.0

Table 4.2. Selected water level scenario likelihood under different sea level rise scenarios based on historical water level record in Westport. Values extrapolated from the hourly water level record from the Westport tide gauge between 2005 and April, 2021. Values 6 inches greater than and less than each water level relative to MHW are expressed in terms of the percent total of the record. Reproduced by permission of Ian Miller.

SLR Probability (%), RCP 8.5	1 ft SLR	2 ft SLR	3 ft SLR	4 ft SLR	5 ft SLR	6 ft SLR	7 ft SLR
2050	2	0	0	0	0	0	0
2100	77	27	5	1	1	0	0
2150	92	70	41	20	9	5	3

Table 4.3. Sea level rise likelihood of exceedance in the Lower Chehalis region of Grays Harbor County under a high greenhouse gas scenario (RCP 8.5).²³⁷ Values are extracted from the University of Washington’s Climate Impacts Group Interactive Sea level Rise Data Visualization tool. Sea level rise projections include relative sea level changes due to inter-seismic deformation, not co-seismic land level changes. Reproduced by permission of Ian Miller.

A key element in hazard management and mitigation is to fully account for uncertainty. A scenario planning exercise could provide a tool to address the limit of predictions and may be an advantageous method of approaching the information in this thesis. As previously mentioned, by integrating predictive modeling with scenario planning would allow to expand the boundary conditions of interactions between significant, uncertain drivers such as earthquakes, earthquake-generated tsunamis, and water levels in South Beach. For instance, while the predicted earthquake scenarios M1 and L1 are used to model potential, alternative futures in South Beach,

²³⁷ I Miller et al., “Projected Sea Level Rise for Washington State - A 2018 Assessment” (Washington Coastal Resilience Project, July 2019).

an S or XXL event could generate unforeseen future conditions. (See Figure 4.3). A scenario planning exercise that includes the drivers explored in this thesis would allow planners to consider a more full range of plausible, alternative futures and help shape robust resilience strategies for the community.

4.1.1 Methodology

The study area selected is designed to be familiar to participants that attended previous UW engagements. The selected area includes the City of Westport, the community of Grayland, and the Elk River and Johns River estuaries. Stakeholders will be interested in areas with heavy investment, such as the Westport Marina, as well as the Johns River estuary where evidence of onshore shaking, liquefaction, and ground subsidence supports the theory of multiple past great Cascadia earthquake events.²³⁸

Members of the UW's Tsunami Modeling Group, Frank Gonzalez and Randy LeVeque, simulated the two selected earthquake scenarios, M1 and L1, with the GeoClaw model.²³⁹ The GeoClaw model code, developed with Clawpack's Version 5.7.1²⁴⁰, has been validated for tsunami modeling by the US National Tsunami Hazard Mitigation Program (NTHMP) after conducting multiple benchmark tests as part of an NTHMP benchmarking workshop.²⁴¹ GeoClaw was also used to model and assess the tsunami hazard in the development of the tsunami vertical evacuation structure at the Ocosta Elementary School in South Beach.²⁴² The subsidence in South Beach was obtained by applying the earthquake crustal deformation M1 and L1 models developed by Witter, et al (2013) to the existing topography.²⁴³ The UW Tsunami Modeling Group conducted simulations which modeled the generation, propagation, and inundation of the area over a period of 8 hours. Tsunamis were then modeled over an eight-hour simulation. Each model run included a different background water level (BWL) relative to MHW which can be interpreted as the sum of two factors - tide level and sea level rise. The model produced data reflecting tsunami flooding depth and land subsidence in the study area which were then interpreted in maps for this research and future community use.

²³⁸ Brian F. Atwater et al., "The Orphan Tsunami of 1700—Japanese Clues to a Parent Earthquake in North America," USGS Numbered Series, *The Orphan Tsunami of 1700—Japanese Clues to a Parent Earthquake in North America*, Professional Paper 1707, 2005, <https://doi.org/10.3133/pp1707>, 22.

²³⁹ Randall J. LeVeque, David L. George, and Marsha J. Berger, "Tsunami Modelling with Adaptively Refined Finite Volume Methods," *Acta Numerica* 20 (2011): 211–89, <https://doi.org/10.1017/S0962492911000043>.

²⁴⁰ Clawpack Development Team, *Clawpack Version 5.7.1*, 2020, <http://www.clawpack.org>.

²⁴¹ NTHMP, "Proceedings and Results of the 2011 NTHMP Model Benchmarking Workshop," 2011, 437.

²⁴² Frank Gonzalez, Randall J. LeVeque, and Loyce Adams, "Tsunami Hazard Assessment of the Ocosta School Site in Westport, WA," September 11, 2013, <https://digital.lib.washington.edu:443/researchworks/handle/1773/24054>.

²⁴³ Robert C. Witter et al., "Simulated Tsunami Inundation for a Range of Cascadia Megathrust Earthquake Scenarios at Bandon, Oregon, USA," *Geosphere (Boulder, Colo.)* 9, no. 6 (2013): 1783–1803, <https://doi.org/10.1130/GES00899.1>.

Two sets of maps were developed for each post-earthquake scenario, the first reflecting maximum tsunami inundation over an eight hour period. The second set of maps reflect subsidence after an earthquake and the water level for that scenario, after the tsunami has retreated. The outputs from the model were converted to a raster format and then polygon format in ESRI's ArcMap. Symbology was designed for both the subsidence maps and tsunami inundation maps to be useful for community members in a workshop setting. For example, the tsunami inundation gradient symbology was based on tsunami inundation maps from the 2018 workshops. Additionally, an outline of the current shoreline is overlaid on water level maps in order to give viewers a reference for the change presented by subsidence and water level changes.

Finally, a spatial analysis of each map was conducted in order to compare scenarios. The areas of South Beach that are not inundated by tsunami waters were collected and highlighted. This information is valuable for comparison of the severity of each tsunami scenario. Similarly, land loss in South Beach was collected and analyzed.

Analysis of tsunami inundation is depicted relative to a 'king scenario'. The water level of the king scenario is 5 feet higher than contemporary MHW. The highest water level recorded in Westport is 4.25 feet higher than contemporary MHW. While a water level 0.75 feet higher than this has never been experienced in South Beach, this water level is used to represent and discuss the upper limit of a tsunami impact under extreme conditions today.

While the full suite of water level scenarios was used to develop and analyze maps related to tsunami inundation, the choice was made to eliminate the MHW - 3 feet water level for land loss maps. As seen in Table 4.3, the probability of at least one foot of sea level rise by 2150 is 92%. Therefore, water levels will be increasing over the long-term which is represented by the remainder of the water level scenarios.

4.1.2 Limitations and Assumptions

The future coastline change maps developed for this thesis are limited by several factors. Some viewers may be interested in understanding what South Beach will look like under various sea level rise conditions where coseismic subsidence is not modeled. These conditions would be interesting to compare to maps found in Section 4.1.3 and can be viewed in the Climate Impacts Group's recently developed interactive tool Sea Level Rise Visualization.²⁴⁴ This data is locally specific, and in South Beach takes into account uplift due to the CSZ.

²⁴⁴ University of Washington Climate Impacts Group, "Interactive Sea Level Rise Data Visualizations," *Climate Impacts Group* (blog), accessed February 11, 2021, <https://cig.uw.edu/our-work/applied-research/wcrp/sea-level-rise-data-visualization/>.

A finite number of CSZ earthquake scenarios and water levels were selected for development and analysis for this project. These scenarios do not represent the full range of potential futures in South Beach. The selected M1 and L1 earthquakes are just two of many possible earthquakes along the CSZ, some of which can be seen in Figure 4.3 below.

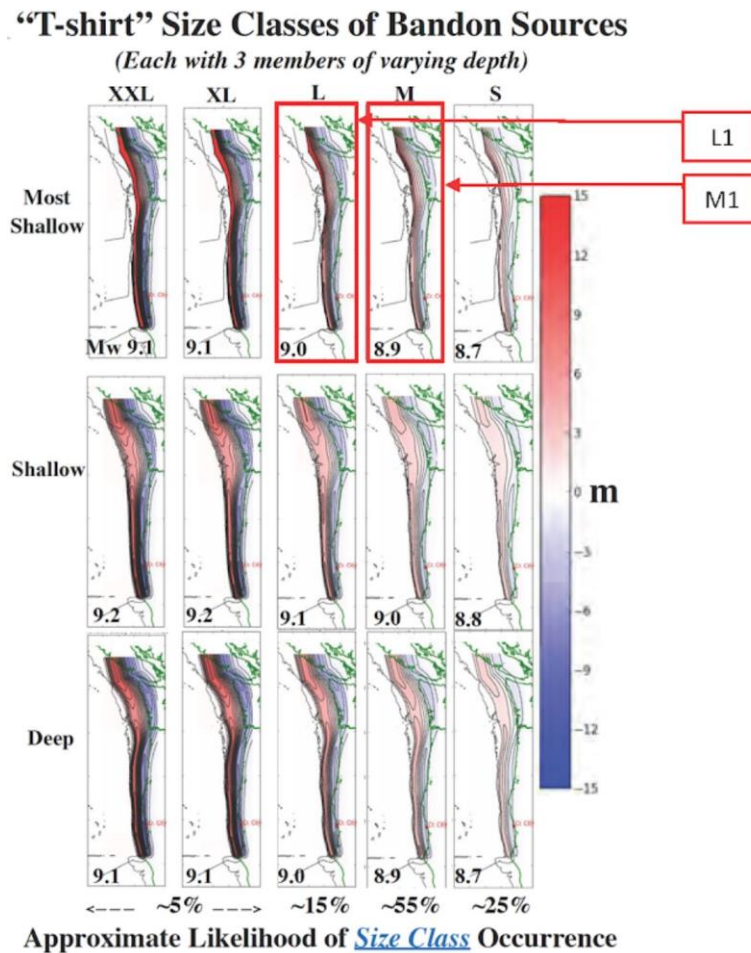


Figure 4.3. Vertical crustal deformation fields of the suite of 15 CSZ earthquakes developed by Witter, et al. (2013) for 5 Size Classes expressed as T-shirt sizes and 3 Fault Geometry Classes labeled qualitatively with the relative depth of the fault. The moment magnitude, M_w , below each panel is listed in Table 4.3 of Witter, et al. (2013).²⁴⁵ The "relative likelihood" estimates for each Size Class shown are derived by summing the associated weights in that table assigned to each of the 15 logic tree branches, expressing this as a percentage contribution to the sum of all 15 weights, and rounding to the nearest multiple of 5. Note that these "relative likelihood" estimates are not intended to represent the frequency of occurrence nor the annual probability that a particular earthquake scenario will happen. Figure courtesy of Frank Gonzalez.

²⁴⁵ Robert C. Witter et al., "Simulated Tsunami Inundation for a Range of Cascadia Megathrust Earthquake Scenarios at Bandon, Oregon, USA," *Geosphere (Boulder, Colo.)* 9, no. 6 (2013): 1783–1803, <https://doi.org/10.1130/GES00899.1>.

The coseismic subsidence data reflected in all future hazard maps pertains to two specific scenarios that are based on a set of assumptions that include fault geometry, slip range, rupture geometry, where the earthquake is located, the distance from the coastline, the maximum coseismic fault slip, and the size of the rupture area. These specific assumptions are likely to differ from an actual CSZ earthquake event.

As with earthquake scenarios, the water levels selected represent only some of the many potential base water levels possible when an earthquake occurs. For instance, if an earthquake occurred in 2021 at mean low water (MLW), the water level would be 7 feet below MHW,²⁴⁶ even lower than the scenario MHW - 3 feet. This could create a less severe tsunami in South Beach which would greatly reduce the impact but could damage coastal infrastructure. The water levels selected were chosen with input from a local stakeholder, who is interested in future scenarios for infrastructure planning purposes.

The probabilities associated with sea level rise depicted throughout this section are based on the data from *Projected Sea Level Rise for Washington State - A 2018 Assessment* for the Lower Chehalis Grays Harbor County region estimated at 46.9°, -124.1°.²⁴⁷ Sea level rise for this project is only discussed in terms of the high greenhouse gas scenario, RCP 8.5, and the likelihoods for different sea level rise scenarios shown in Table 4.3 are estimates associated with RCP 8.5. This greenhouse gas scenario is one of many possible future greenhouse gas emission possibilities. Should greenhouse gas emissions slow, probabilities associated with the low greenhouse gas scenario may be more appropriate.

Several assumptions were made to generate the GeoClaw simulations that may differ greatly from a future earthquake event. A full-length rupture was modeled with GeoClaw which may or may not occur. The model does not take into account scouring, deposition or weathering of the topography nor the influence of any man-made structures on the evolution of the tsunami. The subsidence and water level maps, therefore, do not take into account any topographic changes that may occur during or after a tsunami which could greatly alter the landscape of South Beach.

²⁴⁶ National Oceanic and Atmospheric Administration, “Datums - NOAA Tides & Currents,” National Oceanic and Atmospheric Administration Tides & Currents, September 29, 2020, <https://tidesandcurrents.noaa.gov/datums.html?datum=MHW&units=0&epoch=0&id=9441102&name=Westport&state=WA>.

²⁴⁷ University of Washington Climate Impacts Group, “Interactive Sea Level Rise Data Visualizations,” *Climate Impacts Group* (blog), accessed February 11, 2021, <https://cig.uw.edu/our-work/applied-research/wcrp/sea-level-rise-data-visualization/>.

Several more important limitations of these maps should be noted:

- The model results and associated maps are informal, preliminary products that were generated to support general, qualitative workshop discussions and they do not represent final, quantitative guidance for planning.
- The M1 and L1 earthquake source models fail to meet guidelines published by the American Society of Civil Engineers for the design and structural engineering of vertical evacuation structures (VES).²⁴⁸
- Model limitations include important uncertainties in the magnitude and deformation patterns of the M1 and L1 models as well as other model parameters such as friction; furthermore, the model does not account for a number of physical processes, including the effects of erosion and deposition, current variations, the presence of structures, and the impact of debris on structures.

Despite the limitations of the maps in section 4.1.3, future hazard maps could still be useful for planning. Each map depicts a plausible future of South Beach and therefore could be useful for long-term planning. Public investments in infrastructure, such as schools and bridges, are long-lasting and should consider a range of future conditions, such as those depicted. Zoning and design standards also have long-lasting impacts in communities. Based on these maps and their limitations, local governments may choose to require higher development standards for residential structures or may rezone a commercial district to recreation space to prevent damage. That said, the maps in Section 4.1.3 could be intimidating to viewers and may inspire a range of responses from the community, therefore, it is particularly important that the extreme scenarios be contextualized appropriately with information throughout Chapter 4.1.

A key element in hazard management and mitigation is to fully account for uncertainty. A scenario planning exercise could provide a tool to address the limit of predictions and may be an advantageous method of approaching the information in this thesis. As previously mentioned, integrating predictive modeling with scenario planning would allow us to expand the boundary conditions of interactions between significant, uncertain drivers such as earthquakes, earthquake-generated tsunamis, and water levels in South Beach. For instance, while the predicted earthquake scenarios M1 and L1 are used to model potential, alternative futures in South Beach, an S or XXL event could generate unforeseen future conditions. (See Figure 4.3). A scenario planning exercise that includes the drivers explored in this thesis would allow planners to consider a more full range of plausible, alternative futures and help shape robust resilience strategies for the community.

²⁴⁸ American Society of Civil Engineers, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*, ASCE/SEI 7-16 (Reston, VA: American Society of Civil Engineers, 2017), <https://doi.org/10.1061/9780784414248>.

4.1.3 Findings

As can be seen in Figures 4.4 and 4.5 below, South Beach's topography is low lying along Grays Harbor and the Pacific Ocean. Westport and unincorporated Grays Harbor County near the SR-105 are already affected by events such as storm surge and king tides. The various types of topography today are used to residents' advantage. Residents and tourists alike enjoy searching for and farming shellfish along the ocean front beaches and in the bayside estuarial tidal wetlands and residents hunt and gather food in the forested hills. However, properties along the eastern bay side of the peninsula are already vulnerable to flooding while those on the oceanfront west side are vulnerable to erosion. Figure 4.5 indicates the potential reach of a king tide or storm surge event based on historical data but does not reflect the multiple hazards facing the community in the future - earthquakes, tsunamis, and sea level rise.

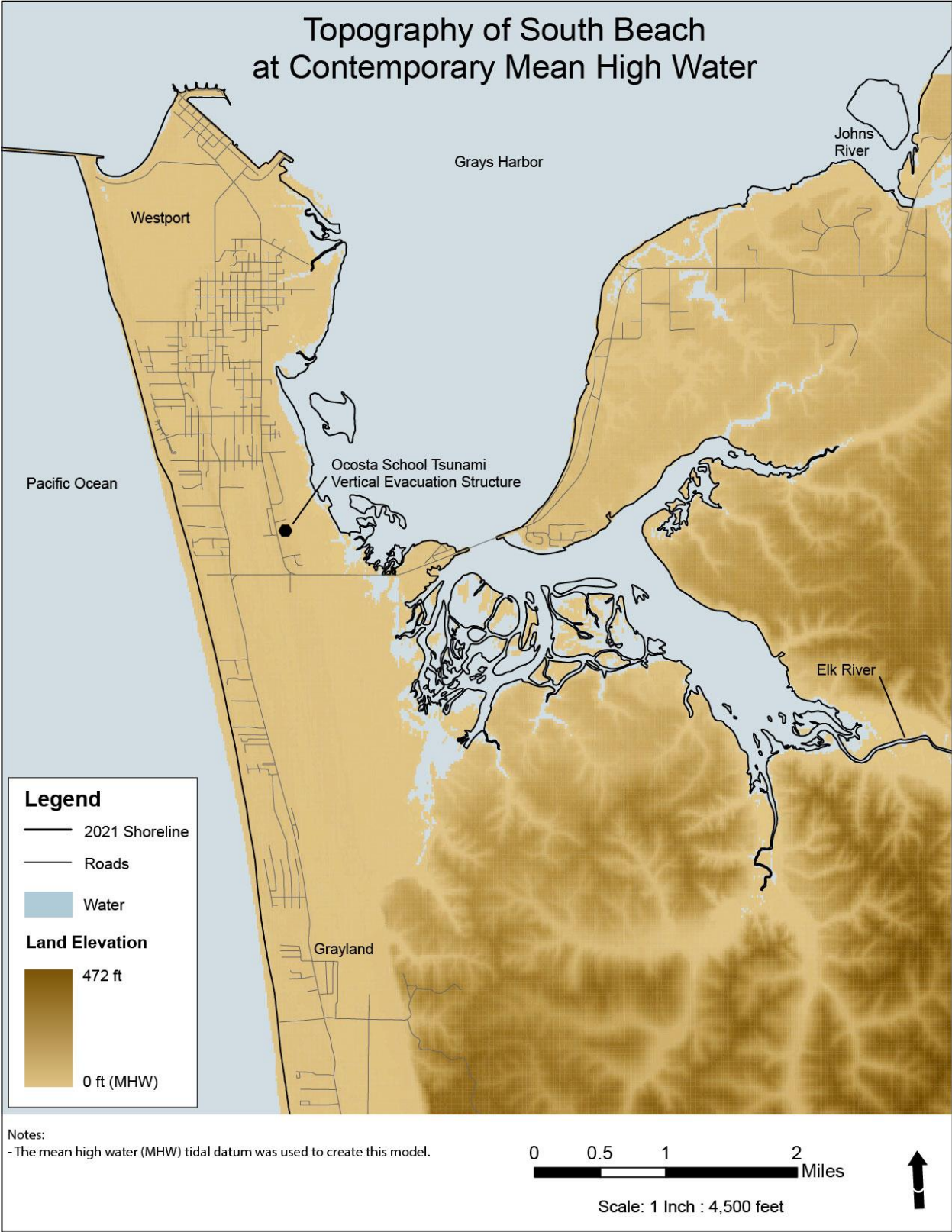


Figure 4.4. Topography of South Beach at contemporary mean high water.

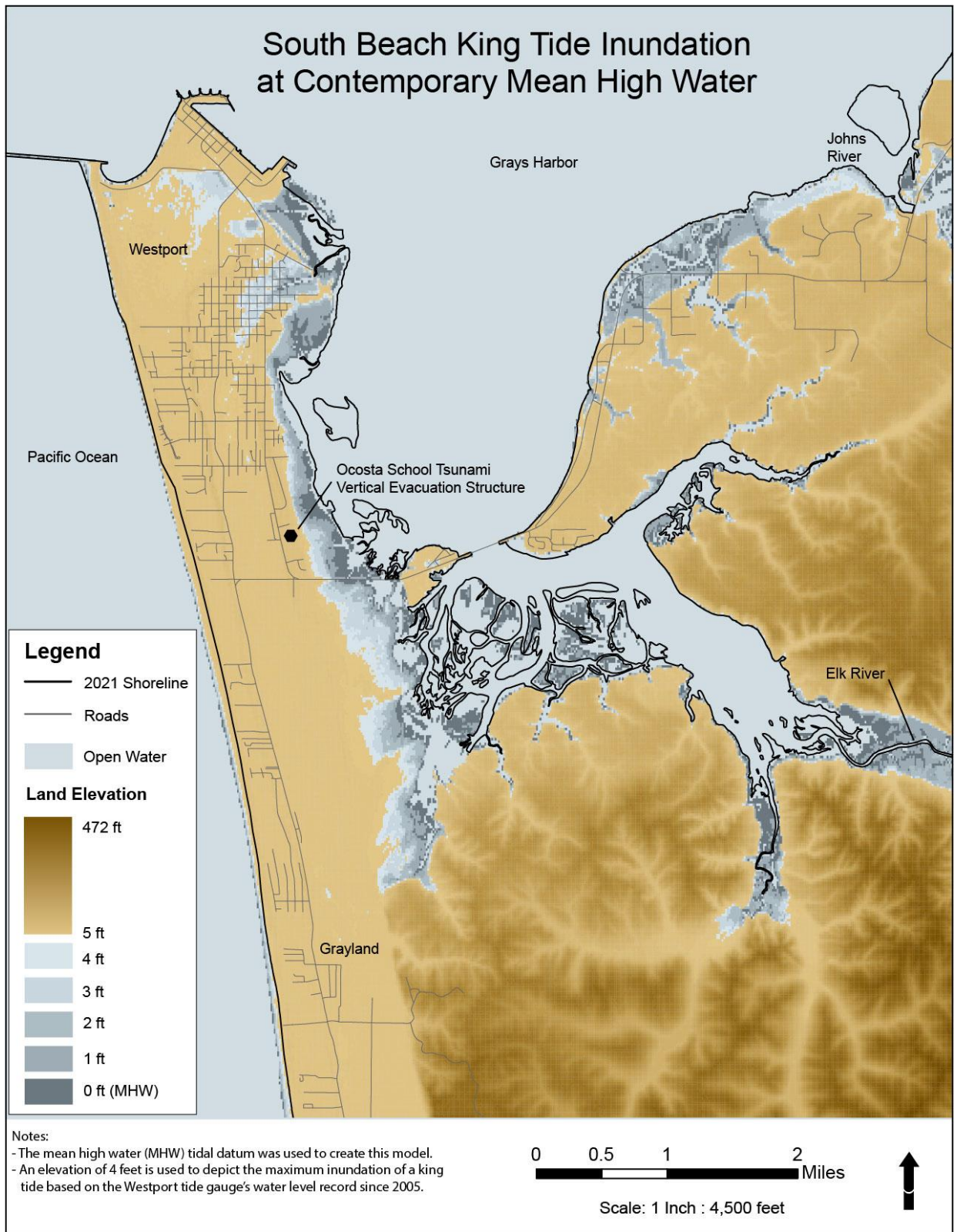


Figure 4.5. Today's pre-earthquake topography in South Beach. A gradient indicates where today's mean high water level is and up to where a king tide can reach - 4 feet above today's MHW.

A CSZ earthquake would change the topography in South Beach, possibly to a dramatic extent. This project maps the subsidence after an M1 and L1 earthquake event as modeled by Witter et al (2013).²⁴⁹ The modeled subsidence following each scenario can be seen in Figures 4.6 and 4.7 below. As indicated by the names, an L1 or ‘large’ earthquake will have a more devastating impact on the region than an M1 or ‘medium’ earthquake. South Beach will see a less severe but still significant amount of subsidence after an M1 earthquake. The area where the Ocosta School is located may drop on the order of 4 feet, for example, following the rupture. Following an L1 event, the same area may subside on the order of 6 feet. The topography is modeled to subside more in inland areas than along the Pacific Ocean coast. SR-105 connects South Beach to other communities such as Aberdeen. This vital road can be seen crossing Johns River in the upper righthand corner of Figures 4.6 and 4.7. This portion of road will see the greatest topographic changes, possibly on the order of 6 feet after the M1 earthquake and on the order of 9 feet under the L1 earthquake. A closed, damaged, or blocked road, such as SR-105, could isolate the South Beach population and prevent access from emergency service providers.²⁵⁰

²⁴⁹ Robert C. Witter et al., “Simulated Tsunami Inundation for a Range of Cascadia Megathrust Earthquake Scenarios at Bandon, Oregon, USA,” *Geosphere (Boulder, Colo.)* 9, no. 6 (2013): 1783–1803, <https://doi.org/10.1130/GES00899.1>.

²⁵⁰ Bridgeview Consulting, “Grays Harbor County 2018 Multi-Jurisdiction Hazard Mitigation Plan Update Volume 1: Planning-Area-Wide Elements,” July 2018, https://cms5.revize.com/revize/graysharborcounty/Emergency%20Management/Planning/Grays%20Harbor%20County%20HMP_Plan_Final_2018.pdf, 12-32.

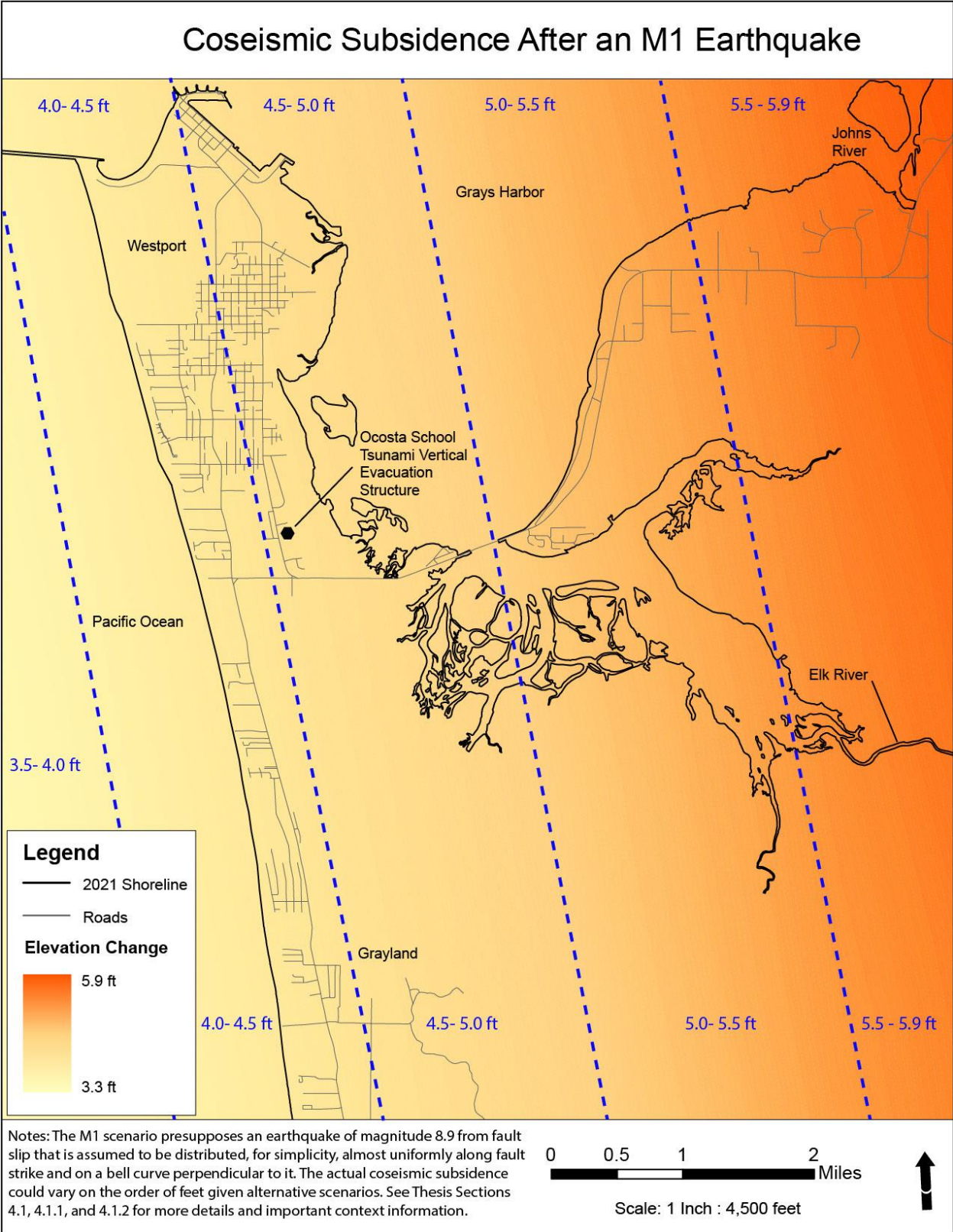


Figure 4.6. Coseismic subsidence after an M1 earthquake event.

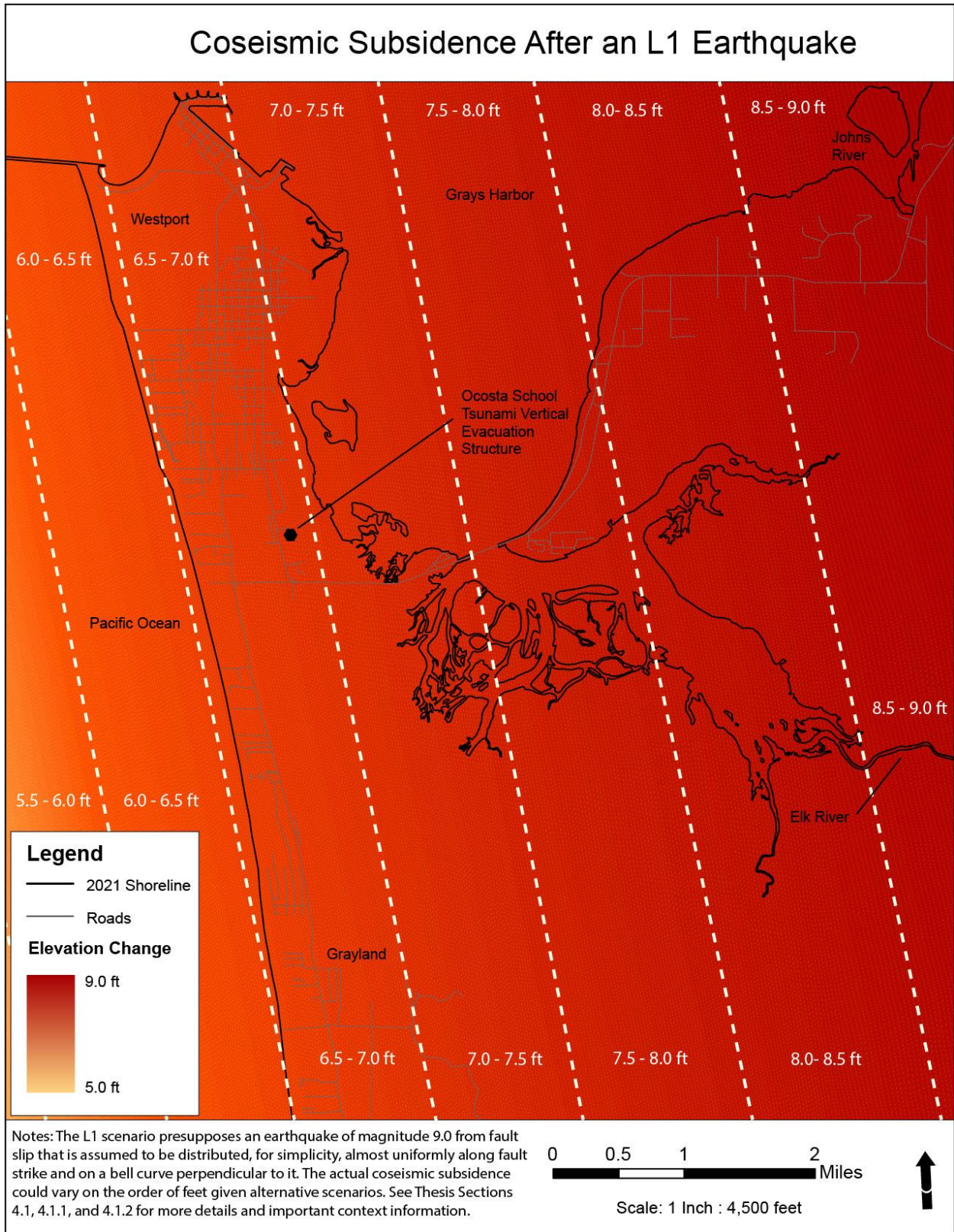


Figure 4.7. Coseismic subsidence after an L1 earthquake event.

Approximately 20 minutes after a CSZ megaquake, South Beach will be hit with a tsunami.²⁵¹ This research is specifically interested in the multiple, interconnected hazards facing South Beach which are connected to the dynamic water levels in the region. The tsunami inundation levels in South Beach will be a direct result of the earthquake magnitude and the water level when the tsunami approaches the shoreline. Background water levels were adjusted and coupled with the M1 and L1 earthquake scenarios to depict inundation under different water level scenarios, the results of which can be seen in Figures 4.8 and 4.9. Larger maps of each scenario can be found in Appendix A.

The least severe inundation occurs under an M1 earthquake scenario with the lowest water level, 3 feet below today's mean high water (MHW). There are pockets of the peninsula that would see up to 30 feet of inundation, particularly along the coast, jetty, and the edges of the marina. As the water level increases through each scenario, more of the peninsula is inundated and the inundation depth becomes greater. Inundation of up to 30 feet is widespread following an M1 event with a water level 7 feet above contemporary MHW. The coastal areas, jetty, and edges of the marina now see up to 40 feet of inundation. The Ocosta school in all M1 scenarios is free from inundation or will see up to 1 foot of tsunami water, under the MHW + 7 ft scenario.

As seen in Table 4.4, under the king scenario, 5 feet above contemporary MHW, 13.22 square miles of the study area remain free from tsunami inundation. These are largely located along the sand dunes of the peninsula and in the hills along the Elk River estuary. In comparison, a wider portion of these same areas remains dry in the least severe scenario. Additionally, portions of the marina area and Laidlaw Island, where SR-105 runs, remains free of tsunami flooding under the MHW - 3 ft scenario. These areas add up to 11.77% more dry area in South Beach than the king scenario.

²⁵¹ Grays Harbor County Emergency Management, "Project Safe Haven: Grays Harbor County," 2011, <https://mil.wa.gov/asset/5ba41ffb35f02>.

Earthquake Scenarios	Water Level Scenarios	Non-Inundated Area (square miles)	Percent Difference from King Scenario
M1	MHW - 3	14.99	11.77%
	MHW + 0	13.79	4.11%
	MHW + 3	13.41	1.41%
	MHW + 5 (King Scenario)	13.22	-
	MHW + 7	13.12	-0.82%
L1	MHW -3	13.60	2.77%
	MHW + 0	13.14	-0.61%
	MHW + 3	12.84	-3.00%
	MHW + 5	12.57	-5.20%
	MHW + 7	12.45	-6.20%

Table 4.4. Areas of South Beach not flooded by a tsunami under each scenario. A positive value in the final column indicates there is more area not inundated by tsunami waters than the king scenario. A negative value in the final column indicates the king tide scenario is inundated with less tsunami flooding than that scenario. For example, 6.20% more land is inundated with tsunami flooding in the MHW + 7 ft than the king scenario.

An L1 earthquake dramatically increases the severity and reach of tsunami waters in South Beach under the same water level scenarios. Under the least severe inundation following an L1 earthquake, inundation levels of up to 40 feet are very common. Pockets on the jetty and nearby beach will see inundation up to 50 feet. Once again, as the water level increases through each scenario, more of South Beach is inundated and the inundation depth becomes greater. The most severe scenario, the MHW+7 feet water level under an L1 earthquake, inundates wide swaths of the study area, leaving only the hilly regions and very small portions of sand dunes on the peninsula unaffected. Now, inundation levels of up to 50 feet are widely seen near the Pacific coast, Halfmoon Bay, and in the Grayland community. Under this scenario, the Ocosta school will see up to 10 feet of tsunami inundation.

Table 4.4 shows that compared to the king scenario, all L1 scenarios but lowest water level have less dry land during a tsunami event than the king scenario. In fact, 6.20% more land is inundated in the most severe scenario than the king scenario. The land that would remain free of

tsunami water is largely unoccupied and free of many structures and major infrastructure. Thus, infrastructure throughout the region, including the majority of SR-105, will be inundated with some level of tsunami waters under the most severe scenario.

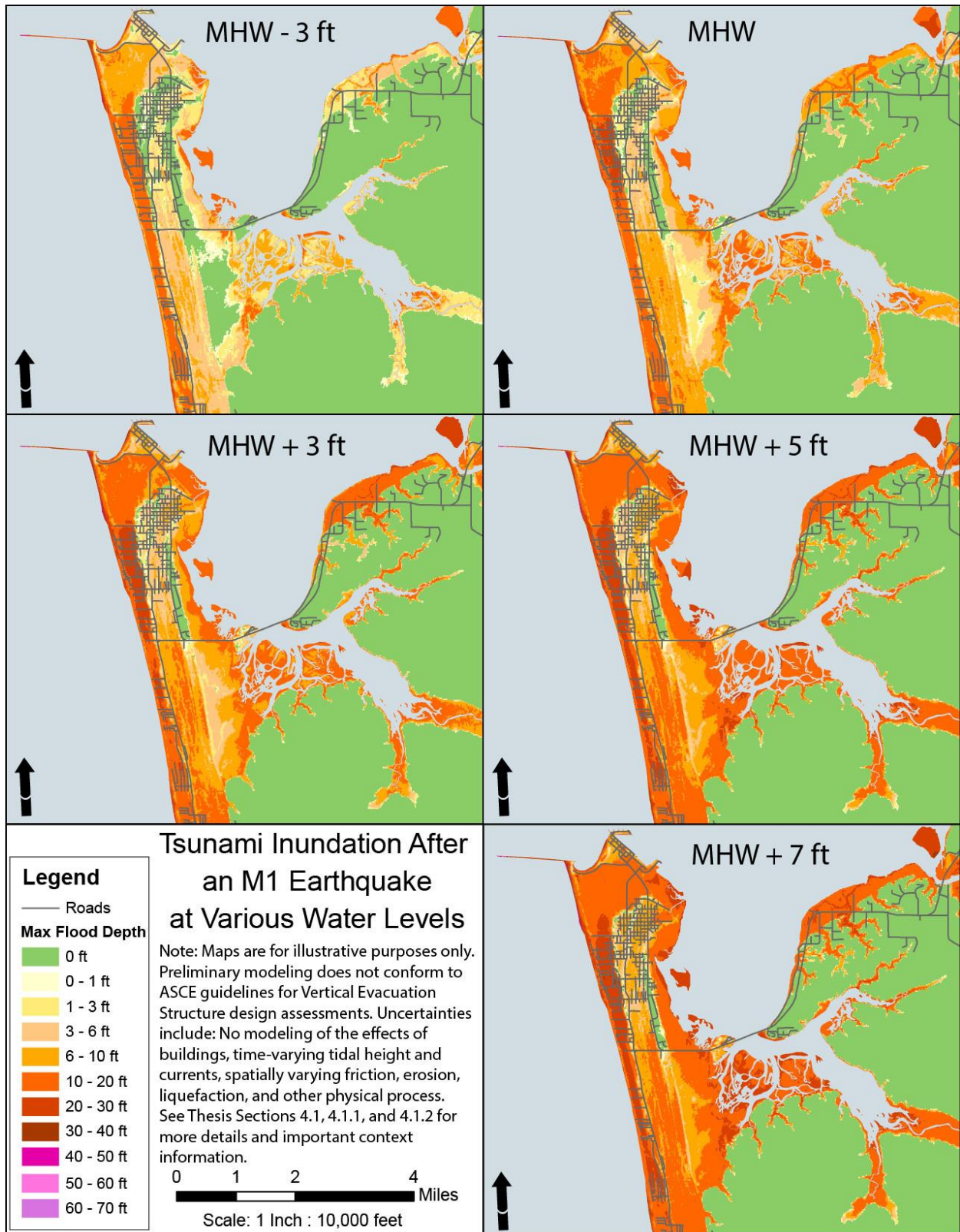


Figure 4.8. Tsunami inundation after an M1 earthquake under each water level scenario.

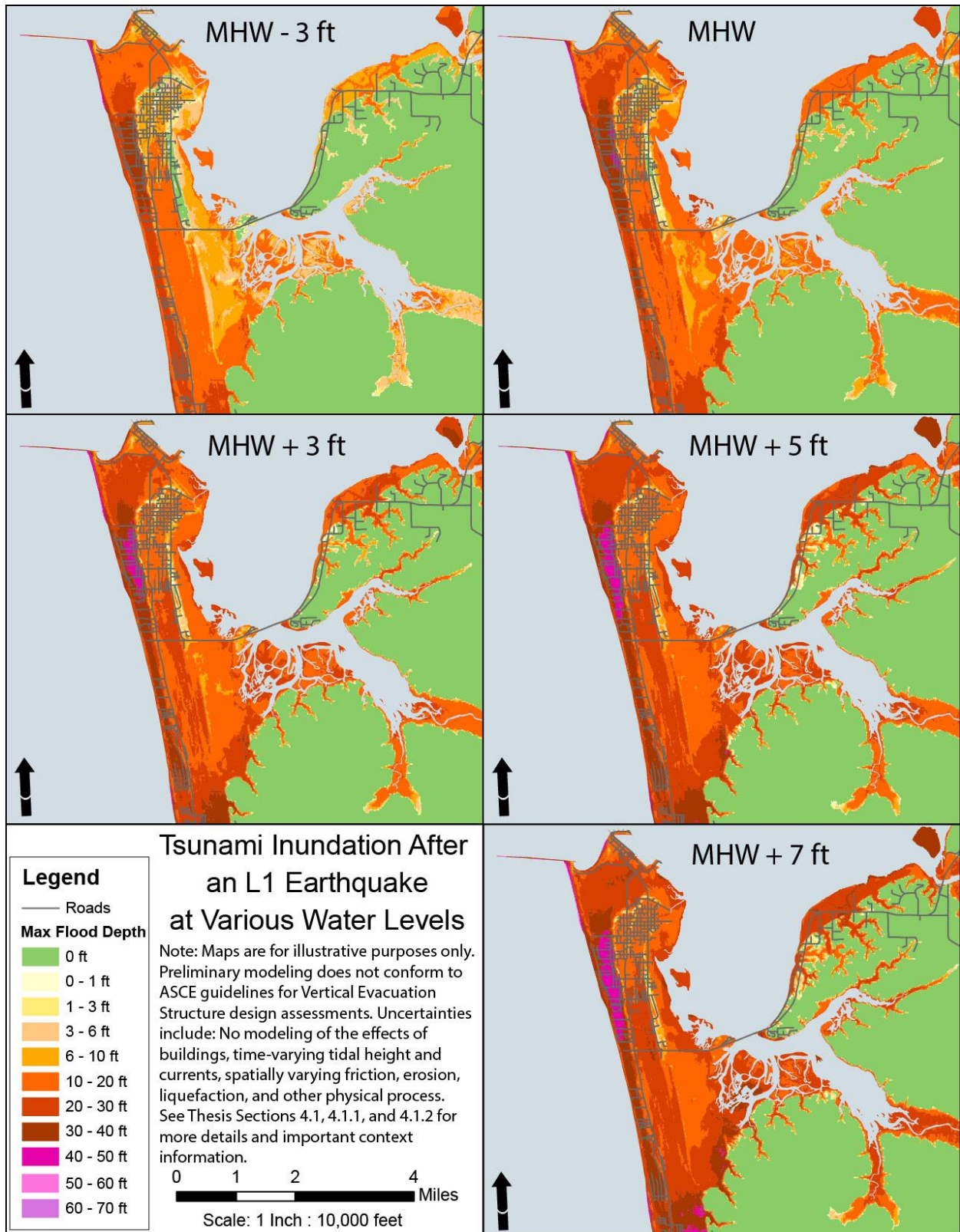


Figure 4.9. Tsunami inundation after an L1 earthquake under each water level scenario.

As with tsunami inundation, the long-term land loss in the study area will be the result of the magnitude of subsidence following a CSZ earthquake and water levels, which could change dramatically due to sea level rise. The subsidence from the tsunami model following each earthquake scenario was coupled with the selected water levels to depict the impact these environmental hazards will have on the study area following a CSZ earthquake. These future land loss scenario maps can be seen in Maps A - H in Figures 4.10 and 4.11. Larger maps of each scenario can be found in Appendix B.

Tables 4.5 and 4.6 can be used to identify the combination of each of the three factors that were used to develop Maps A - H. Maps A - D represent the South Beach landscape following an M1 earthquake event while Maps E - H represent the landscape following an L1 earthquake. The water level at any given time in South Beach is a function of the tide and sea level rise (background water level = tide + sea level rise). Thus, Tables 4.5 and 4.6 depict discrete combinations of these two factors that create conditions that are reflected in certain maps. For example, Map A represents the landscape after an L1 earthquake at contemporary MHW. Contemporary MHW exists with no sea level rise, however the same water level could exist 3 feet below mean high water after 3 feet of sea level rise. There are also an infinite number of combinations of tide levels and sea level rise levels outside of these discrete values that can create the same water level. These tables are only meant to give a few static combinations of these factors relevant to each map. It should be noted that some of these combinations are extremely unlikely. For instance, Map D could technically exist with no sea level rise with the tide 7 feet above MHW. However, as noted in Table 4.1, the tide has never reached this level in Westport. Therefore, these tables represent theoretical possible combinations that can create the water level scenarios while some are improbable.

Post-M1 Earthquake (Maps A - D)		Tide Level Relative to Contemporary MHW (feet)				
		-3	0	3	5	7
Sea Level Rise above MHW (feet)	0		Map A	Map B	Map C	Map D
	1					
	2			Map C	Map D	
	3	Map A	Map B		Note: Each map represents a water level which is the result of an infinite number of possible combinations of tide levels and sea level rise, some of those combinations are given in this table.	
	4			Map D		
	5		Map C			
	6	Map B				
	7		Map D			

Table 4.5. Water level combinations depicted in maps representing topography after an M1 earthquake.

Post-L1 Earthquake (Maps E - H)		Tide Level Relative to Contemporary MHW (feet)				
		-3	0	3	5	7
Sea Level Rise above MHW (feet)	0		Map E	Map F	Map G	Map H
	1					
	2			Map G	Map H	
	3	Map E	Map F		Note: Each map represents a water level which is the result of an infinite number of possible combinations of tide levels and sea level rise, some of those combinations are given in this table.	
	4			Map H		
	5		Map G			
	6	Map F				
	7		Map H			

Table 4.6. Water level combinations depicted in maps representing topography after an L1 earthquake.

It is evident that subsidence after an earthquake plays a large role in the amount of land loss in the study area. As seen in Map A in Figure 4.10, following an M1 earthquake today's mean high water will reach further inland than before the earthquake. Following this CSZ rupture, the eastern portion of the peninsula will be regularly below contemporary MHW levels. Portions of Westport that today are neighborhoods, commercial areas, and parks will become part of the intertidal zone. Grayland will be largely unchanged. The Ocosta school will remain free from flooding. Additionally, the Elk River estuary will grow significantly in size and Laidlaw Island will shrink, further isolated from other land. As seen in Table 4.7, at contemporary water levels 19.47 square miles of the study area would remain above MHW which is 10.21% less land than today's landscape at mean high water. Major infrastructure such as the Westport Airport, the Westport Wastewater Treatment Plant, portions of SR-105, and more will be affected by the daily tide or elevated tide levels due to king tides or storm surges.

The highest water level seen in Westport was 4.25 feet above contemporary MHW. Thus, flooding during an extreme tidal event such as a king tide, would look similar to Map C in Figure 4.10. Water levels 5 feet above contemporary MHW would flood large swaths of the City including the majority of Westport Light State Park. Unaffected areas will largely be isolated to the sand dunes. Should sea level rise 5 feet, South Beach would look similar to Map C daily during mean high tide events. According to Table 4.3, under a high greenhouse gas scenario there is a 9% probability of sea levels rising 5 feet by 2150.

Under more extreme sea level rise conditions, such that MHW is 7 feet higher than today's level, the region as we know it today would be dramatically different. While the possibility of sea levels rising 7 feet are only 3% by 2150 per Table 4.3, this extreme scenario would be devastating to the South Beach community. In fact, compared to today's landscape, 30.05% less land would be at or above MHW than before the M1 earthquake (see Table 4.7). The remaining areas of land out of reach of dynamic water levels are largely the foothills in addition to three distinct strips of land along the peninsula that would resemble islands. For example, the elevated portion of land where the Ocosta school is located would remain mostly dry, other than the occasional king tide or storm surge that would increase the water level another 5 feet. Most, if not all, infrastructure where it is currently located would be permanently underwater including much of SR-105, the majority of infrastructure in Westport, the Port of Grays Harbor, and more.

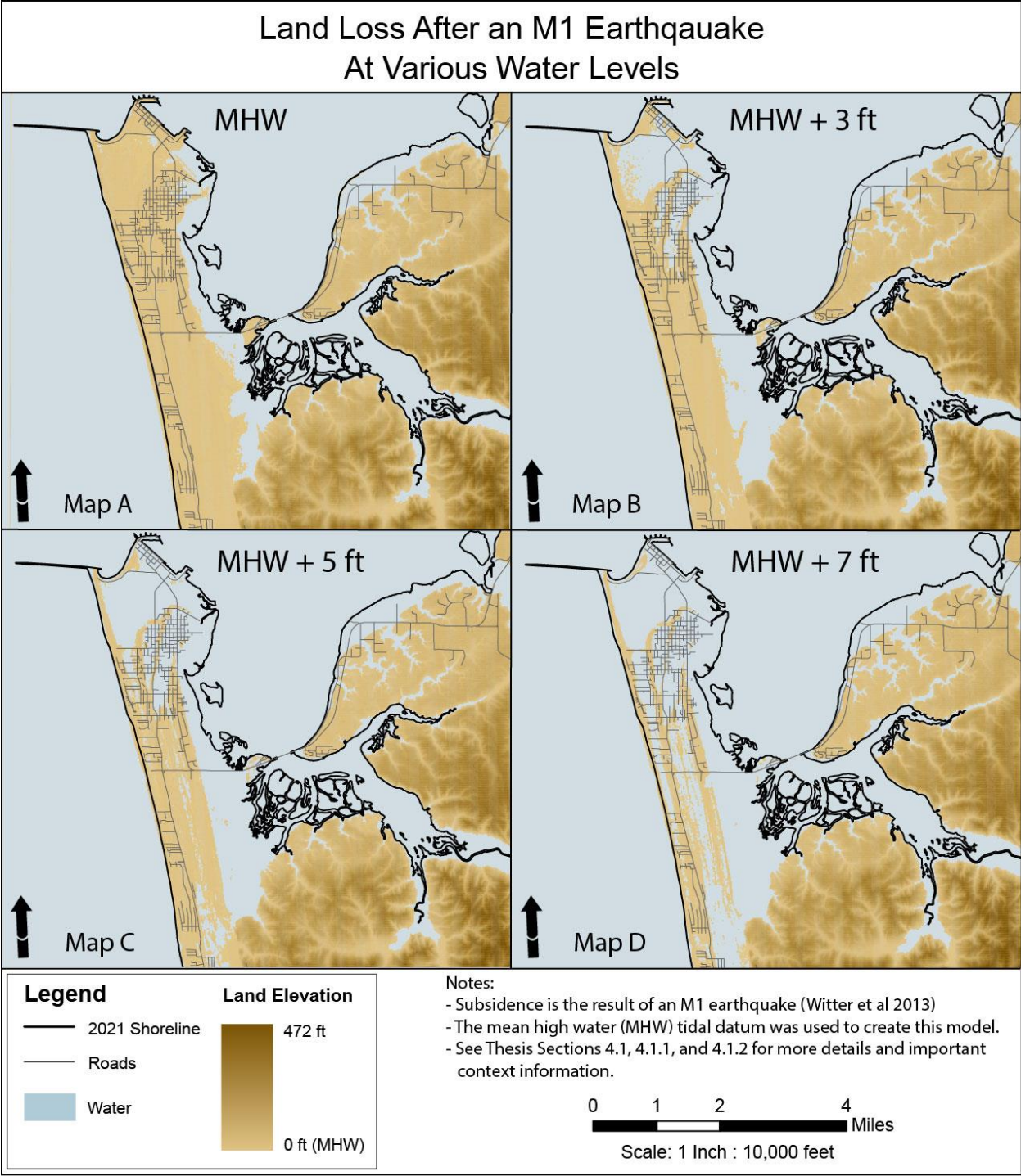


Figure 4.10. Land loss after an M1 earthquake under each water level scenario.

Conditions following an L1 earthquake would be more severe under each water level scenario due to the greater levels of subsidence compared to an M1 event. As indicated in Table 4.7, under each water level scenario more land is below MHW following an L1 event than an M1 event. An additional 1.13 - 1.52 square miles is lost following the L1 scenario under each water level.

Therefore, following an L1 event under contemporary MHW, even more of South Beach would remain underwater than following an M1 event. Compared to today, before an L1 earthquake, the community would lose 15.43% of the study area. The marina would be regularly flooded by the daily tide as would much of the remaining residential and commercial zones of the city. The Westport Wastewater Treatment Plant, Westport Airport, large portions of SR-105, and more would be below mean high water. The Ocosta School would remain elevated above even the highest storm event.

Under the most extreme conditions, under the highest water scenario following an L1 event, the vast majority of the developed areas of South Beach would be underwater. While the Ocosta School would still remain free of flooding, it would be located on an isolated island.

It is important to note that the model used to create these products does not take into account a number of physical processes, including the effects of erosion and deposition, current variations, the presence of structures, and the impact of debris on structures. This includes any effects of the tsunami to the landscape and currently existing structures, and their effects on the tsunami, in addition to any infrastructure or protection measures put into place by the community.

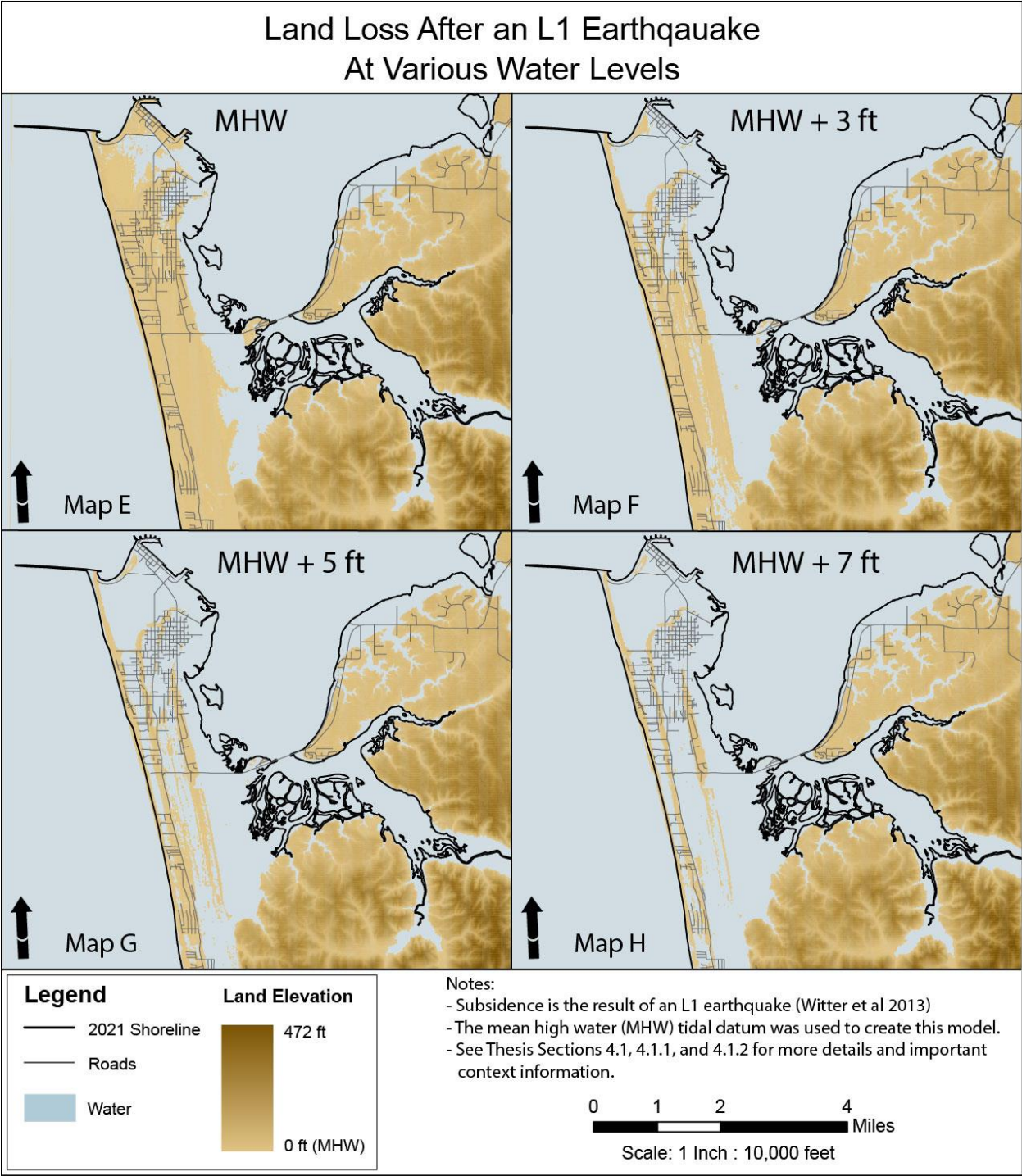


Figure 4.11. Land loss after an L1 earthquake under each water level scenario.

Earthquake Scenarios	Water Level Scenarios	Area at or above MHW (square miles)	Percent Difference from Pre-Earthquake
Pre-Earthquake	MHW + 0	21.68	
M1	MHW - 3	20.86	-3.79%
	MHW + 0	19.47	-10.21%
	MHW + 3	17.45	-19.50%
	MHW + 5	16.45	-24.14%
	MHW + 7	15.17	-30.05%
L1	MHW - 3	19.65	-9.38%
	MHW + 0	18.34	-15.43%
	MHW + 3	16.23	-25.16%
	MHW + 5	14.93	-31.14%
	MHW + 7	14.01	-35.38%

Table 4.7. Areas of South Beach at or above mean high water under each scenario compared to the area of South Beach currently at or above mean high water.

4.2 Framing Future Change Scenarios with Historical Maps

Future change scenarios such as those in Section 4.1 can be framed with historical maps in order to provide viewers and the community with context and memory. While indigenous communities have lived with and on this land for centuries and have passed on stories of the many environmental hazards and changes, recent settlers do not have the same context. It is hypothesized that evoking community members’ living memory of local environmental history, and enhancing it with mapped data, may better enable them to confront the daunting prospect of future change, and to take creative anticipatory action.

4.2.1 Methodology

Rate-of-change statistics from a series of historical shoreline positions were calculated in South Beach with the United States Geological Survey’s (USGS) Digital Shoreline Analysis System (DSAS). DSAS casts transects perpendicular to the user-selected baseline vector that intersect

with historical shorelines at user-specified spacing.²⁵² DSAS measures the distance between the baseline shoreline and each shoreline on a transect. The shoreline date and positional uncertainty are used to calculate the following metrics: shoreline change envelope, net shoreline movement, end point rate, linear regression rate, weighted linear regression rate, confidence interval of linear regression, standard error of linear regression, R-squared of linear regression, confidence interval of weighted linear regression, standard error of weighted linear regression, and R-squared of weighted linear regression.²⁵³ DSAS allows the user significant control of the analysis which was helpful for the complex nature of the shoreline in South Beach.

Available historical data used in this analysis includes t-sheets, historical maps, and geospatial vector data (see Figures 4.12, 4.13, and 4.1.4) was utilized in order to get a representative sample of shoreline change. This data was gathered from the Shoreline Survey tool on Google Earth available through the National Oceanic and Atmospheric Administration (NOAA) and NOAA's Shoreline Data Explorer. Statistical analysis was limited by data availability but the data included represents large shifts in the shoreline.

²⁵² E.A. Himmelstoss et al., "Digital Shoreline Analysis System (DSAS) Version 5.0 User Guide," Open-File Report, Open-File Report (U.S. Geological Survey, 2018).

²⁵³ Himmelstoss et al.

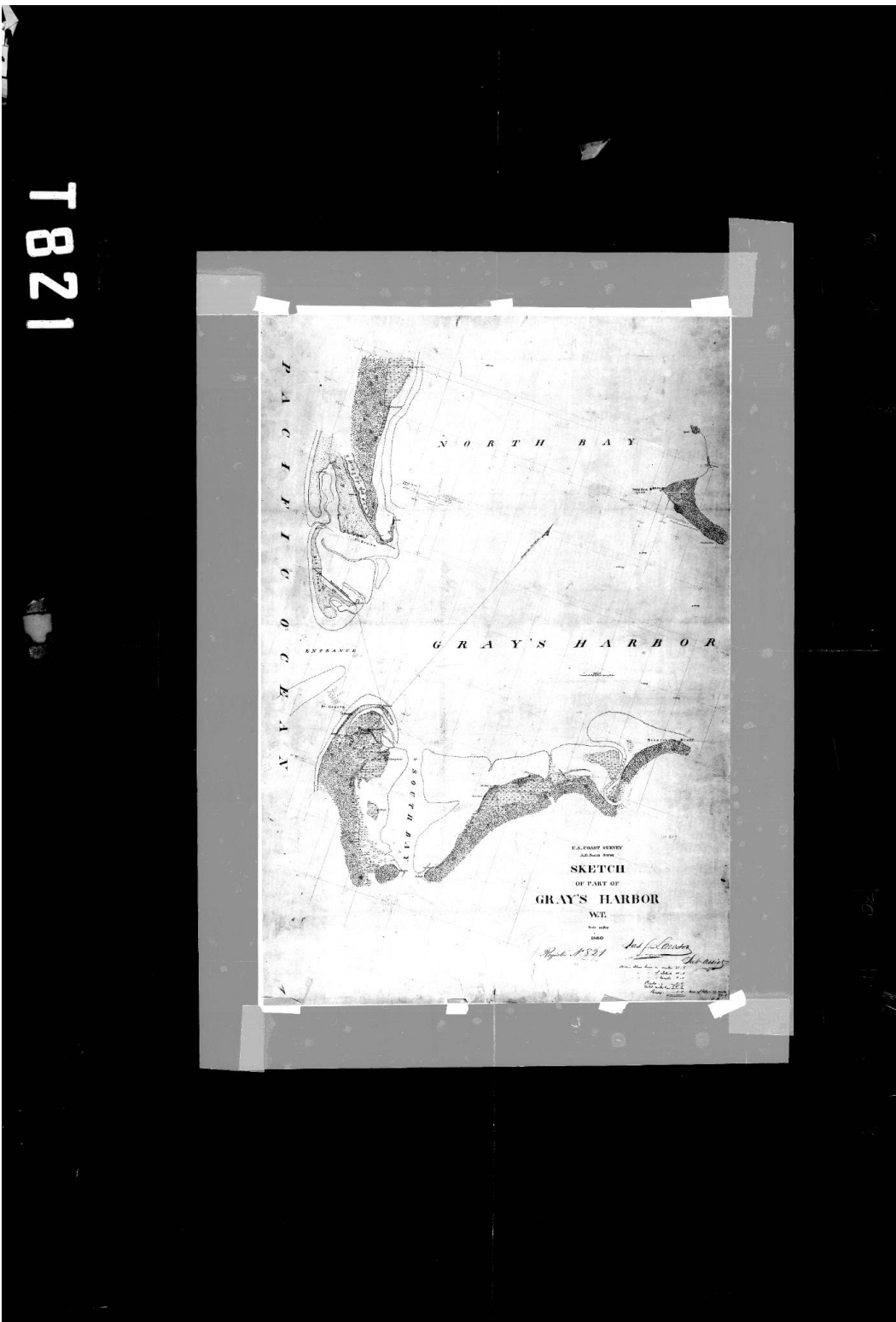


Figure 4.12. T-sheet of Grays Harbor in 1860.²⁵⁴

²⁵⁴ NOAA US Department of Commerce, “National Geodetic Survey - NOAA Shoreline Data Explorer,” 2021, <https://www.ngs.noaa.gov/CUSP/>.

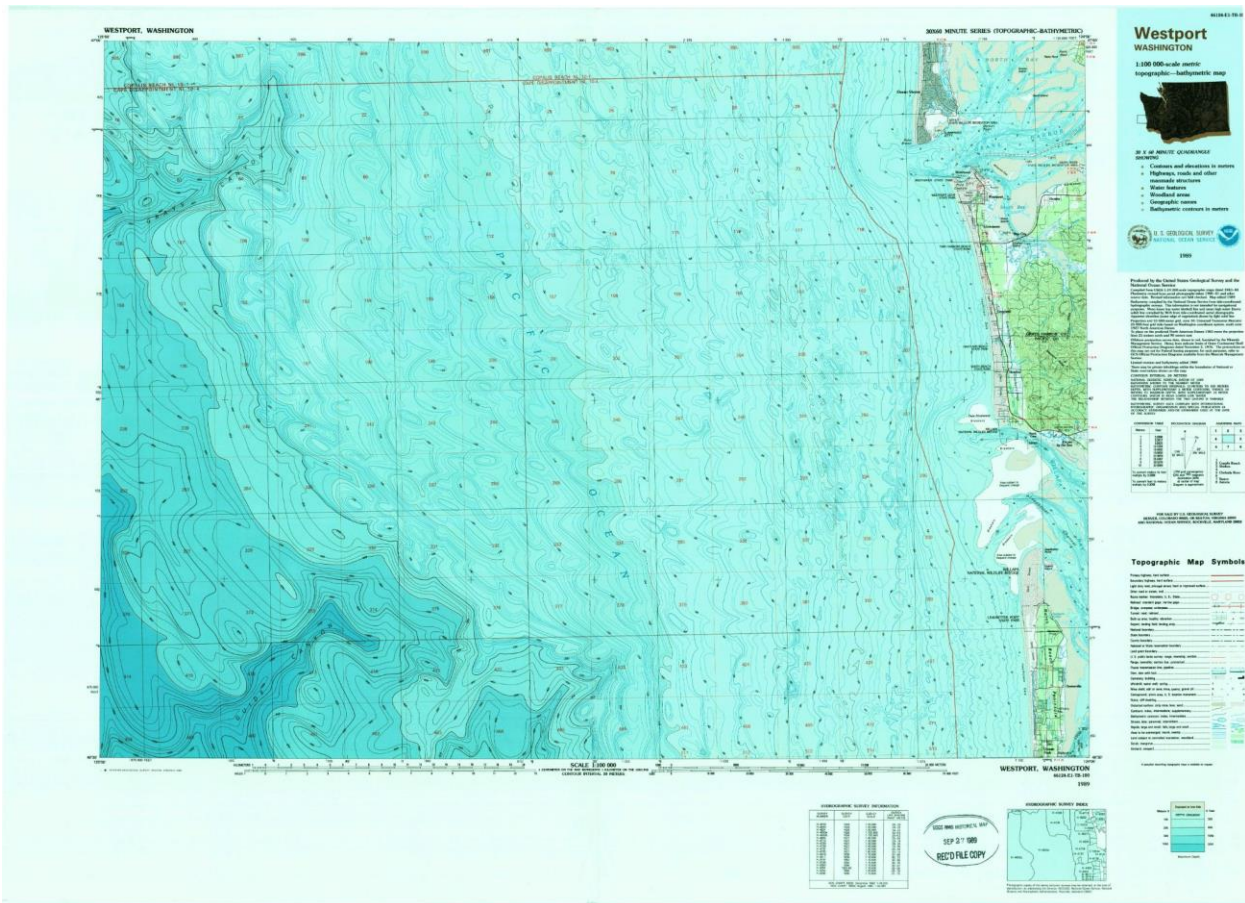


Figure 4.13. Topographic map of South Beach in 1989.²⁵⁵

²⁵⁵ U.S. Geological Survey, "The National Map," National Geospatial Program, accessed June 16, 2021, <https://www.usgs.gov/core-science-systems/national-geospatial-program/national-map>.

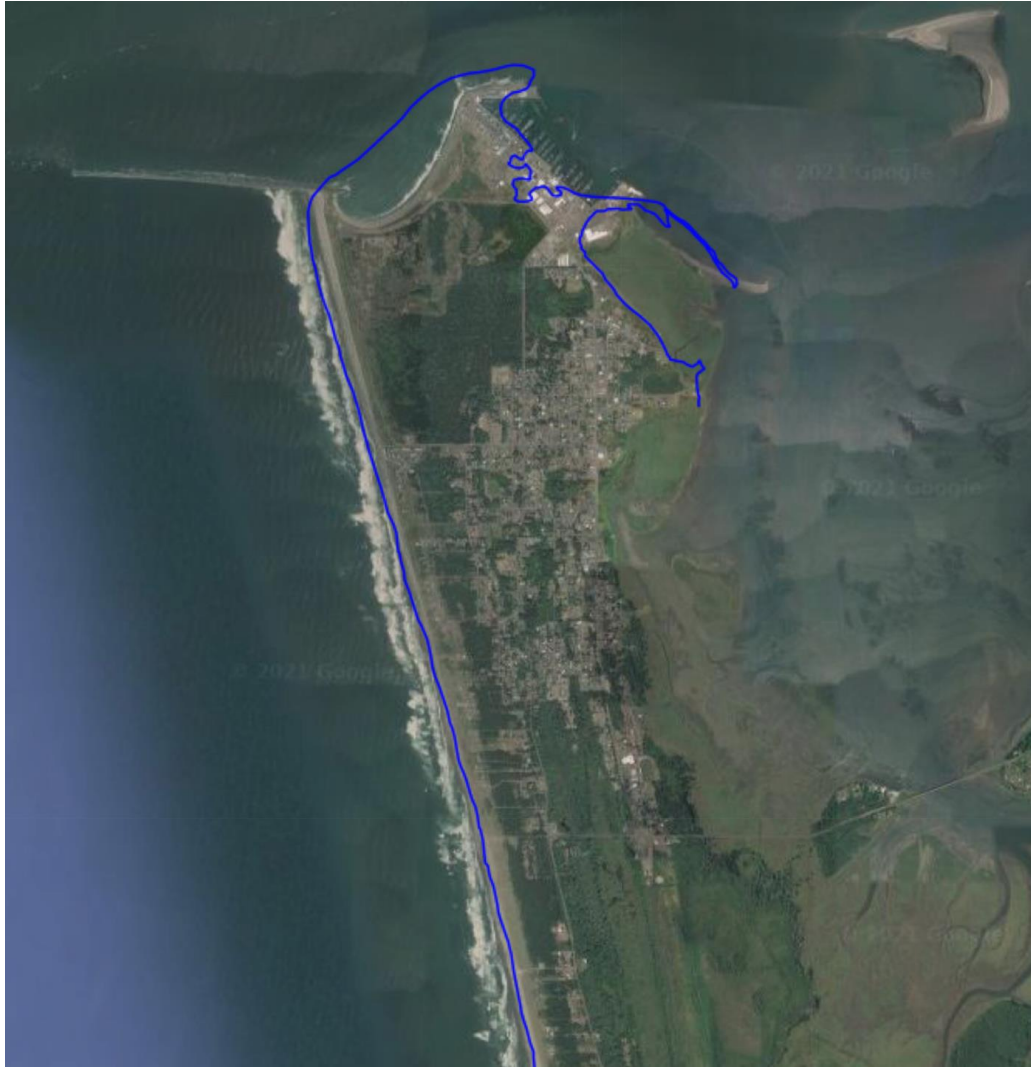


Figure 4.14. Vector of 1926 Westport shoreline downloaded from the Shoreline Data Explorer.²⁵⁶

The majority of t-sheets available in the South Beach region had previously been georeferenced. This georeferenced data was available and used in this analysis. One t-sheet from 1860, seen in Figure 4.12, was georeferenced for this research. This t-sheet was digitized into vector data along with a 1989 map.

The most recent, accurate shoreline for the study area was a 2016 dataset. This was selected as the baseline because it is the most recent, memorable shoreline that residents and the City of Westport are familiar with. The City has and still does make decisions based on this general shoreline. Therefore, calculations based on the relationship to this vector will be comprehensible to today's Westport residents.

²⁵⁶ NOAA US Department of Commerce, "National Geodetic Survey - NOAA Shoreline Data Explorer," 2021, <https://www.ngs.noaa.gov/CUSP/>.

Each vector shapefile was reprojected and placed into a personal geodatabase as feature classes. Each vector was cleaned through editing to reduce error during analysis. Fields were added to each attribute table per the standards set out in the US Geological Survey's user guide for Digital Shoreline Analysis System (DSAS) Version 5.0.

Once all vectors were in the correct projection, attribute fields were added and populated, the default parameters were selected in the DSAS extension. Next, the transects were cast according to the parameters selected by the team. The calculate rates DSAS tool then calculated the statistics related to the transects that were cast. These statistics can be found in Appendix B.

4.2.2 Limitations and Assumptions

The 1860 map was georeferenced using only three data points. These three data points seemed to have been relatively stable historically. They included Ned's Rock near the City of Aberdeen, Grass Island near Westport, and an island at the outlet of St John's River east of Westport. These were the only three clearly relatively stable points in the mapped region. The uncertainty of each shoreline map production was input into DSAS. Calculations are dependent on the accuracy of the map production in addition to the georeferencing of the map image and the vectorization of the georeferenced map. Vectorization was done by hand and relied on many judgement calls of what should be marked as the extent of the shoreline. This process could have been improved through the use of a digitizing tablet to trace shorelines.

Data cleaning for each vector involved personal decisions about which features should be included and which should be removed. Islands, ponds, and other small features were removed in order to ensure these points did not interfere with the transects that would be cast. Additionally, the choice was made to remove some man-made features such as the south jetty and docks along the marina. Transects are cast evenly across the baseline vector so including a feature such as the jetty which is 12,000 feet long would drastically alter the final statistics. Small details such as docks that run perpendicular to the shoreline could also send a transect perpendicular to the rest of the shoreline vectors. These vectors would not produce usable data, therefore these details of the shoreline were removed in order to reduce these incidents.

DSAS requires the user to define whether calculations will be based on seaward intersections or landward intersections along each transect as seen in Figure 4.15. The choice was made to use landward intersections which is appropriate for the majority of vectors used in this analysis. However, the 1860 vector includes two peninsulas. Therefore, the intersection point for one transect was on the eastern peninsula, not the outer, western peninsula.

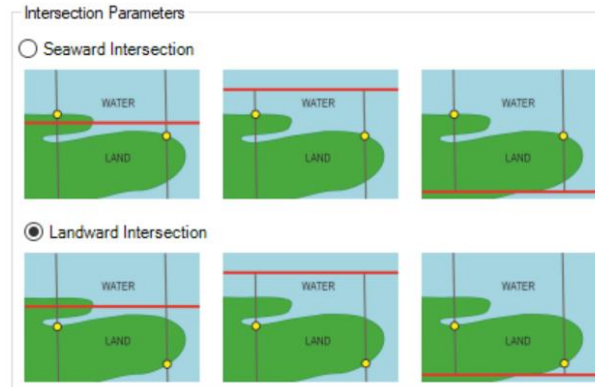


Figure 4.15. DSAS intersection parameter choice available to users.

There were also three choices related to casting transects along the baseline vector. The first value determined was the maximum search distance which was manually determined for each section of the 2016 vector. These values were selected with the goal of only capturing the parts of each vector that should be used to calculate the shoreline change. The second value selected was the transect spacing. 500 meters was selected for this analysis. This value would capture the greatest changes across the landscape while reducing the errors resulting from an excess of transects that would capture unwanted vector intersections. Finally, a smoothing distance of 2,500 meters was chosen in order to cast transects appropriately for the very curvy nature of Westport’s shoreline. This was the largest value allowed in DSAS.

4.2.3 Findings

Historical Coastal Change in Westport, Washington

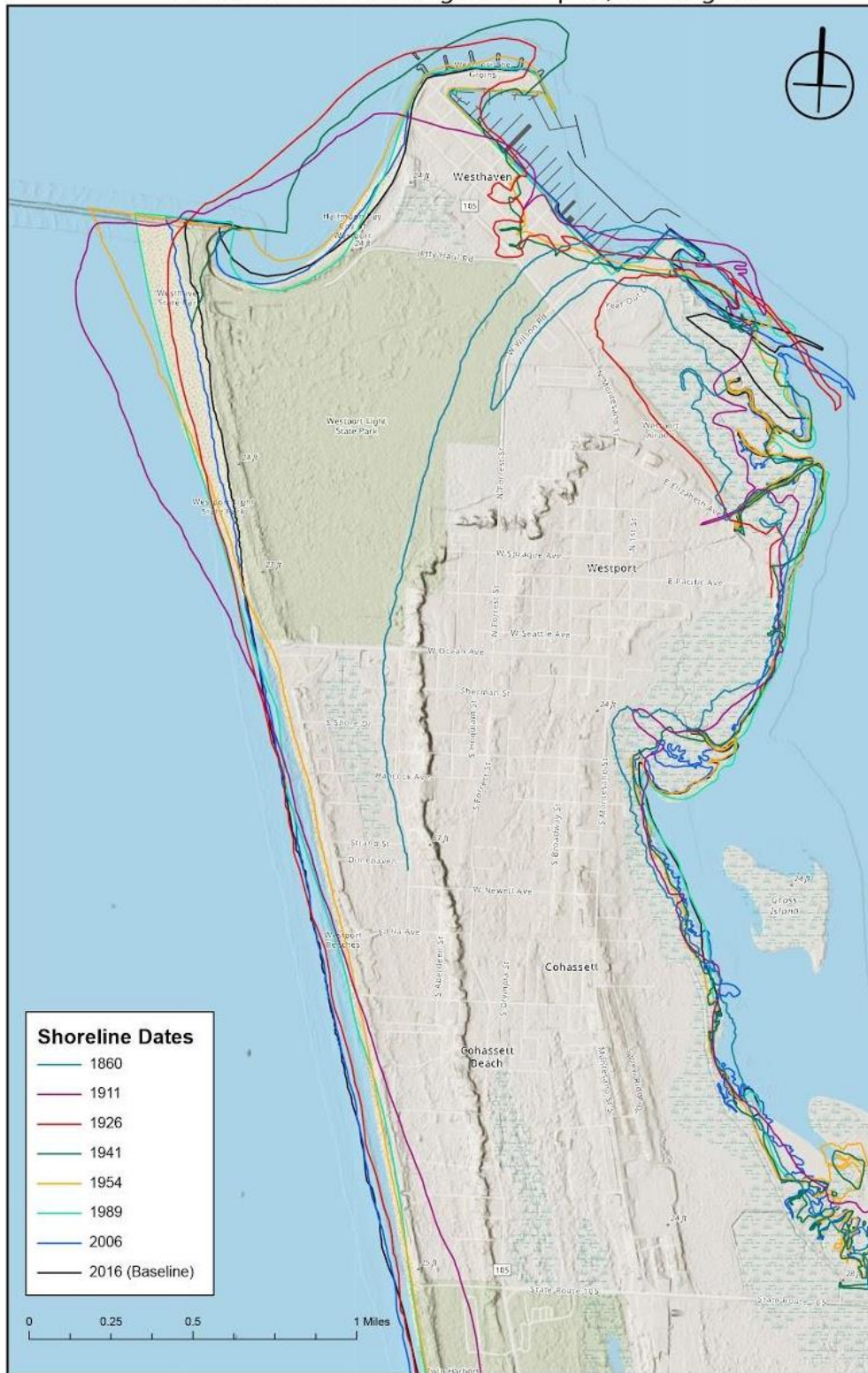


Figure 4.16. All historical vector data used in the analysis.

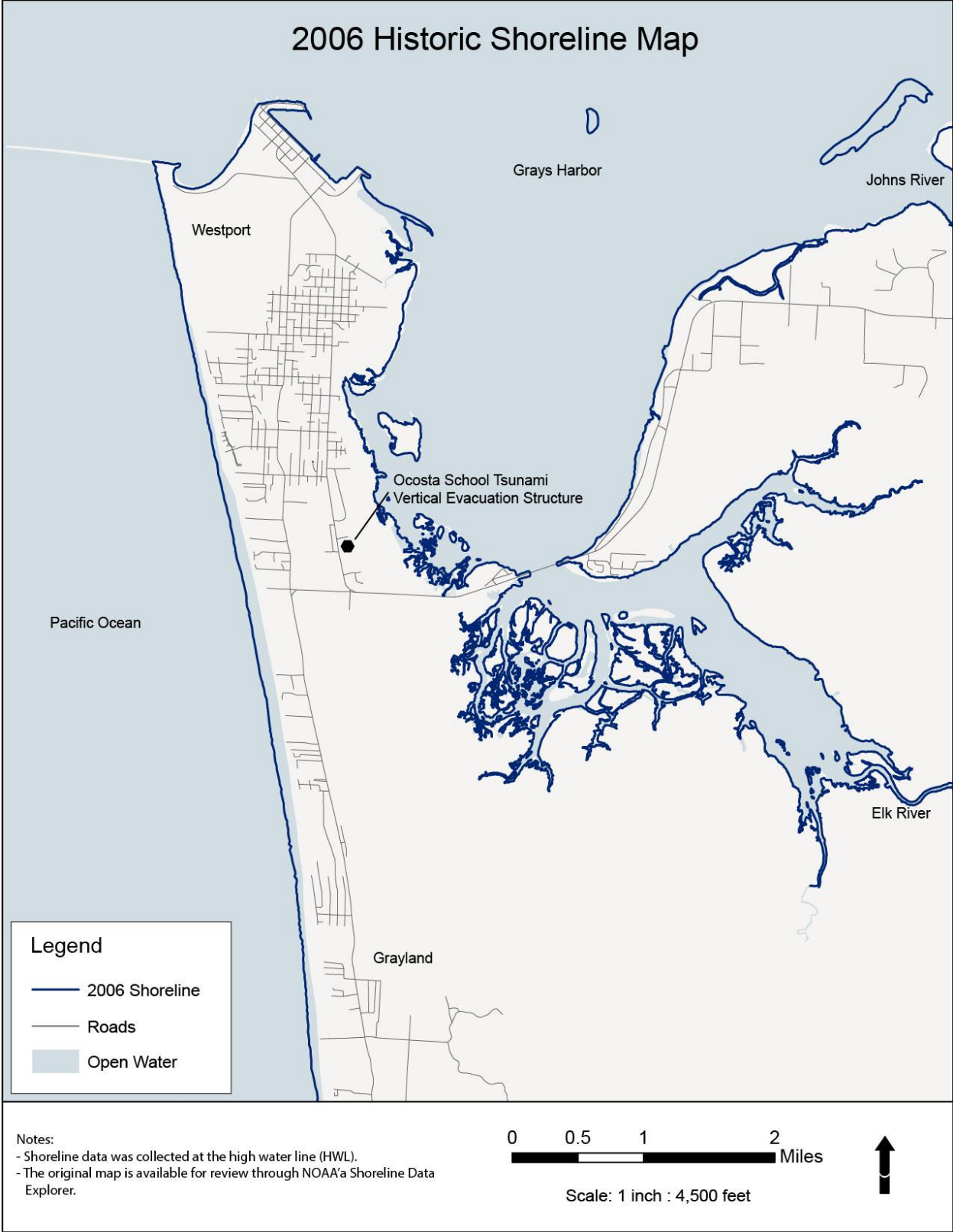


Figure 4.17. 2006 historic shoreline map.



Figure 4.18. 1989 historic shoreline map.

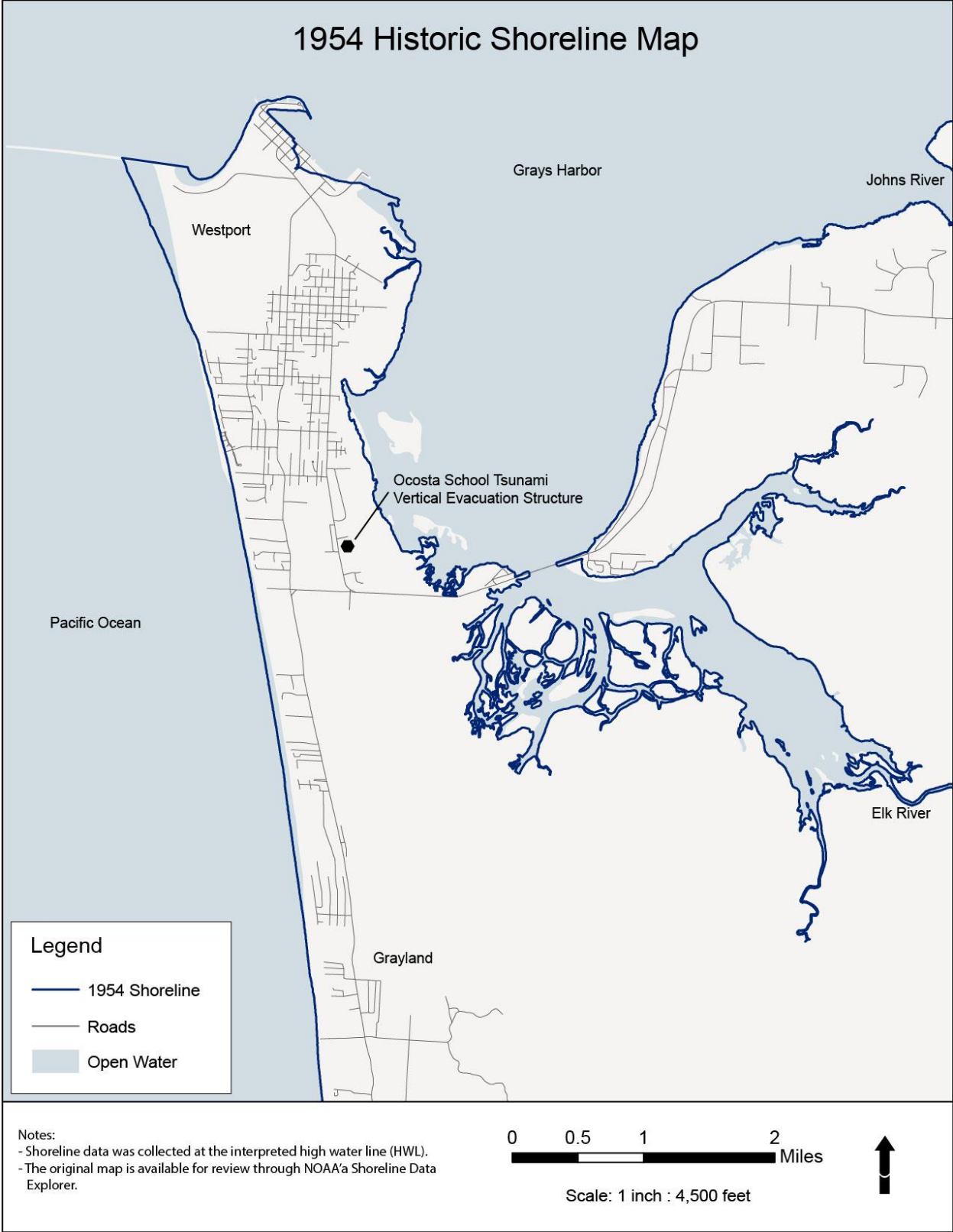


Figure 4.19. 1954 historic shoreline map.

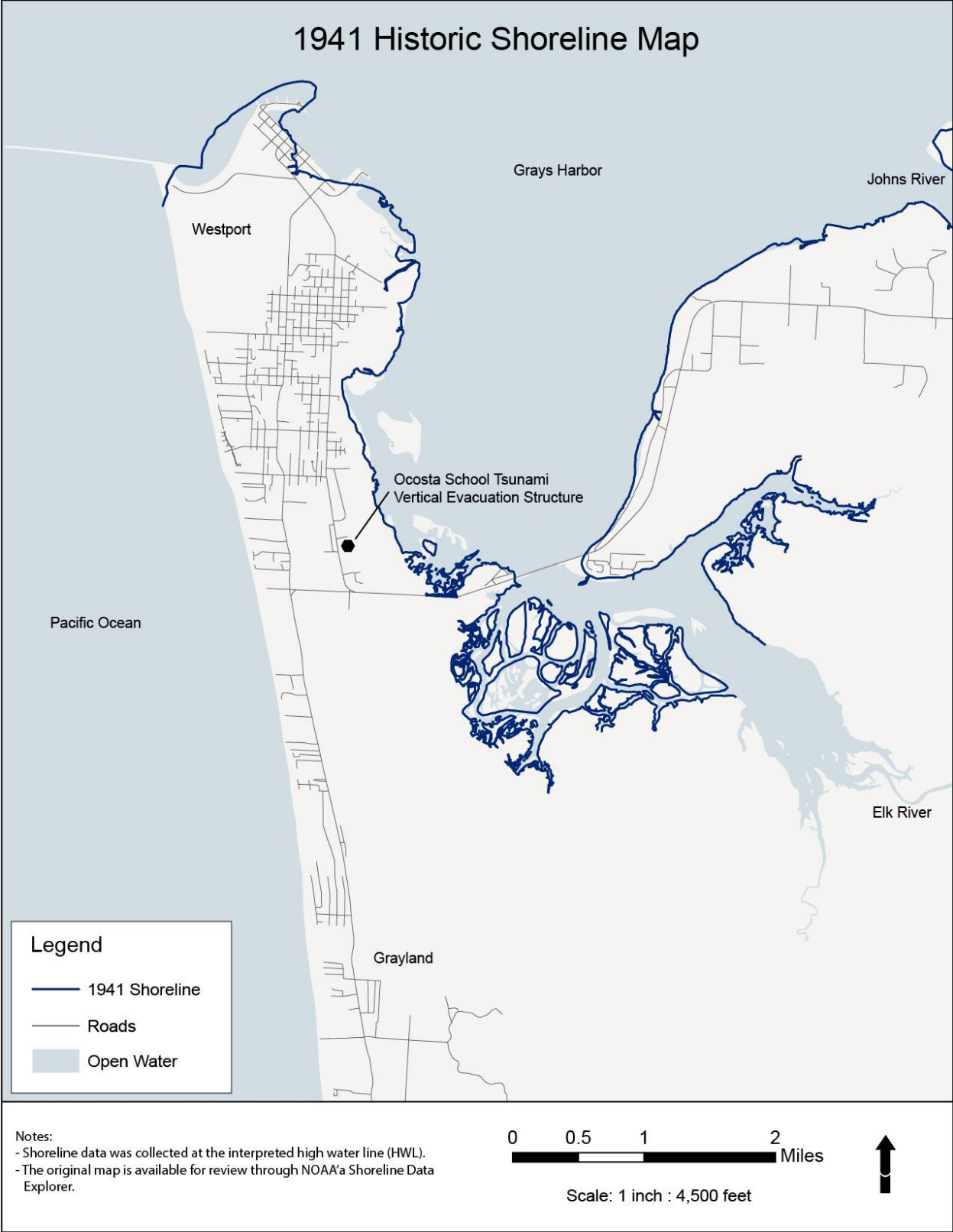


Figure 4.20. 1941 historic shoreline map.



Figure 4.21. 1926 historic shoreline map.

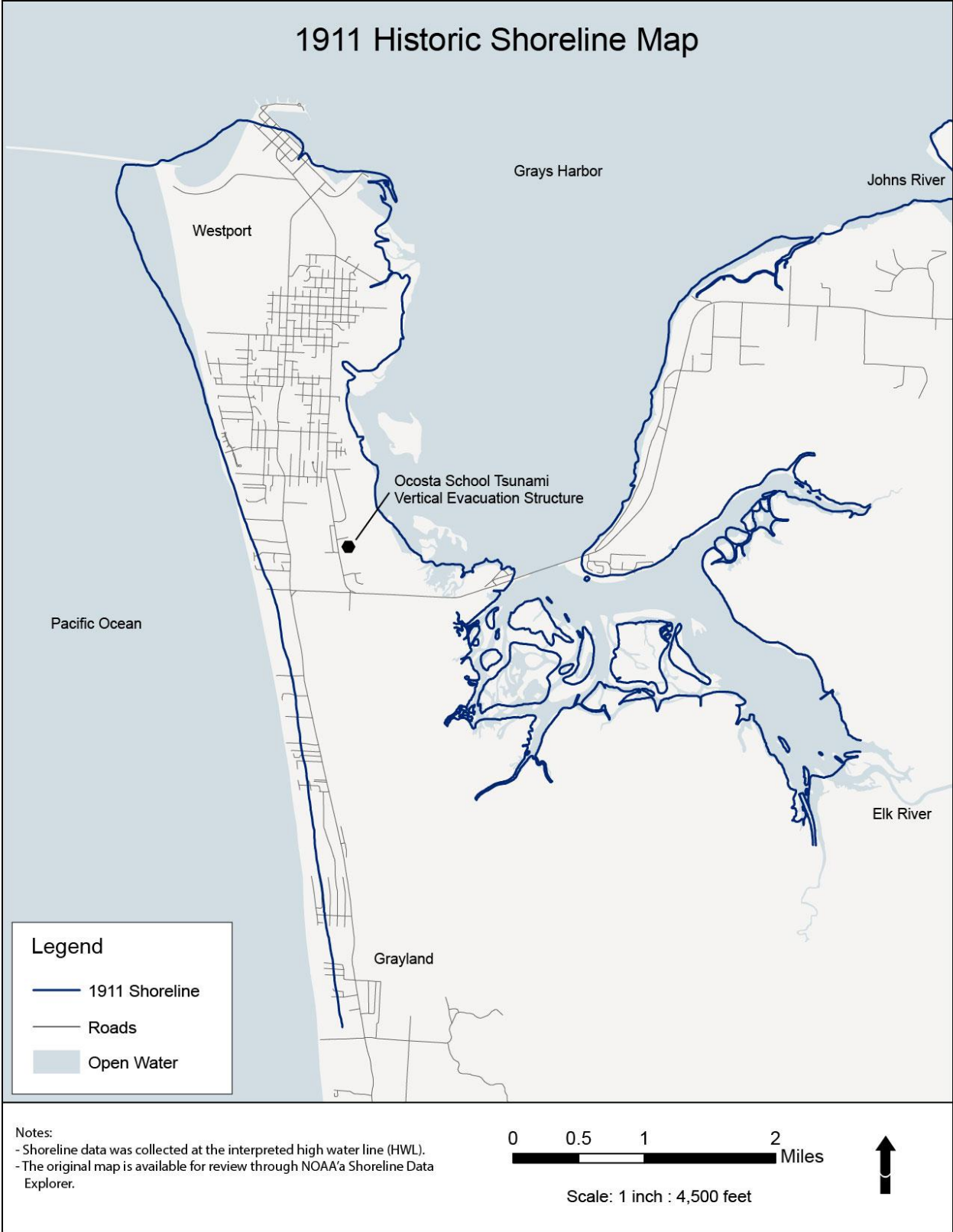


Figure 4.22. 1911 historic shoreline map.



Figure 4.23. 1860 historic shoreline map.

Shoreline Change Transects in Westport, Washington

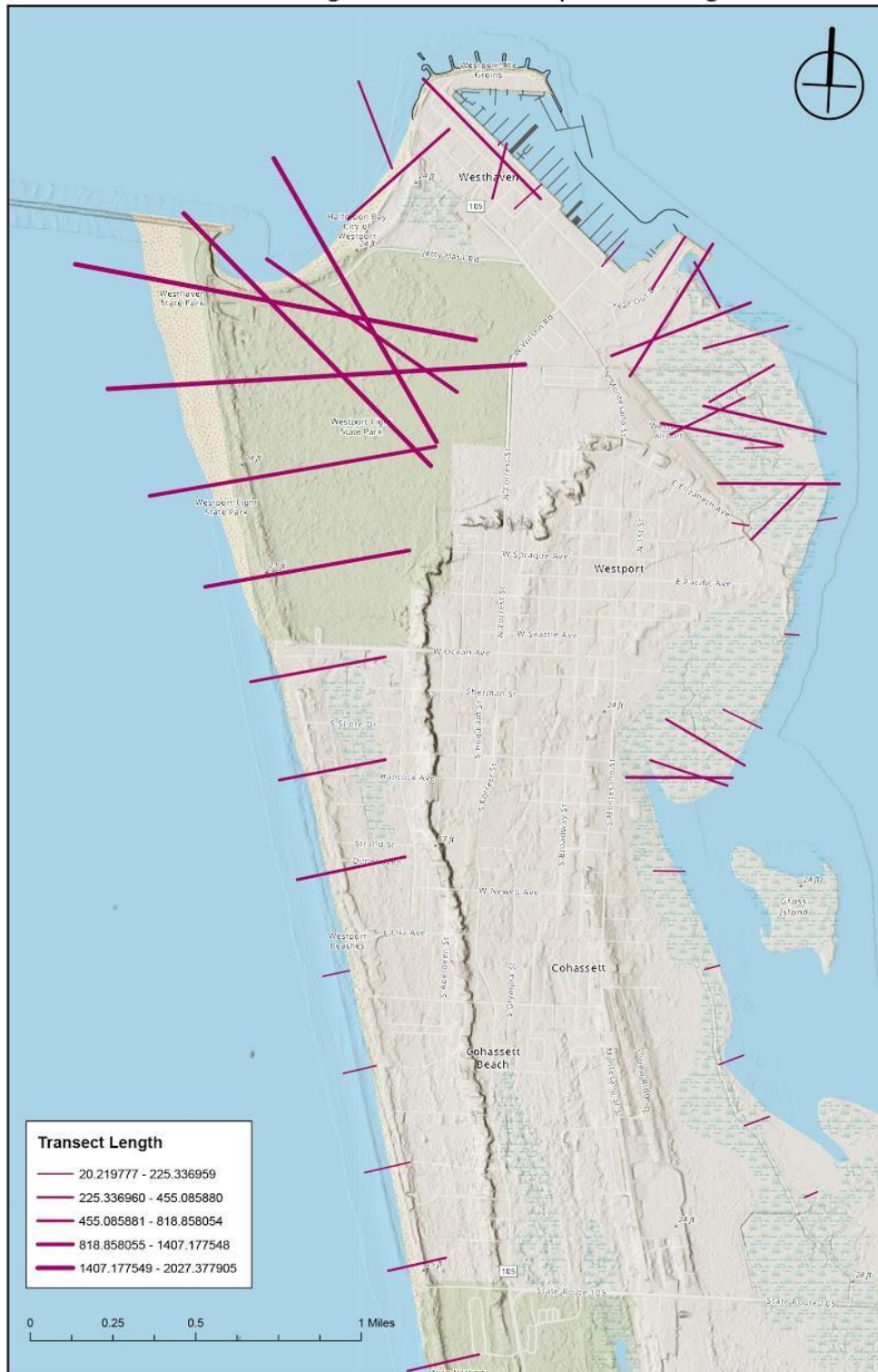


Figure 4.24. Shoreline change transects. Each transect length depicts the largest distance between historical vectors. The greatest distance between vectors is represented by thicker, longer transects while shoreline areas that have changed very little are represented by shorter, thinner transects. Transect length is in meters.

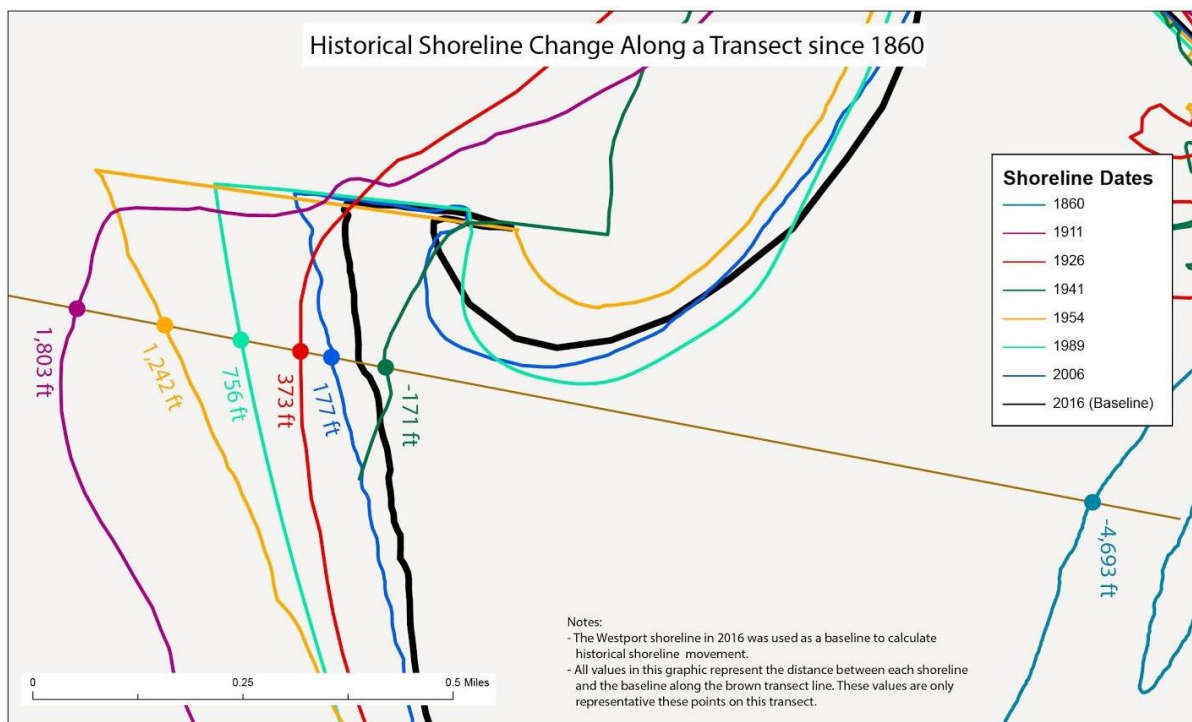


Figure 4.25. Transect intersections along one transect near the south jetty in Westport. Each intersection label represents the distance between that vector and the baseline 2016 vector.

This research has found that there has been significant shoreline change in South Beach, Washington since the region was surveyed in 1860. There has been accretion in some areas while there has been erosion in others. According to the DSAS statistical report, found in Appendix C, the maximum shoreline change captured by a transect is 2,027 meters or 6,651.5 feet. The average shoreline movement is 327 meters or 1,073 feet which is extremely significant in just 150 years. In terms of linear regression, 20.51% of all transects were found to be erosional with 7.69% of all transects having statistically significant erosion. 79.49% of all transects were found to be accretional with 23.08% of all transects having statistically significant accretion.

Figure 4.16 depicts all historical vector data used in this project to calculate these statistics. The transects used to calculate the statistics are depicted in Figure 4.24. Each transect length depicts the largest distance between historical vectors. The greatest distance between vectors is represented by thicker, longer transects while shoreline areas that have changed very little are represented by shorter, thinner transects. The ends of each transect are where the transect intersected with the farthest shoreline from the 2016 baseline shoreline. Therefore, it is evident the least amount of shoreline movement between 1860 and 2016 was on the east side of the peninsula west of Grass Island. This is expected considering this area of the shoreline is protected. Sediment that would accrete in this region drops out from the Elk River further south and this cove is protected from oceanic changes on the west side of the peninsula.

Further north along the eastern and northern sides of the peninsula it is evident that historically this region had significant shoreline movement. However, starting in 1954 this portion of the shoreline has remained incredibly stable due to human intervention. This is where the most recent marina is located and in order to protect this valuable asset the shoreline has been hardened and improved over the last 70 years.²⁵⁷

The greatest coastal changes in this time period took place on the northwest side of the peninsula which can be seen in Figures 4.16, 4.24, and 4.25. Again, there are significant correlations between the timeline of human activities such as jetty construction and these particular shoreline changes. For example, the south jetty that was constructed at the entrance to Grays Harbor in Westport in 1902. Only two years later more than 3,000 linear feet of sediment accumulated westward behind the jetty.²⁵⁸ This analysis found that before and after jetty construction, between 1860 and 1911, the shoreline shifted nearly 6,500 feet northwest along one transect. The shoreline changes along this transect can be seen in Figure 4.25.

The strip of land connecting the jetty to Westport has changed dramatically since the jetty was completed. Figure 4.25 shows a dynamic zone where the land has shrunk and grown repeatedly between 1911 and 2016. Between 1904 and 1933 the jetty deteriorated until the jetty was repaired for the first time between 1933 and 1939.²⁵⁹ From 1939 to 1946 the shoreline had accreted westward 1,100 feet. In 1959 the shoreline receded again until another repair was needed in 1966. Less than a decade later the shoreline began eroding again until a breach took place in 1993.²⁶⁰ Following the breach, a significant amount of dredged material from the Grays Harbor entrance was placed in Half Moon Bay between 1996 and 2002.²⁶¹ Following these efforts, this research shows that the strip of land between the Pacific Ocean and Half Moon Bay has continued eroding.

Another significant human intervention could be contributing to the particularly dynamic shoreline at the northwest corner of Westport. In the 1930s the Columbia River began to undergo strict control through construction of dams.²⁶² The Columbia transported nearly 16 million tons of sediment each year until the Bonneville dam was completed in 1935. Over half of the

²⁵⁷ Jennifer Ott, "Port of Grays Harbor Becomes Washington's Second Public Port on December 12, 1911," HistoryLink, April 8, 2010, <https://www.historylink.org/File/9390.PO>

²⁵⁸ James Phipps and John Smith, "Pacific Ocean Beaches Erosion and Accretion Report," July 1978, <https://www.govinfo.gov/content/pkg/CZIC-gb454-b3-p5-1978/html/CZIC-gb454-b3-p5-1978.htm>.

²⁵⁹ Ty Wamsley et al., "Breach History and Susceptibility Study, South Jetty and Navigation Project, Grays Harbor, Washington," September 2006.

²⁶⁰ Wamsley et al, 1.

²⁶¹ Wamsley et al.

²⁶² Jeremy FiveCrows, "Changing Ecosystem: Reservoir Sedimentation," CRITFC, October 6, 2015, <https://www.critfc.org/blog/2015/10/05/changing-ecosystem-reservoir-sedimentation/>.

sediment in the river system bulbs up behind the series of dams on the river.²⁶³ This low sediment load could be contributing to the dynamic, eroding coast in South Beach today.

Chapter 5: Development and Use of Geonarratives and Other Engagement Materials

The historical data and scenario visualizations from Chapter 4 can be used in many different ways and in many different settings for community engagement in South Beach. A geonarrative could be used as a stand alone tool or could be paired with other engagement materials and methods. A geonarrative could also be used to engage professionals outside of South Beach in a remote planning exercise.

5.1 Geonarrative Development

5.1.1 Implications of Materials in a Geonarrative

Four kinds of coastline change were mapped in Chapter 4. The first depicts tidal flooding under today's conditions, seen in Figure 4.5. King tides affect South Beach seasonally and while they recur frequently these visual representations of tidal fluctuation are very predictable and not very severe. Future tsunami inundation maps depict temporary but severe inundation following a CSZ earthquake. Tsunami inundation shown in Figures 4.8 and 4.9 is extremely rare, occurring on the timescale of centuries. The onset of such inundation is unpredictable until an earthquake occurs, at which time South Beach will be inundated less than 30 minutes later.²⁶⁴ This severe flooding will retreat, unlike sea level rise. Sea level rise will suddenly become much more severe in South Beach due to coseismic subsidence following a CSZ earthquake. The land loss maps depicting this permanent change, Figures 4.10 and 4.11, will be a long-term reality for residents. Finally, historic coastal change maps depict the dramatic changes that have already occurred in South Beach, seen in Figures 4.14 to 4.20. While these changes took place in the past it is evident through this research that human intervention can have a dramatic, long-term impact on our coastlines.

While these maps show dramatic changes, both historically and possibly in the future, there are elements of these maps that could be improved for use in community engagement with stakeholders. First and foremost, it is recommended that all maps in Chapter 4 be available

²⁶³ Jeremy FiveCrows, "Changing Ecosystem: Reservoir Sedimentation," CRITFC, October 6, 2015, <https://www.critfc.org/blog/2015/10/05/changing-ecosystem-reservoir-sedimentation/>.

²⁶⁴ Grays Harbor County Emergency Management, "Project Safe Haven: Grays Harbor County," 2011, <https://mil.wa.gov/asset/5ba41ffb35f02>.

online and in an interactive format. The details in each map will likely have different impacts to different individuals and groups. For example, the Ocosta School District and the Port of Grays Harbor, which operates the Westport marina, and potential developers could all be interested in different areas. The ability to zoom in and select layers of interest will improve the usefulness of these currently static maps.

It would also be useful for viewers for all maps to be consistent. Basemaps from the Resilient Cities on the Pacific Rim studio were used for some graphics, as seen in Figure 4.13. This visual change in basemap, north arrow, scale, etc. may direct viewers to elements of the map that are not the purpose of the maps. It is recommended one basemap be used for all future uses of this data.

Additionally, shoreline change is graphically depicted differently in future hazard maps and historic maps. Figure 4.10, for instance, depicts the shoreline today at contemporary mean high water in a solid, thick, black line. This is consistent across all future land loss maps. However, the shoreline is depicted differently in tsunami inundation maps and historic maps where there is no solid line, only a color change between water and land. Given the tight timeline of this thesis and the format of data, converted from a .asc file to a raster format then polygon groups by attribute, I did not develop maps with consistent cartographic style. It is recommended future users of this data develop graphic standards in order for viewers to focus on the purpose of the maps and not be distracted by inconsistencies.

One use of these maps could be to aid long-term planning discussions. The data represented in these maps is associated with different probabilities and timelines. Future hazard maps associated with high water levels are extremely improbable today, as seen in Table 4.3. While water levels in this thesis account for sea level rise and tidal changes, a water level 7 feet above contemporary mean high water would be unlikely until at least the turn of the century. See Tables 4.5 and 4.6 for combinations of tide and sea level rise that could create this scenario. While these high water levels are unlikely today, robust long-term planning decisions can function under a wide range of possible futures. Thus, choices and investments made today that account for these many possible futures can protect assets over the long-term. That said, geonarratives that include these maps might induce community responses from inspiration on one hand, and paralyzing denial on the other, hence, explanations of each map should be clear.

5.1.2 Recommendations for Geonarrative Development

Information about environmental change and hazards can be depicted in a narrative format, as images, graphically as maps, and in tables and graphs. A geonarrative is one of the most effective ways to integrate these materials and supplementary materials including videos, guided tours, photos, and more can enrich the experience of viewers.

Given the complex nature of the multiple hazards used to develop future hazard maps, it is recommended that a lesson about each hazard is included in a geonarrative before users interact with future maps. Specifically, it is recommended that background information about the Cascadia Subduction Zone, earthquakes, subsidence, tsunamis, tidal fluctuations, and sea level rise be included. For example, a video of a king tide could be included to demonstrate the effects. This background may help some viewers interpret maps and enhance understanding of local science in the community.

It is recommended that a historical timeline such as that described by Marcucci in Section 2.4 be developed using the narrative history materials in Section 3.2. Graphics, including historic shoreline maps in Section 4.2, photographs, video interviews, indigenous stories, renderings, and more can be included alongside the timeline. This will give viewers a greater context surrounding each historic map and ensure viewers know, understand, and appreciate South Beach's history. It is hypothesized that contextualizing future hazard maps with historical information will reduce anxiety around future environmental change and improve development of robust planning strategies.

It is recommended that maps in a geonarrative be interactive, not static as they are found in this thesis. Displaying interactive historical maps would allow users to toggle on historical shorelines of interest and users could compare only historical information of interest. Similarly, allowing users to control future hazard data displayed would allow data of interest or scenarios of interest only to be displayed. This feature would allow data to be as simple or complex as desired by the user, as opposed to a moderator-driven experience. For example, if a property owner is interested in the tsunami inundation on their property they can toggle on only the layer of interest for each scenario. This could create less distraction and could lead to greater understanding than use of a static map or a workshop poster.

Future users of the data in maps could enhance understanding of the data by ensuring the cartography of each map is similar. Multiple different basemaps can be found in maps in Chapters 3 and 4. However, if data is interactive, as recommended, one basemap can be used in the geonarrative which would ensure data is presented more cohesively. This includes map elements such as the north arrow, scale, font, symbology, and more.

Future scenario maps could be paired with 3D visualizations of the community similar to examples provided in Section 5.3.2. Locations of importance such as the Westport marina or the Ocosta elementary school VES could be visualized under each future condition and be on the screen at the same time as future maps. Alternatively, a toggle could be included in the geonarrative which would allow users to see the maps, paired 3D visualization, or both.

The same elements, maps and 3D visualizations, could be used to enhance a story developed for users. The geonarrative could host a story that changes under each future condition. For example, a child walks her dog from her family's mobile home near the Ocosta elementary school, along Montesano Street, past the grocery store and her favorite park, and finds herself at the Westport marina where her dad works as a commercial fisherman. This simple story could be visualized in the geonarrative under each future scenario where the child experiences different changes in her environment. Several 3D visualizations along her walk could be developed under each condition. The following examples could illustrate the effects of multiple hazards in South Beach for the story's subject: today's pre-earthquake setting, 3 feet of sea level rise before an earthquake, her walk to the elementary school during an L1 tsunami scenario, 0 feet of sea level rise after an M1 scenario, etc. It may be difficult for residents to visualize what has been presented in this thesis and a story could allow individuals to envision alternative futures.

There are several other features that could be integrated into interactive maps in a geonarrative. The following could improve user experience:

- Address search
- Basemap options including aerial photos, a street map, a parcel layer, etc.
- Tooltip can be used to display additional information by a user hovering their mouse over map features. This could be limited to the layer itself or attributes associated with the layer as well.

Additional material can be included in the geonarrative in order to improve usability and connection with local residents. For example, it is recommended that photos such as those in Figures 5.1, 5.2, 5.3, and 5.4 below be integrated into a geonarrative in order to give viewers an understanding of the dramatic differences of water levels in South Beach. These images can even be georeferenced to pop-up with tooltip on a map. Additionally, indigenous stories related to content could be video recorded, georeferenced, and included. This could enrich a users' experience with a different type of media which could integrate art and photos associated with stories. Additionally, this could preserve native heritage. Similarly, the history of South Beach could be recorded and paired with historical photos, videos, and maps which could be integrated into the geonarrative.



*Figures 5.1 (above) and 5.2 (below): South Beach low tide (above) and King tide (below).*²⁶⁵



²⁶⁵ Westport Maritime Museum, *South Beach Tide Variation*, 2021, 2021.



*Figures 5.3 (above) and 5.4 (below): South Beach low tide (above) and King tide (below).*²⁶⁶



²⁶⁶ Westport Maritime Museum.

The development process for the geonarrative developed for the City of Flensburg, described in Chapter 2.5, can be adapted to this project.²⁶⁷ The following are recommended steps in developing a geonarrative using information in Chapters 3 and 4.

1. Determine the objectives of the geonarrative.
2. Collaborate with partners.
3. Identify local and regional stakeholders.
4. Identify potential users.
5. Hold consultation meetings with key partners to discuss user needs.
6. Finalize the core team that will develop the geonarrative.
 - a. The Flensburg team consisted of a social scientist, a natural scientist, a web designer, city administrators, a journalist, users, and coastal experts specializing in coastal adaptation, engineering, and modeling.
7. Develop the structure of the geonarrative through storyboarding.
8. Finalize content.
9. Create a prototype of the geonarrative for internal review.
 - a. The Flensburg team had the professional journalist review the language to ensure it was accessible for the target users. Coastal experts and partners reviewed technical content and clarity.
10. Revise the geonarrative based on internal feedback.
11. Demonstrate the first version of the geonarrative to a small group of users.
 - a. The Flensburg team included an anonymous web-based questionnaire survey for feedback from a wide variety of local and regional users.
12. Analyze and categorize feedback.
13. Edit and finalize the final geonarrative.

5.2 Different Uses of a Geonarrative

A geonarrative is extremely versatile and can be used for many different purposes. Geonarratives can be adapted to specific uses and can be enriched with content such as videos, audio, photos, interviews, interactive maps, slideshows, guided tours, and links to other resources specific to the users' needs.²⁶⁸ A geonarrative could be utilized in four distinct situations: to enrich an existing engagement in South Beach, with South Beach stakeholders, in a scenario planning exercise, and in a hypothetical planning exercise.

²⁶⁷ Vollstedt et al., "Co-Production of Climate Services."

²⁶⁸ Environmental Systems Research Institute, "Digital Storytelling with Maps | ArcGIS StoryMaps."

5.2.1 Enrichment of Existing Engagement

A National Science Foundation Coastlines and People (CoPe) Early-Concept Grants for Exploratory Research (EAGER) research project entitled Coastal Hazard Planning in Time is currently being developed with the intention of testing in South Beach in the near future. The project aims to develop new communication tools for coastal resilience. Through the application of scientific consensus and investigation in partner communities, the research team hopes to produce an interactive geonarrative for public education, community planning, and emergency preparedness workshops.

The CoPe EAGER team plans to evaluate the extent to which three geonarratives help the South Beach community in planning and policy decisions related to subduction zone hazards and climate change. The project could demonstrate integration of knowledge across the sciences and inform planning practices that seek to communicate and address geohazard risks in order to increase coastal resilience. Community participants would be placed into focus groups during a workshop and would be interviewed and/or take a survey evaluating the geonarratives. The historical information and scenarios developed in Chapter 4 could be used directly or could be used to inform development of geonarratives.

5.2.2 Geonarrative Development with Local Stakeholders

A second use of the geonarrative is a workshop involving local stakeholders that have not previously interacted with the University of Washington's various engagements in the South Beach community. The objective of this experiment would be to determine the effect that a historical perspective has on planning efforts in communities faced with multiple hazards. The study design is an independent measures design where two different community groups will be presented with different information prior to determining strategies that address multiple natural hazards. The hypothesis is that a community group presented with historical information will develop more creative, innovative mitigation strategies that will be robust in the face of a wider variety of future scenarios than a community group not presented with historical information.

Community workshops would be taught and guided by University of Washington researchers. Professionals could also be present such as geologists, historians, tsunami modelers, scenario planners, emergency managers, and more. Student research assistants could also assist after being trained on protocol. Given the study design, researchers could use two distinct geonarratives. One geonarrative could depict the history of South Beach while a second geonarrative could depict future environmental scenarios for sea level rise, earthquake subsidence, and tsunami inundation. Geonarratives could be used to depict discrete topics or to guide the entire workshop.

The baseline group, herein referred to as ‘group 1’, is modeled on previous engagement workshops in the region. The workshop will begin with participants identifying community values, community assets, and community goals. Values and goals will be recorded by the research team and assets will be mapped for use later in the workshop. Group 1 will go through three phases of the community workshop. Each phase consists of an educational component about the topic and the potential effects to the community. These presentations will be followed by a discussion about mitigation strategies for the topics presented. During the first phase, participants will learn about sea level rise and the potential impacts on the South Beach community. Potential impacts will refer back to the values and assets identified by the participants earlier in the workshop. Then, the participants will brainstorm mitigation strategies to address sea level rise scenarios. During the second phase, participants will learn about the interactions between sea level rise and a CSZ earthquake, including subsidence. Participants will then determine whether mitigation strategies developed during phase 1 will be effective with the addition of an earthquake hazard. In other words, how robust would strategies identified in the first phase be following an earthquake coupled with sea level rise? New strategies can then be explored that would address these coupled hazards. Finally, the third phase will build on phase 2 by addressing sea level rise, a CSZ earthquake, and the resultant tsunami. Once again, group 1 will determine how effective previously discussed strategies would be in a scenario where all three hazards are interacting. The community members will then deliberate effective strategies for all future environmental hazard scenarios outlined in Chapter 4.

The experimental group, herein referred to ‘group 2’, will begin the community workshop by learning about the narrative history of South Beach, outlined in Chapter 3. Group 2 will also be presented with historical environmental change information, including the historical maps detailed in Chapter 4. Participants will then discuss strategies that were implemented that enabled the community to be resilient during various historical changes. It will be emphasized that threats can be environmental changes in addition to economic downturns, population change, technological changes, and so on. Next, the community will identify community values, community assets, and community goals. Values and goals will be recorded by the research team and assets will be mapped for use later in the workshop. Group 2 will then follow the same phases outlined for group 1 above. Researchers can incorporate history into the narrative during each phase. For example, in the sea level rise discussion, strategies implemented at Washaway Beach could be displayed from the American Roundtable project.

Researchers will evaluate the effect a historical perspective had on participants through qualitative analysis. Strategies developed by both groups during each phase will be evaluated by robustness. It is hypothesized that strategies developed by group 2 will be more robust and would create a more resilient community. In other words, strategies would consider and benefit a wider variety of identified community values, assets, and goals.

The Westport South Beach Historical Society would be a natural partner in promoting greater public awareness of local community and environmental history, and in seeing that awareness made relevant to future planning. By partnering in the research, the Historical Society would help to ensure that other local stakeholders ultimately have a stake in the outcomes of the activity, even if some of the other participants are not fully briefed on all aspects of the experimental design until after it is conducted. Such a partnership would also help gain the trust of local participants in advance.

5.2.3 Scenario Planning Exercise

A scenario planning exercise with South Beach stakeholders could be enhanced with a geonarrative that includes information and maps from Chapters 3 and 4. Scenario planning offers South Beach stakeholders a novel approach to exploring long-term planning. Scenario planning considers improbable but possible conditions of drivers such as a CSZ earthquake and climate change driven sea level rise.

The recommended approach to scenario development was originally described by Schwartz as an eight-step scenario planning framework which has been depicted graphically by Tenneson et al. (2013)²⁶⁹ in Figures 5.5 and 5.6. In Step 1 of this process, a geonarrative could serve to assist stakeholders in defining the focal issue by presenting historic information, as described in Section 2.4, and coastal change maps as seen in Section 4.2. This thesis has developed information related to coastal change, driven by earthquake-driven tsunamis and sea level rise, which will have long-term effects in South Beach. Previous community engagement indicates these are drivers the community is interested in. In a scenario planning workshop additional drivers could be explored by the community, one of which could characterize the scenario logics matrix seen in Step 4 in Figure 5.5. Like multiple natural hazards, the second driver selected would have an influence in South Beach and have an element of uncertainty associated with it which, when combined with natural hazards, would create divergent, compelling futures. For example, the economy has already proven to have changed dramatically in South Beach and has had significant impacts on the community. Uncertainty of the economic strength of the region could be influenced heavily by commercial fishing legislation, year-round tourism, an aging population, and more in the foreseeable future. The two chosen drivers would be plotted in a scenario matrix. The four scenarios developed would be “created by crossing the most extreme yet plausible end states of the selected drivers.”²⁷⁰

²⁶⁹ Karis Tenneson, Michal Russo, and Marina Alberti, *Snohomish Basin 2060 Scenarios: Adapting to an Uncertain Future*, 2013, <https://doi.org/10.13140/RG.2.2.14535.39844>.

²⁷⁰ Tenneson, Russo, and Alberti, A5-4

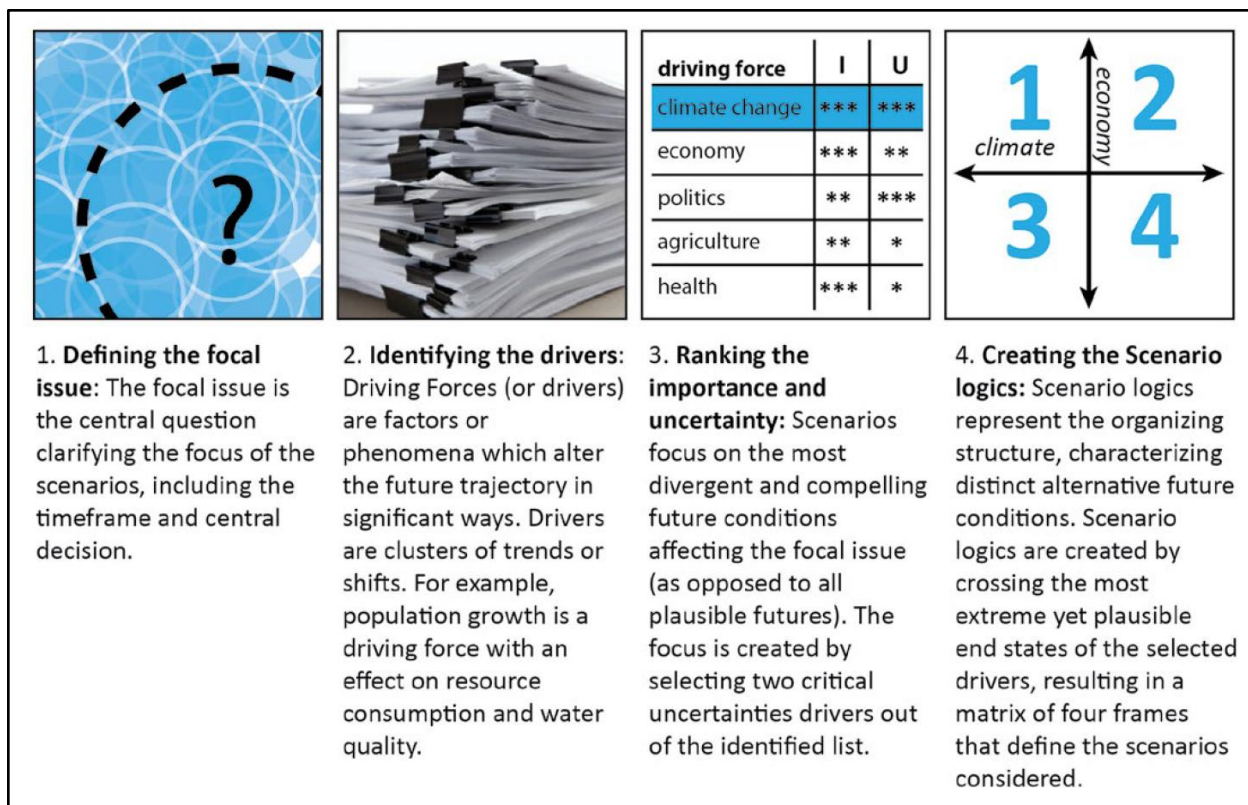


Figure 5.5. Steps 1 to 4 of the scenario planning process, as described by Schwartz (1991)²⁷¹ and visualized by Tenneson et al. (2013).²⁷²

²⁷¹ Peter Schwartz, *The Art of the Long View*, First edition. (New York: Doubleday/Currency, 1991).

²⁷² Karis Tenneson, Michal Russo, and Marina Alberti, *Snohomish Basin 2060 Scenarios: Adapting to an Uncertain Future*, 2013, <https://doi.org/10.13140/RG.2.2.14535.39844>. A5-4.

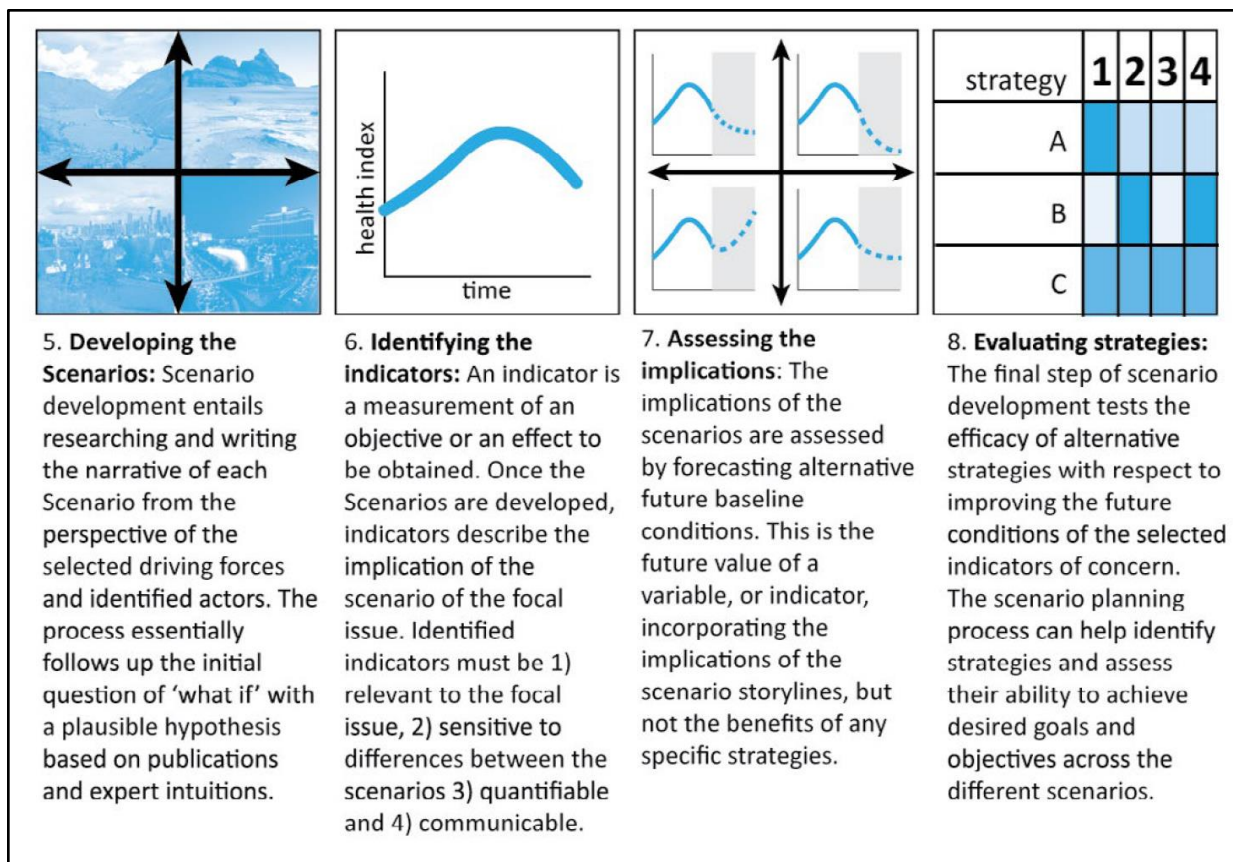


Figure 5.6. Steps 5 to 8 of the scenario planning process, as described by Schwartz (1991)²⁷³ and visualized by Tenneson et al. (2013).²⁷⁴

Development of the scenarios, Step 5, could be aided by a geonarrative which could provide easily-accessible and understandable information for stakeholders to write narratives for each of the four scenarios. For example, descriptions of various earthquake possibilities could be hosted in a geonarrative. Once indicators have been selected, the geonarrative could yet again play a role in visualizing the implications of each of the scenarios. Maps (see Chapter 4), 3D visualizations (see Figures 5.7, 5.8, 5.9, and 5.10), videos, photos, and other supplemental materials could be hosted on a geonarrative and could allow users to assess the implications of various scenarios.

Geonarratives could serve to inform the scenario planning process but could also be developed alongside the scenario planning process. Researchers and stakeholders could add information into a geonarrative as decisions about scenarios are finalized. This geonarrative could host the

²⁷³ Peter Schwartz, *The Art of the Long View*, First edition. (New York: Doubleday/Currency, 1991).

²⁷⁴ Karis Tenneson, Michal Russo, and Marina Alberti, *Snohomish Basin 2060 Scenarios: Adapting to an Uncertain Future*, 2013, <https://doi.org/10.13140/RG.2.2.14535.39844>. A5-5.

scenario planning process and final outcome, as opposed to or in addition to a report such as that developed for the Snohomish Basin 2060 Scenarios project.²⁷⁵

5.2.4 Remote Planning Exercise

A fully developed geonarrative or set of geonarratives could be used to guide a planning exercise for individuals that have no previous knowledge of South Beach or the environmental hazards that threaten the community. This exercise could be individually guided or could be integrated into a design charrette or other workshop. This approach to a planning exercise would allow researchers to control all local information including information outlined in Chapters 3 and 4. In addition, researchers could include community values and assets collected during the UW 2018 multi-disciplinary studio. Participants could gain insight into the history of the region and the community dynamics, go on a self-guided tour of South Beach, and assess the hazards facing the community. Participants could then develop planning and design interventions in response to the environmental hazard scenarios in South Beach. The interventions developed during this exercise could be beneficial for both planners and the South Beach community. This type of exercise could be particularly useful during situations such as the COVID-19 pandemic where travel is restricted or for multi-national planning groups that have a need to understand communities without having the opportunity to visit themselves.

5.3 Other Community Engagement Materials

While a geonarrative is a potentially useful tool, communities can be engaged in many different ways and in a variety of settings. In recent years, technological innovation has introduced novel methods of engagement. The following materials and methods could be used independently or in conjunction with one another in future South Beach engagement.

5.3.1 Printed Materials

As seen in the community engagement effort for the 2018 Grays Harbor County Hazard Mitigation Plan, residents in South Beach are traditionally presented with printed materials such as maps, posters, and handouts.²⁷⁶ These materials were paired with presentations by subject matter experts who were available to the public throughout events. Given the aging population of the South Beach population, printed materials could continue to be useful as a means to educate

²⁷⁵ Karis Tenneson, Michal Russo, and Marina Alberti, *Snohomish Basin 2060 Scenarios: Adapting to an Uncertain Future*, 2013, <https://doi.org/10.13140/RG.2.2.14535.39844>.

²⁷⁶ Bridgeview Consulting, "Grays Harbor County 2018 Multi-Jurisdiction Hazard Mitigation Plan Update Volume 1: Planning-Area-Wide Elements," July 2018, https://cms5.revize.com/revize/graysharborcounty/Emergency%20Management/Planning/Grays%20Harbor%20County%20HMP_Plan_Final_2018.pdf.

and engage residents in addition to or in place of a geonarrative. Printed materials could be particularly useful for group discussions including asset mapping or strategic placement of mitigation strategies.

5.3.2 Digital Materials

Digital materials for community engagement could consist of materials developed for online use or digitized materials that were adapted from print media. While a geonarrative could host all the following online materials, these materials could be individually available for review by South Beach residents: images, videos, interviews, audio files, maps, timelines, virtual tours, 3D models, and more.

Visual learning tools used in a proposed public participation process in British Columbia, Canada could be similarly useful in South Beach. Researchers developed a framework to build awareness, capacity, and agency on climate change at a local level by generating scenarios and visualizations in collaboration with local stakeholders and scientists.²⁷⁷ Four holistic scenarios combined multiple aspects of climate change and integrated a wide range of scenario drivers, impacts, responses, and adaptation and mitigation strategies. Visual tools were developed to maximize engagement, achieve rapid learning, and ensure public interaction with action plans and solutions. Visualization media can range from 2D photorealistic tools such as Photoshop to 3D programs such as ArcSCENE, Google Earth, Sketch-up, Visual Nature Studio and Community Viz. One 3D visualization developed for engagement can be seen in Figure 5.7. 3D visualizations over multiple points in time created 4D visualizations of community features, as seen in Figure 5.8. Visioning workshops used a multimedia PowerPoint presentation, accompanied by verbal commentary, photographs, maps, and charts. Participants noted that the local context and visualizations made climate change information ‘hit home’ and there was a dramatic increase in the belief that actions can significantly reduce the impacts of climate change. One participant stated “I learned how climate change could affect my community in a very graphic way. Numbers may not stay with me but visuals will.”²⁷⁸ Following the workshop, participants were more willing to make personal changes and more willing to support climate change policies at the local scale.²⁷⁹ South Beach stakeholders could be similarly educated and inspired by visualizations depicting climate change, natural hazards, scenarios, and mitigation strategies.

²⁷⁷ Stephen Sheppard et al., “Future Visioning of Local Climate Change: A Framework for Community Engagement and Planning with Scenarios and Visualisation,” *Futures* 43, no. 4 (May 1, 2011): 400–412, <https://doi.org/10.1016/j.futures.2011.01.009>.

²⁷⁸ Sheppard et al., 408.

²⁷⁹ Sheppard et al, 409.

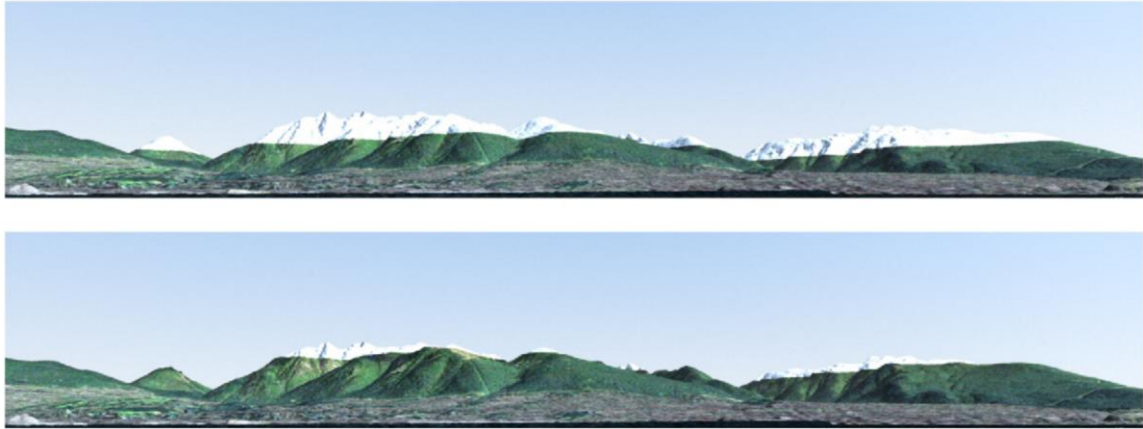


Figure 5.7. 3D visualization of snow pack in Vancouver's Northshore mountains in 2000 and a 2100 scenario.²⁸⁰



Figure 5.8. 4D visualizations of sea level rise scenarios and strategies in South Delta, British Columbia.²⁸¹

²⁸⁰ Stephen Sheppard et al., "Future Visioning of Local Climate Change: A Framework for Community Engagement and Planning with Scenarios and Visualisation," *Futures* 43, no. 4 (May 1, 2011): 400–412, <https://doi.org/10.1016/j.futures.2011.01.009>, 407.

²⁸¹ Sheppard et al, 408.

3D visualization technology, available at the National Home Education Research Institute Natural Hazards Reconnaissance Facility at the University of Washington, is currently being used to develop a 3D model of the Westport Peninsula.²⁸² This visualization effort, through the CoPe EAGER Coastal Planning in Time project, could have equally significant influence for South Beach stakeholders. As in British Columbia, workshop participants interacting with these visualizations could learn how the multiple hazards outlined in this thesis will influence their home and be more willing to support local mitigation efforts.

Another impressive project, the “Resilience Nantucket” project, aimed to understand the threat of climate change in the community and work towards a resilient future. The project team also developed 3D visualizations of sea level rise in the historic core of Nantucket Town.²⁸³ The initiative aimed to digitally document the core of the historic area, the waterfront, and Brant Point and prepare 3D visualizations of sea level rise projections.²⁸⁴ Visualizations of 3.25 feet of sea level rise in 2040 and 8.04 feet of sea level rise in 2100 can be seen in Figures 5.9 and 5.10 below. Realistic visualizations of the community and sea level rise such as those in Nantucket could be equally impactful in discussions of long-term resilience with South Beach stakeholders.

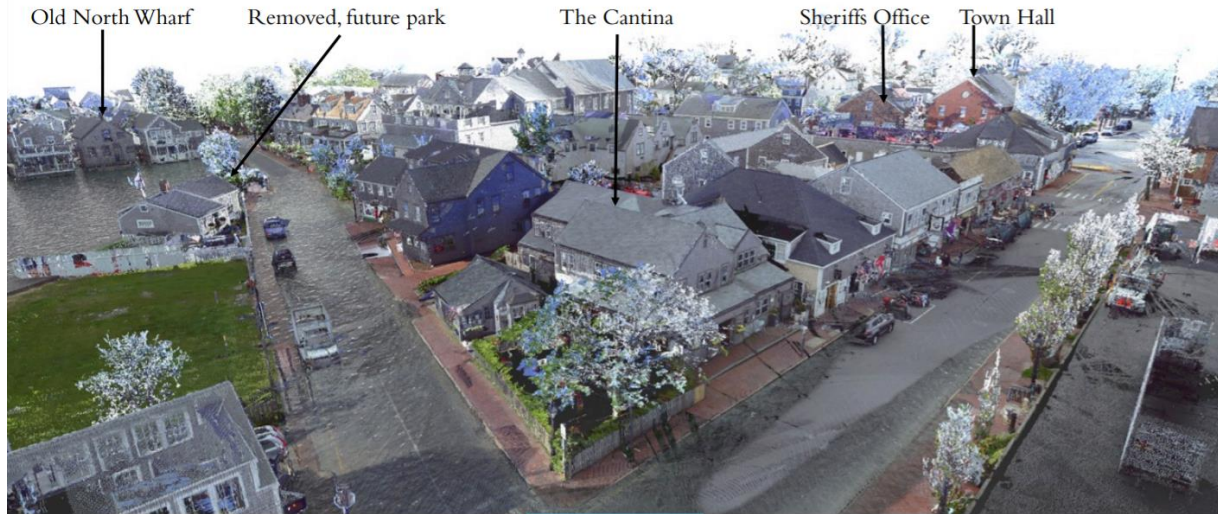
²⁸² Daniel Abramson et al., “CoPe EAGER: Coastal Hazard Planning in Time” (National Science Foundation Award #1940024, 2019), Abstract available at https://www.nsf.gov/awardsearch/showAward?AWD_ID=1940024.

²⁸³ Lisa Craig et al., “Resilient Nantucket Preparing Your Historic Property for a Future of Rising Seas,” <https://www.nantucket-ma.gov/DocumentCenter/View/37494/Resilient-Nantucket---Community-Forum-1-September-18-2020-PDF>.

²⁸⁴ Lisa Craig et al.

EASY & BROAD STREETS

3.25 FEET in 2040



UF UNIVERSITY of FLORIDA

RESILIENT NANTUCKET

Figure 5.9. Easy and Broad Streets, Nantucket under 3.25 feet sea level rise.²⁸⁵

EASY & BROAD STREETS

8.04 FEET in 2100



UF UNIVERSITY of FLORIDA

RESILIENT NANTUCKET

Figure 5.10. Easy and Broad Streets, Nantucket under 8.04 feet sea level rise.²⁸⁶

²⁸⁵ Lisa Craig et al., “Resilient Nantucket Preparing Your Historic Property for a Future of Rising Seas,” <https://www.nantucket-ma.gov/DocumentCenter/View/37494/Resilient-Nantucket---Community-Forum-1-September-18-2020-PDF>.

²⁸⁶ Lisa Craig et al., “Resilient Nantucket Preparing Your Historic Property for a Future of Rising Seas,” <https://www.nantucket-ma.gov/DocumentCenter/View/37494/Resilient-Nantucket---Community-Forum-1-September-18-2020-PDF>.

Another particularly useful tool could be developed with the information in this thesis. Due to the complex nature of future environmental scenarios in South Beach, an interactive website where users can easily access customizable, science-based, local information could be extremely useful for hazard planning. One tool the website could be modeled after, the Surging Seas Risk Finder, has a short video introduction that introduces users to the tool and explains how to use it.²⁸⁷ This could be useful for South Beach residents that may be unfamiliar with similar tools. Users can also download factsheets, tables, and figures from the Surging Seas Risk Finder tool.²⁸⁸ Additionally, The Surging Seas tool allows users to identify over 100 potential impacts for communities from vital infrastructure to hazardous waste sites.²⁸⁹ This tool allows users multiple ways to look at the future.²⁹⁰ Other scenario planning efforts are giving users control, such as the Interactive Sea Level Rise Data Visualization Tool.²⁹¹ This tool allows users to visualize and compare local sea level projections. A localized version of these tools could be developed which incorporates historical environmental change data and future environmental change maps overlaid on identified community assets. It is recommended this tool be discussed with local stakeholders but it could include SLR, earthquake severity, time, probability, and more elements the community values. This would allow users to understand the potential impacts of each situation on the community in different self-selected scenarios.

Digital materials can create equitable access to data and planning discussions. South Beach stakeholders are not limited to residents and property owners. Other stakeholders such as business operators or employees may have conflicts with in-person meetings, may have a language barrier, or have other concerns that would prevent them from participating in traditional community engagement meetings. Digitally available materials could allow these individuals access to the same information on a flexible schedule, increasing the number of individuals involved in community hazard planning.

5.3.3 Interactive Materials

New, innovative tools are being introduced into the public engagement sphere which allows groups to collaborate in a workshop setting. One such tool is weTable which was used during the 2018 workshop with South Beach stakeholders. WeTable allows participants to interact with data

²⁸⁷ Climate Central, “Surging Seas Risk Finder,” Climate Central, 2021, <http://riskfinder.climatecentral.org>.

²⁸⁸ Climate Central.

²⁸⁹ Climate Central.

²⁹⁰ Climate Central.

²⁹¹ University of Washington Climate Impacts Group, “Interactive Sea Level Rise Data Visualizations.”

with little guidance using tables and pens.^{292,293} This tool is “an ideal tool for use in community projects where participants use data and maps to help define planning priorities and strategies”.²⁹⁴ This tool is especially useful when for small groups exploring GIS data at a table as opposed to crowding around a computer or viewing presentations at an inconvenient distance.²⁹⁵ Tools such as weTable can be useful in South Beach for asset mapping, comparison of different scenarios, discussing hazard mitigation options, and so on.

Another interactive tool that could be useful in South Beach is interactive visualization. One case study in Scotland attempted to address the preferences of future land use in the face of climate change using spatially explicit quantitative scenarios of land use change in combination with interactive visualization.²⁹⁶ Four scenarios for 2050 were developed and adjusted to the local context using two axes: scale of governance and societal values. 3D models were created to reflect each scenario. A virtual reality environment was then used to collect public opinion of land use. A drag-and-drop feature allowed participants to position desired elements such as wind turbines, forests, parking, playgrounds, and housing developments in the landscape. Another feature allowed users to define where they strongly opposed certain features. Feedback from participants was strongly positive. Over 80% of participants found the interactive environment effective for capturing future land use priorities including the role of climate change in modifying options. Users found it easy to represent alternative future land uses and had positive feedback regarding the opportunity to discuss benefits and risks associated with each scenario.²⁹⁷ This interactive method could be adapted to reflect multi-hazard scenarios in South Beach using 3D models and drag-and-drop assets. This approach to visualizing the effects of future hazards could be beneficial to residents and, similar to the Scotland case study, could spark discussions about benefits and risks associated with various scenarios.

5.3.4 Workshop

A traditional community workshop can be implemented or adapted in South Beach in order to gather input on hazard planning. However, the traditional workshop can also be adapted with the tools above: geonarratives, digital materials, and interactive materials. These tools can be used to enhance understanding of complex hazard material, improve discussions between participants

²⁹² Steven Mikulencak and John Jacob, “The WeTable: A Tool for Participatory GIS,” September 2011, 7.

²⁹³ Juita-Elena Yusuf et al., “Participatory GIS as a Tool for Stakeholder Engagement in Building Resilience to Sea Level Rise: A Demonstration Project,” *Marine Technology Society Journal* 52, no. 2 (March 1, 2018): 45–55, <https://doi.org/10.4031/MTSJ.52.2.12>.

²⁹⁴ Steven Mikulencak and John Jacob, “The WeTable: A Tool for Participatory GIS,” September 2011, 1.

²⁹⁵ Mikulencak and Jacob.

²⁹⁶ Chen Wang et al., “Visualisation Techniques to Support Public Interpretation of Future Climate Change and Land-Use Choices: A Case Study from N-E Scotland,” *International Journal of Digital Earth* 9, no. 6 (June 2016): 586–605, <https://doi.org/10.1080/17538947.2015.1111949>.

²⁹⁷ Wang et al, 600.

and subject matter experts, track discussions and decisions, and potentially raise understanding and support for local policy changes. As with one Grays Harbor Hazard Mitigation Plan workshop, participants can visit relevant sites, such as the Ocosta School tsunami vertical evacuation structure. Workshops can also be supplemented with online surveys such as Google Surveys 360, Survey Monkey, and other tools to determine understanding following a workshop.

One unique approach to multi-hazard planning in a workshop setting is a multi-hazard tournament (MHT). In a case study in Cedar Rapids, Iowa an MHT framework was used as a collaborative, holistic, and proactive planning approach to address multiple water-related hazards.²⁹⁸ In this case study, the traditional trade-off analysis and iterative planning approach was adapted to include a serious gaming approach which incorporated a competitive, team-oriented element to a workshop. Participants increased their understanding of strategic policies and investments to reduce risks and saw the potential impacts of investments in mitigation options under different climate scenarios. In order to win the tournament, a team had to plan and develop “the most socially, economically, and environmentally acceptable watershed management strategies that minimize the flood, drought, and water quality vulnerability for current and future climate conditions in the Cedar River basin”.²⁹⁹ Researchers note the MHT framework can be applied differently depending on the workshop details and objectives. Tools can range from paper materials to excel based or web-based tools. In this workshop, players used a web-based decision support system developed for the watershed to improve understanding of trade-offs between adaptation options.³⁰⁰ A serious gaming approach that involves a competitive, team approach to a multi-hazard planning workshop could be a fun, engaging way for South Beach stakeholders to develop adaptation and mitigation strategies appropriate for the local environment.

Chapter 6: Conclusion

This thesis aimed to provide stories about the community and environment that can be used by the South Beach community, researchers, and policy makers with the goal of maintaining a resilient social-ecological system in the face of multiple natural hazards. These materials include a narrative history of the region, a description of the community today, future environmental change scenarios, and historical maps depicting environmental change of the region. These materials are recommended for use in an accessible, web-based format such as a geonarrative. While developing a geonarrative with these materials is beyond the scope of this thesis, a development process is outlined for future practitioners. Use of this versatile tool is described for

²⁹⁸ Andrea Carson et al., “Serious Gaming for Participatory Planning of Multi-Hazard Mitigation,” *International Journal of River Basin Management* 16, no. 3 (2018): 379–91, <https://doi.org/10.1080/15715124.2018.1481079>.

²⁹⁹ Carson et al., 383.

³⁰⁰ Carson et al.

four community engagement settings, all of which could be beneficial for the long-term resilience of South Beach. Finally, alternative materials, technologies, and settings aside from a geonarrative are explored for community engagement. Alternative materials could be used independently or in conjunction with one another in order to allow South Beach stakeholders an opportunity to develop stories.

The community of South Beach exists within a social-ecological system that has experienced over 10,000 years of Cascadia Subduction Zone earthquakes and tsunamis.³⁰¹ The environment of South Beach has adapted to these catastrophic events in the past and remembers how to cope with the environmental change. Land that today hosts a forest of large trees may be subsided below daily tides, killing those trees and creating a ghost forest. However, the larger forest will continue to live on despite the subsidence. Oyster beds that are thriving today may be permanently underwater after a CSZ event or sea level rise, but new oyster beds could develop in other locations. The people that make up the social-ecological system today have not personally experienced a CSZ earthquake, nor sea level rise. They do not remember drastic environmental change, but like the forests and oyster beds they can also adapt and ‘remember’ in new ways, through use of history, scientific models, and maps. The topography is largely unvaried in South Beach, so when presented with the potential of a tsunami the community created an alternative high ground - the Ocosta School VES. Therefore, South Beach has already shown they can be resilient in the face of a hazard. This work takes previous work a step farther and integrates a historical perspective and multiple hazards for community contemplation. It is hypothesized, and yet to be tested, that this information will yet again encourage creative, long-term thinking. The system could be triggered by one of the hazards to enter a reorganization phase, however, as Holling notes, remembering aids in the system’s reorganization and recovery.³⁰² It is believed that these various perspectives on the system will increase the memory of the people living within this social-ecological system.

The products and processes outlined in this thesis for disaster communication and planning have built on lessons learned from other literature. Non-indigenous South Beach stakeholders do not have experiences or stories of their own to pass down through the generations like indigenous peoples or village residents in Southwest England. Christchurch, New Zealand had little experience with earthquakes prior to 2010. As a result, residents and the City alike struggled to adapt. It is the goal that the information in Chapters 3 and 4 will encourage South Beach residents and local governments to prepare and create robust plans to respond to the dynamic future ahead, increasing the resilience of the community.

³⁰¹ Bridgeview Consulting, “Grays Harbor County 2018 Multi-Jurisdiction Hazard Mitigation Plan Update Volume 1: Planning-Area-Wide Elements,” July 2018, https://cms5.revize.com/revize/graysharborcounty/Emergency%20Management/Planning/Grays%20Harbor%20County%20HMP_Plan_Final_2018.pdf.

³⁰² C. S. Holling, “Understanding the Complexity of Economic, Ecological, and Social Systems,” *Ecosystems (New York)* 4, no. 5 (2001): 390–405, <https://doi.org/10.1007/s10021-001-0101-5>.

The way that the story is told to the community will influence their sense of resilience in the face of incredible environmental change. It could be important to frame future scenarios with history, both of the people and the environment. After all, “as an activity, planning is imbued with time”³⁰³ - past, present, and future. Each is an important element of the story. Marcucci argued that without history of the landscape and processes that guided change, “we are unable to envision future landscape changes”. Abbott and Adler had similar views: “Scenario building in one sense is history in reverse; focused on the future, it utilizes the same combination of disparate pieces of information within a broad context to create an understandable narrative of events.”³⁰⁴ Through this research, it became evident that environmental change has shaped life in South Beach. It is also evident that environmental change will affect the future of life in the region.

³⁰³ Daniel J Marcucci, “Landscape History as a Planning Tool,” *Landscape and Urban Planning* 49, no. 1 (May 25, 2000): 67–81, [https://doi.org/10.1016/S0169-2046\(00\)00054-2](https://doi.org/10.1016/S0169-2046(00)00054-2). 69.

³⁰⁴ Carl Abbott and Sy Adler, “Historical Analysis as a Planning Tool,” *Journal of the American Planning Association* 55, no. 4 (December 31, 1989): 467–73, <https://doi.org/10.1080/01944368908975435>.

Appendices

Appendix A. Tsunami Inundation Maps

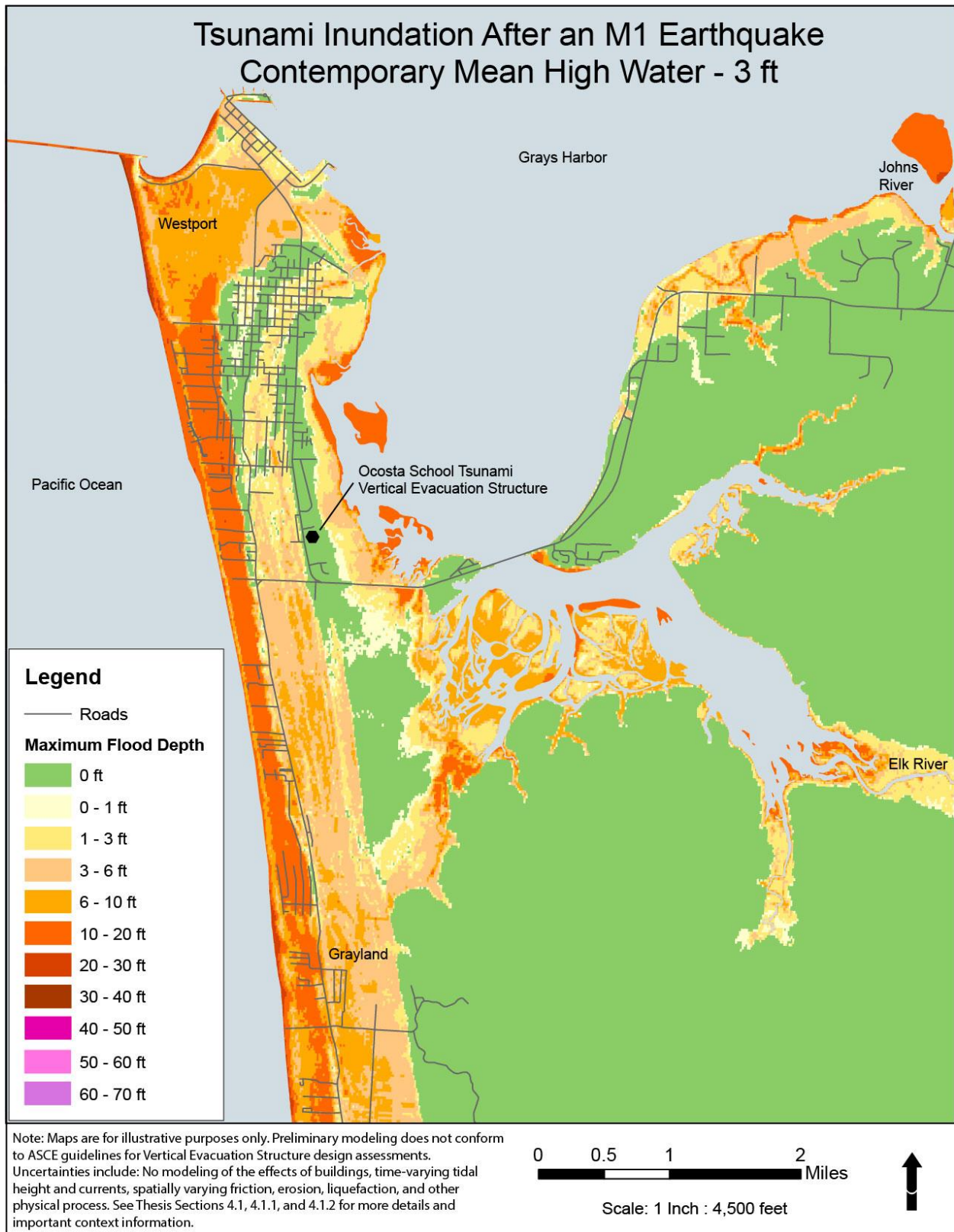


Figure A.1. Tsunami inundation map for M1 earthquake scenario at background water level contemporary mean high water - 3 feet

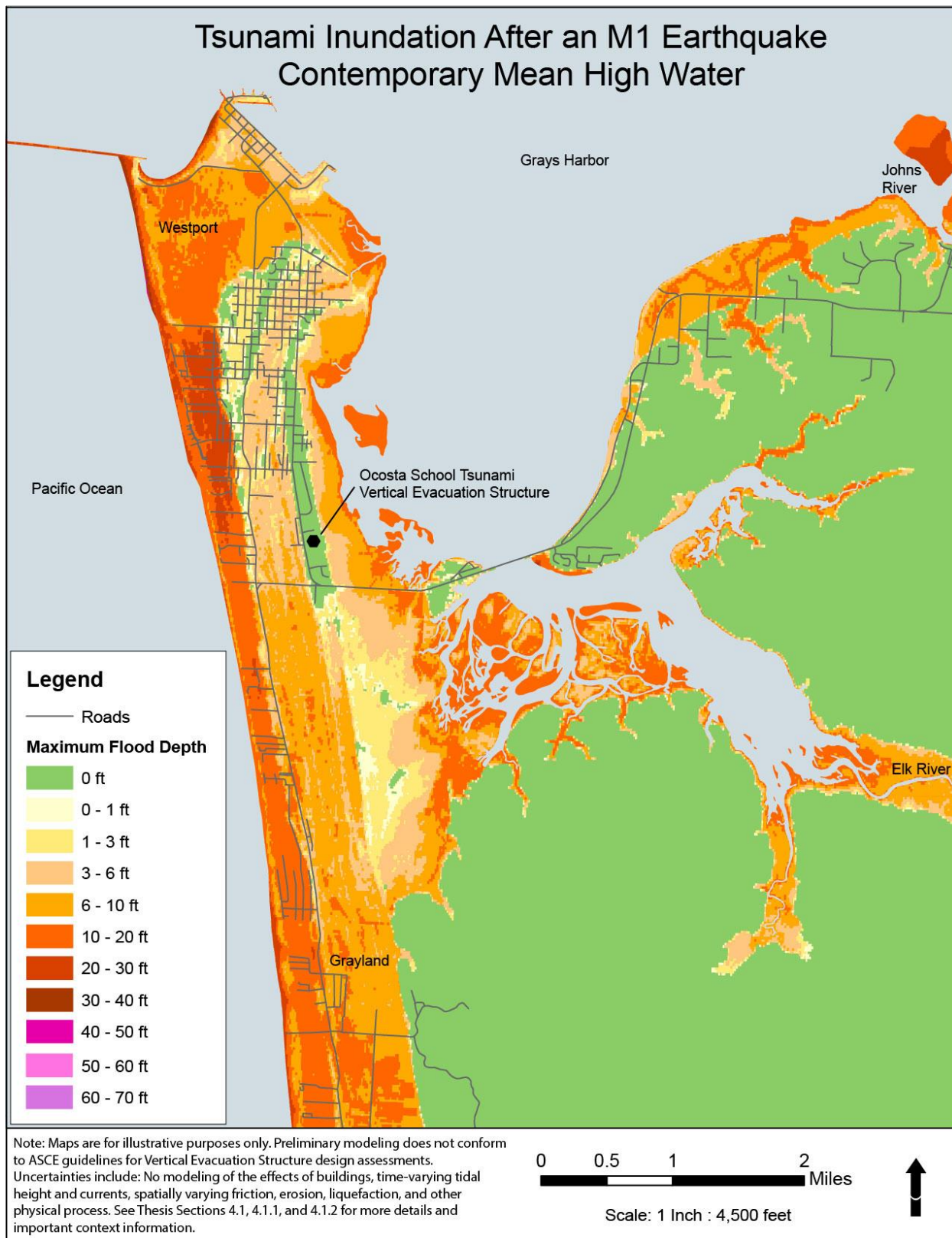


Figure A.2. Tsunami inundation map for M1 earthquake scenario at background water level contemporary mean high water

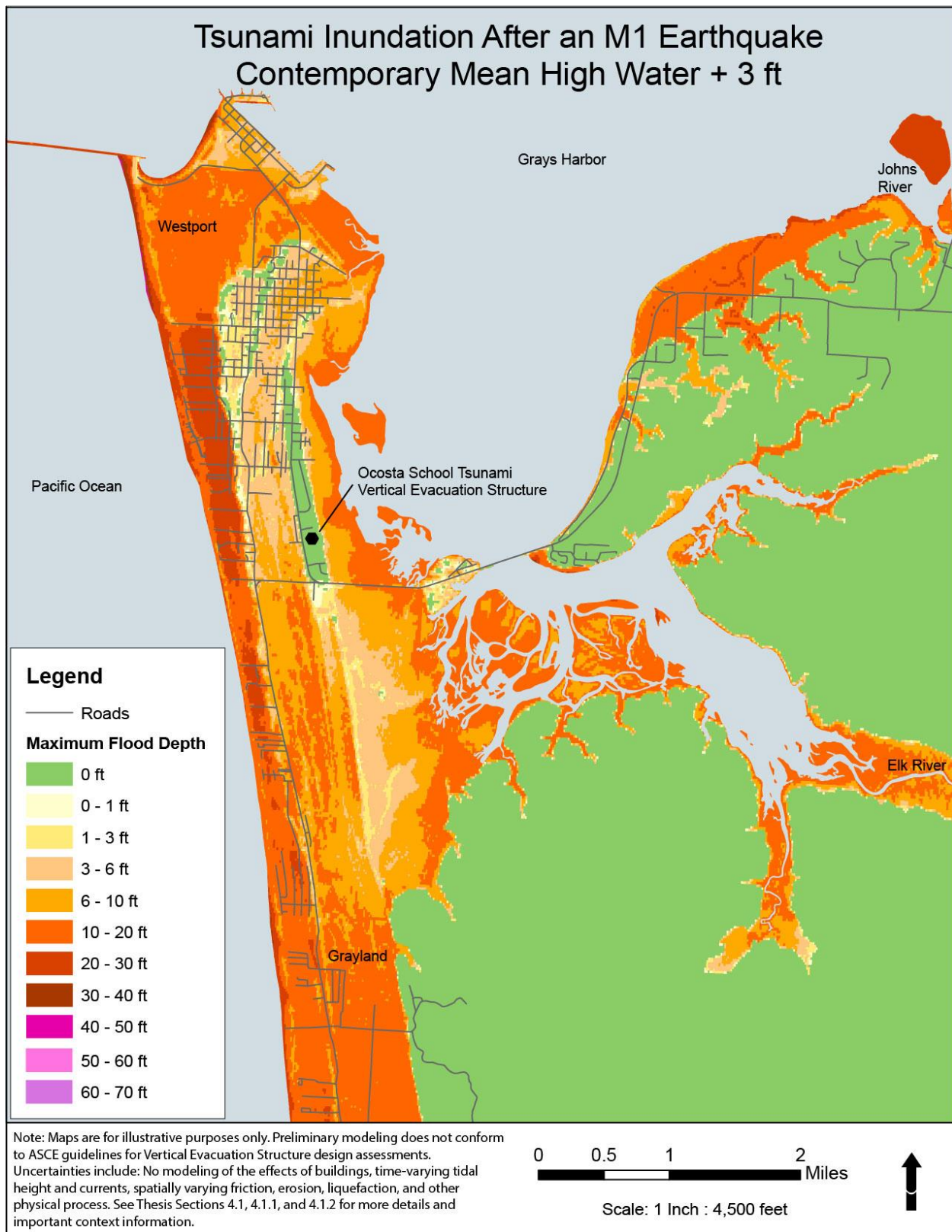


Figure A.3. Tsunami inundation map for M1 earthquake scenario at background water level contemporary mean high water + 3 feet

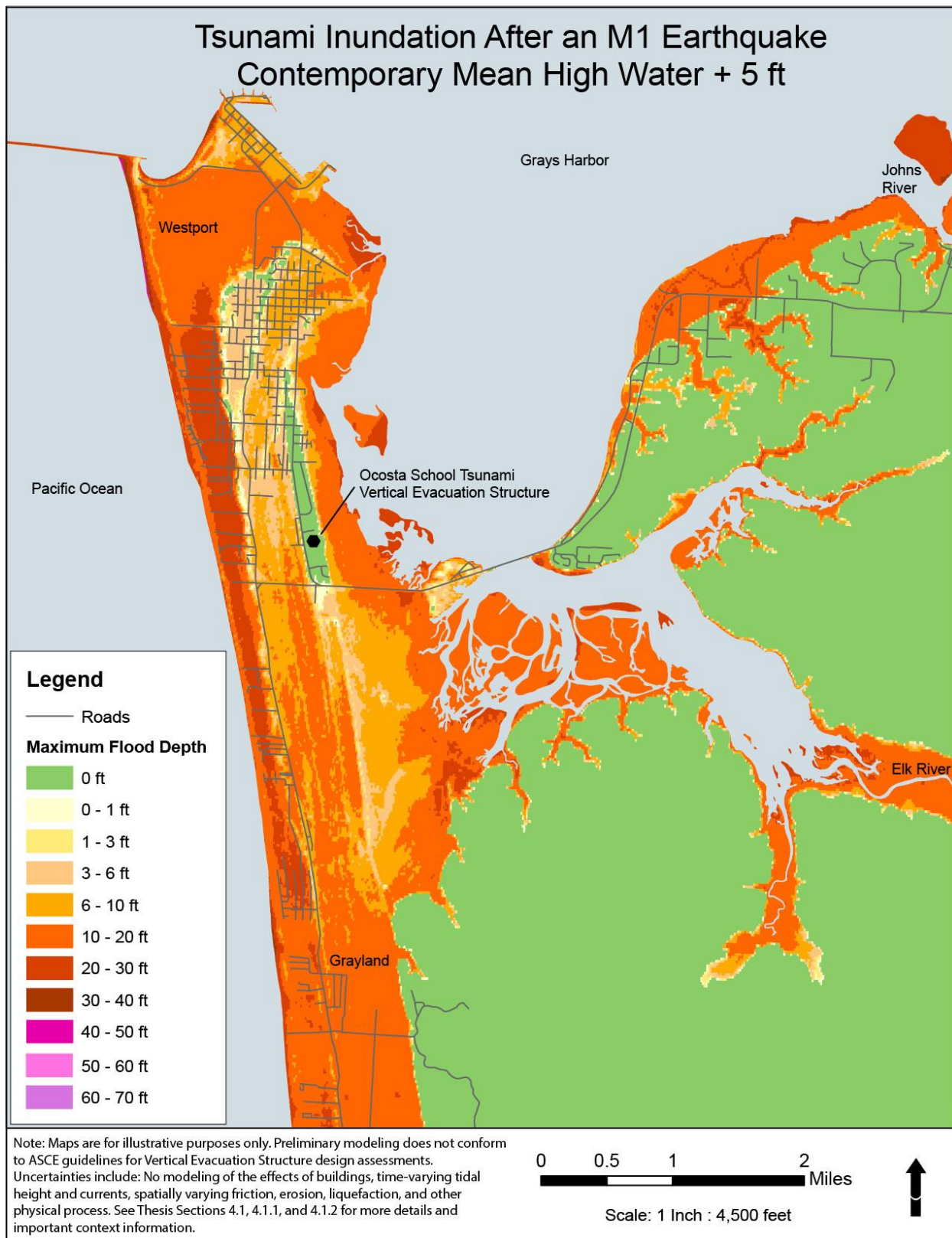


Figure A.4. Tsunami inundation map for M1 earthquake scenario at background water level contemporary mean high water + 5 feet

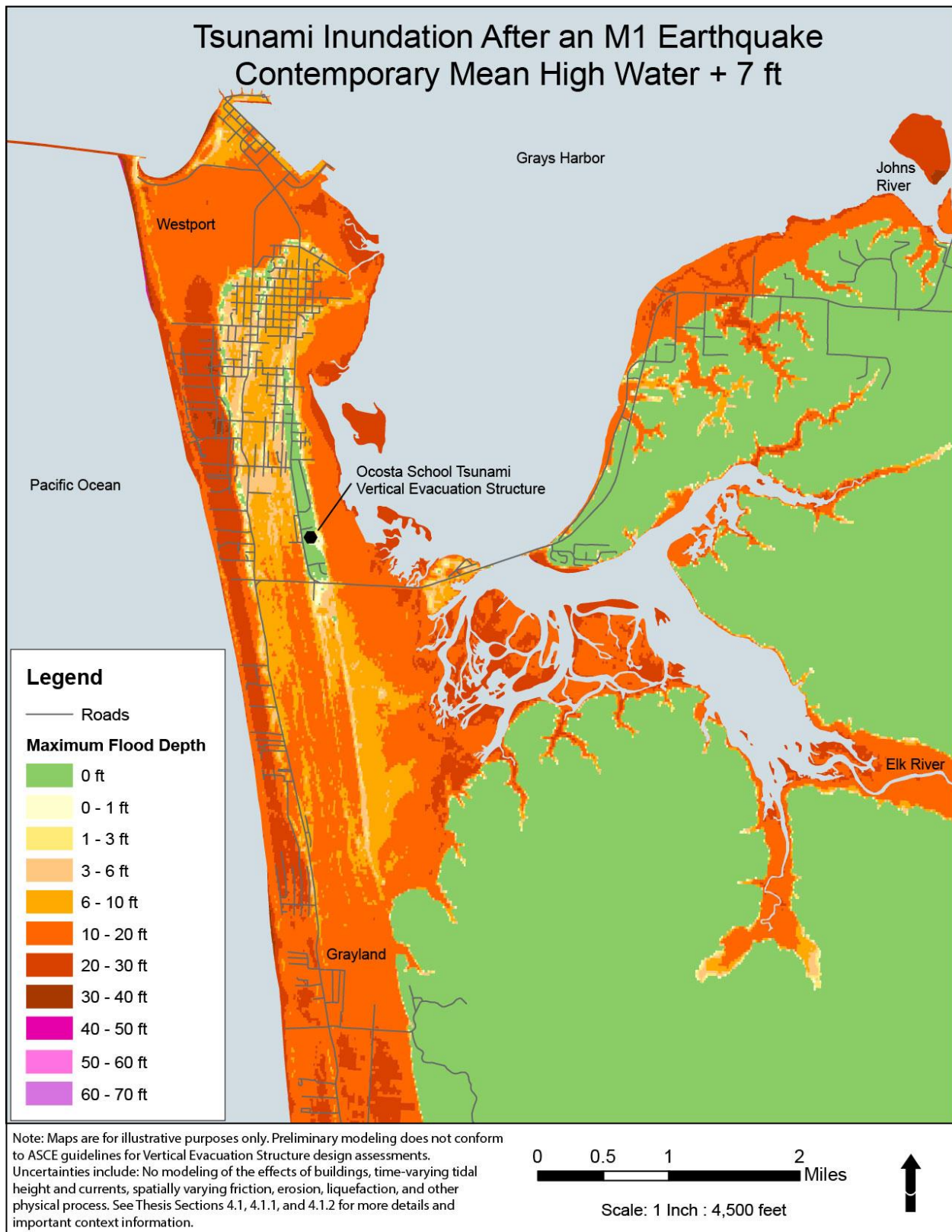


Figure A.5. Tsunami inundation map for M1 earthquake scenario at background water level contemporary mean high water + 7 feet

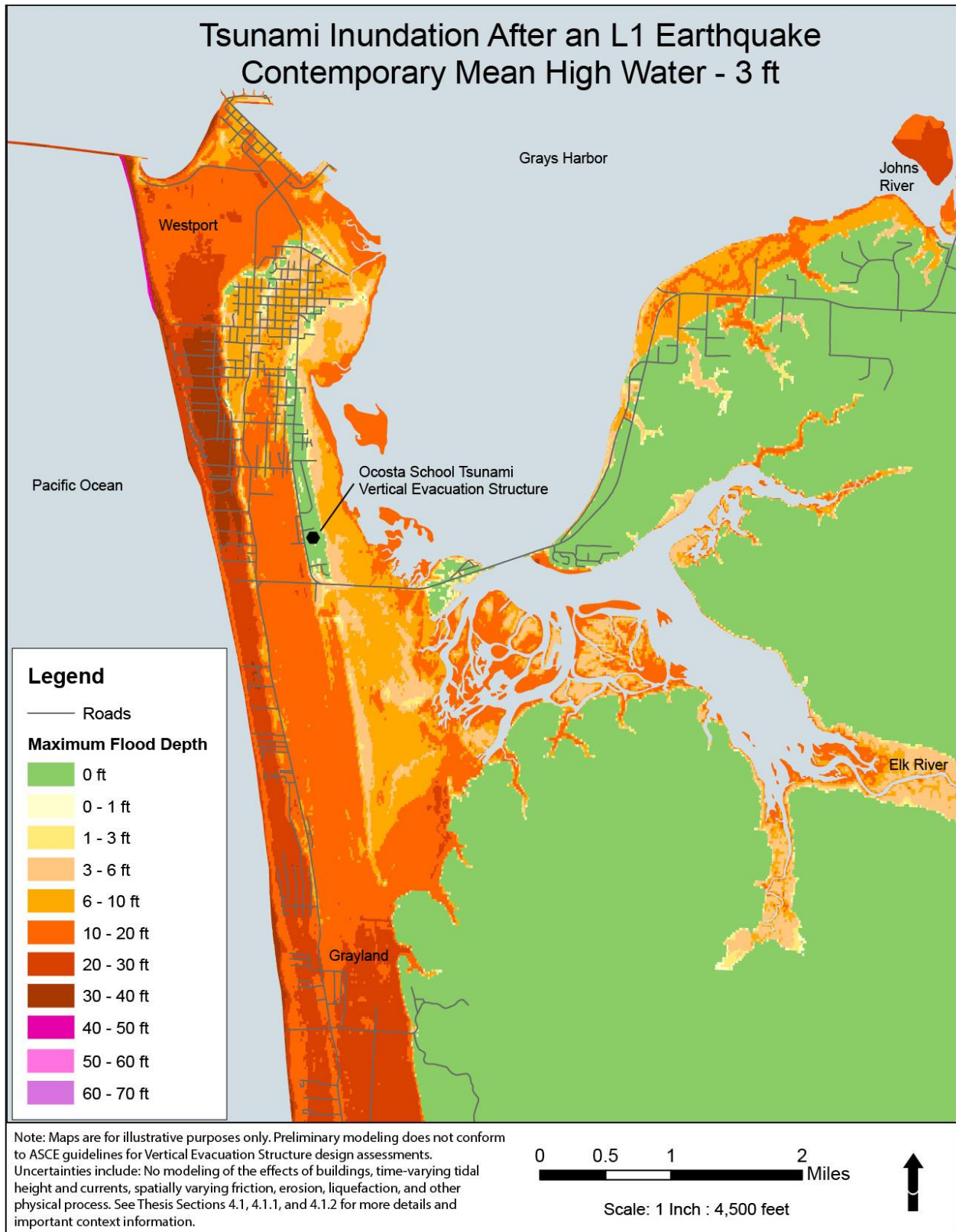


Figure A.6. Tsunami inundation map for L1 earthquake scenario at background water level contemporary mean high water - 3 feet

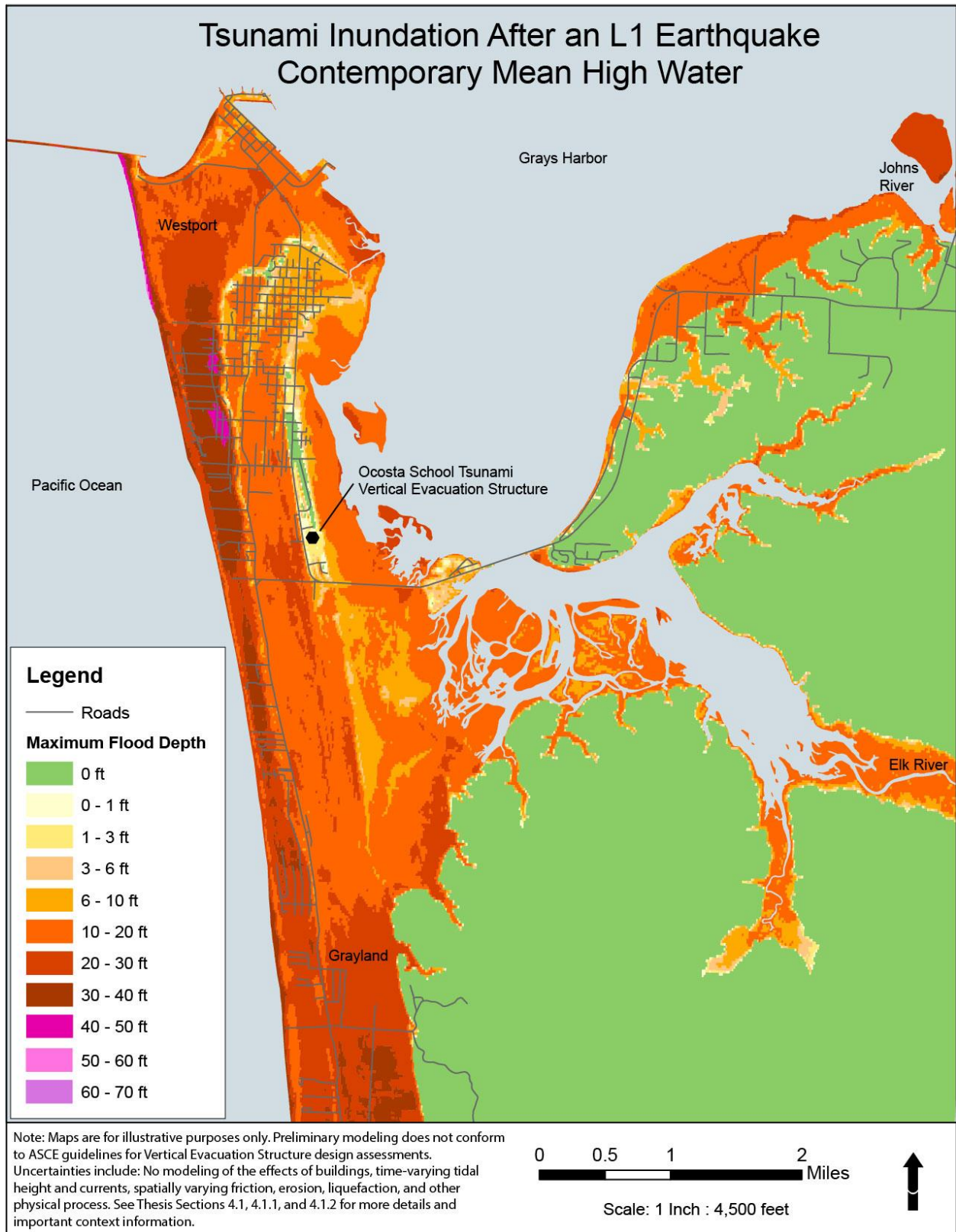


Figure A.7. Tsunami inundation map for L1 earthquake scenario at background water level contemporary mean high water

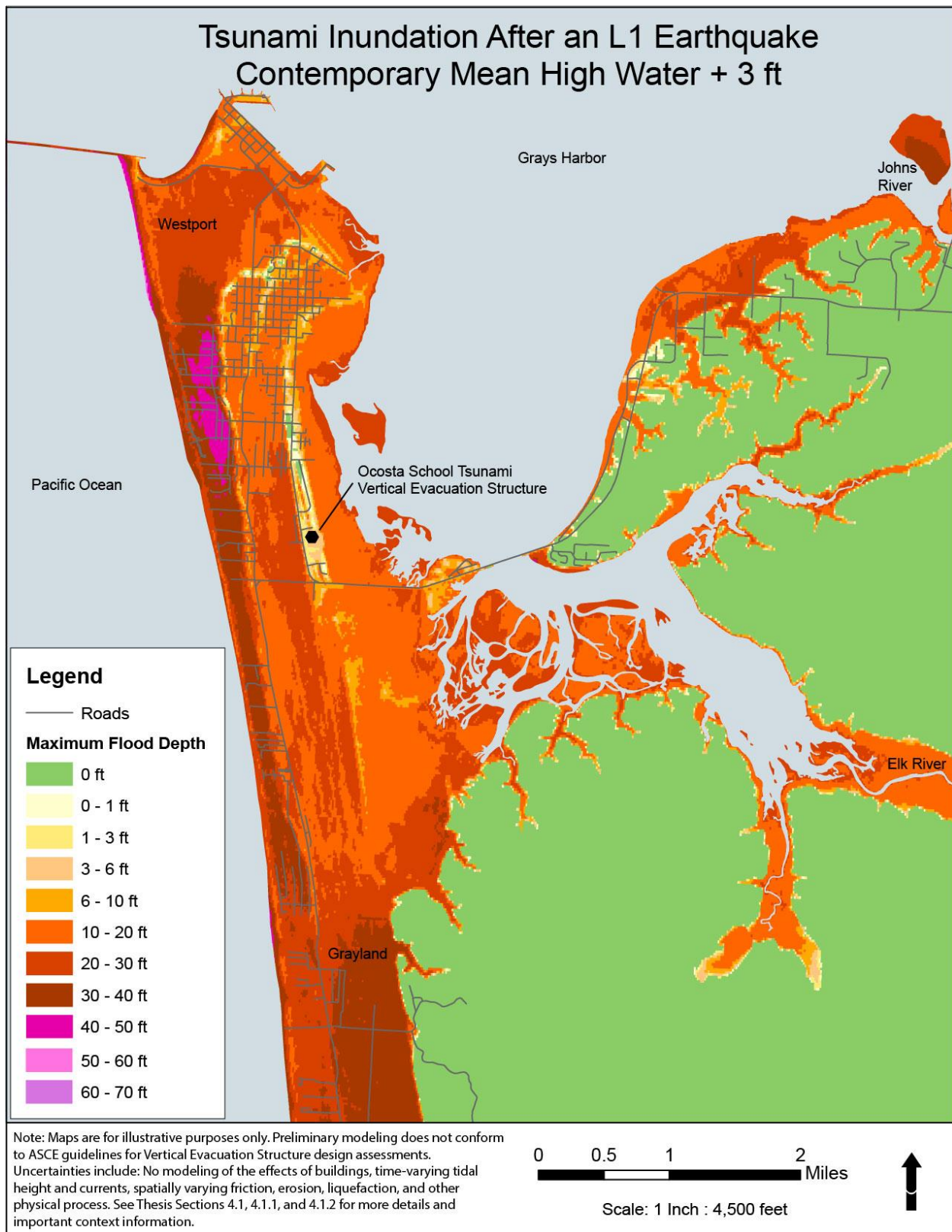


Figure A.8. Tsunami inundation map for L1 earthquake scenario at background water level contemporary mean high water + 3 feet

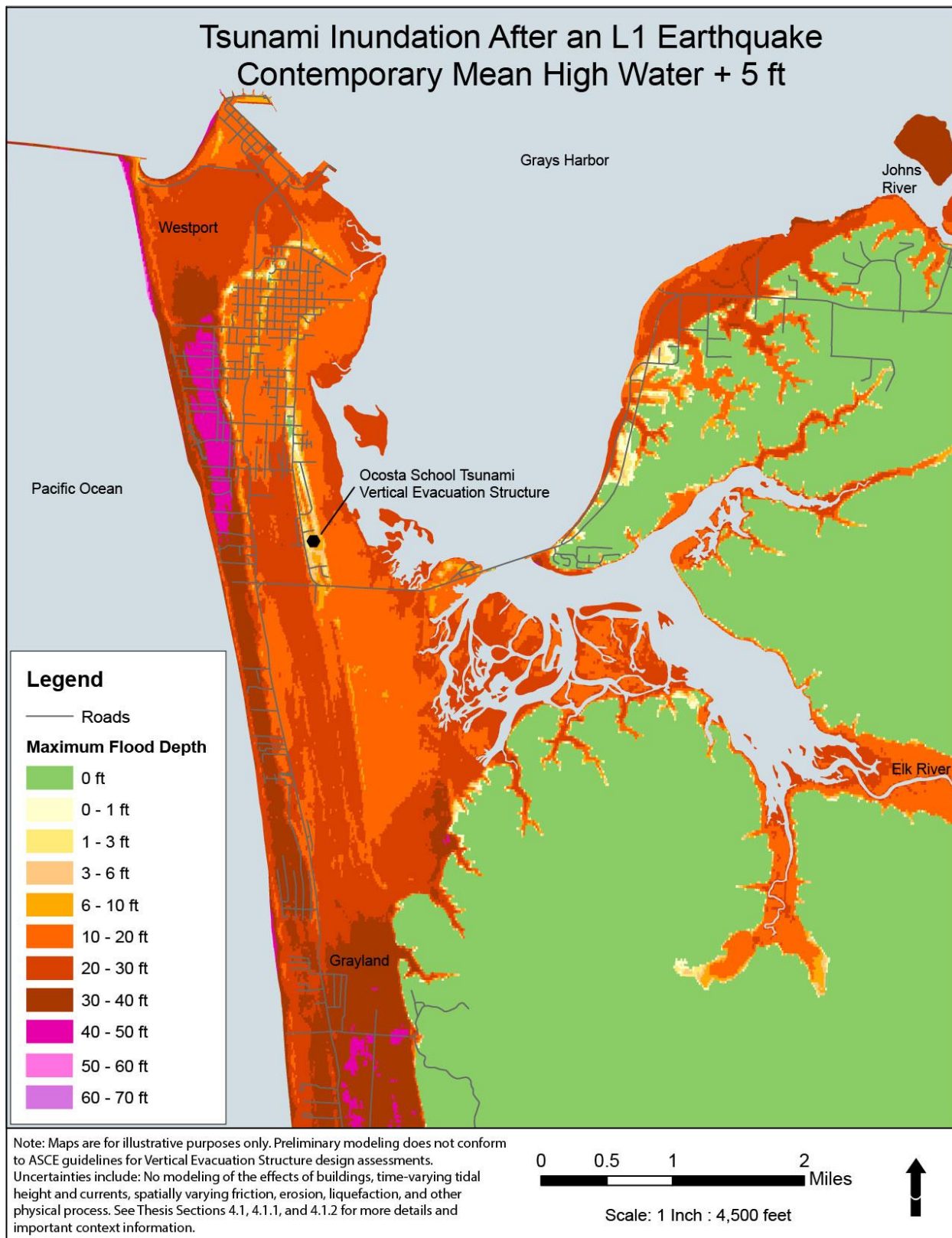


Figure A.9. Tsunami inundation map for L1 earthquake scenario at background water level contemporary mean high water + 5 feet

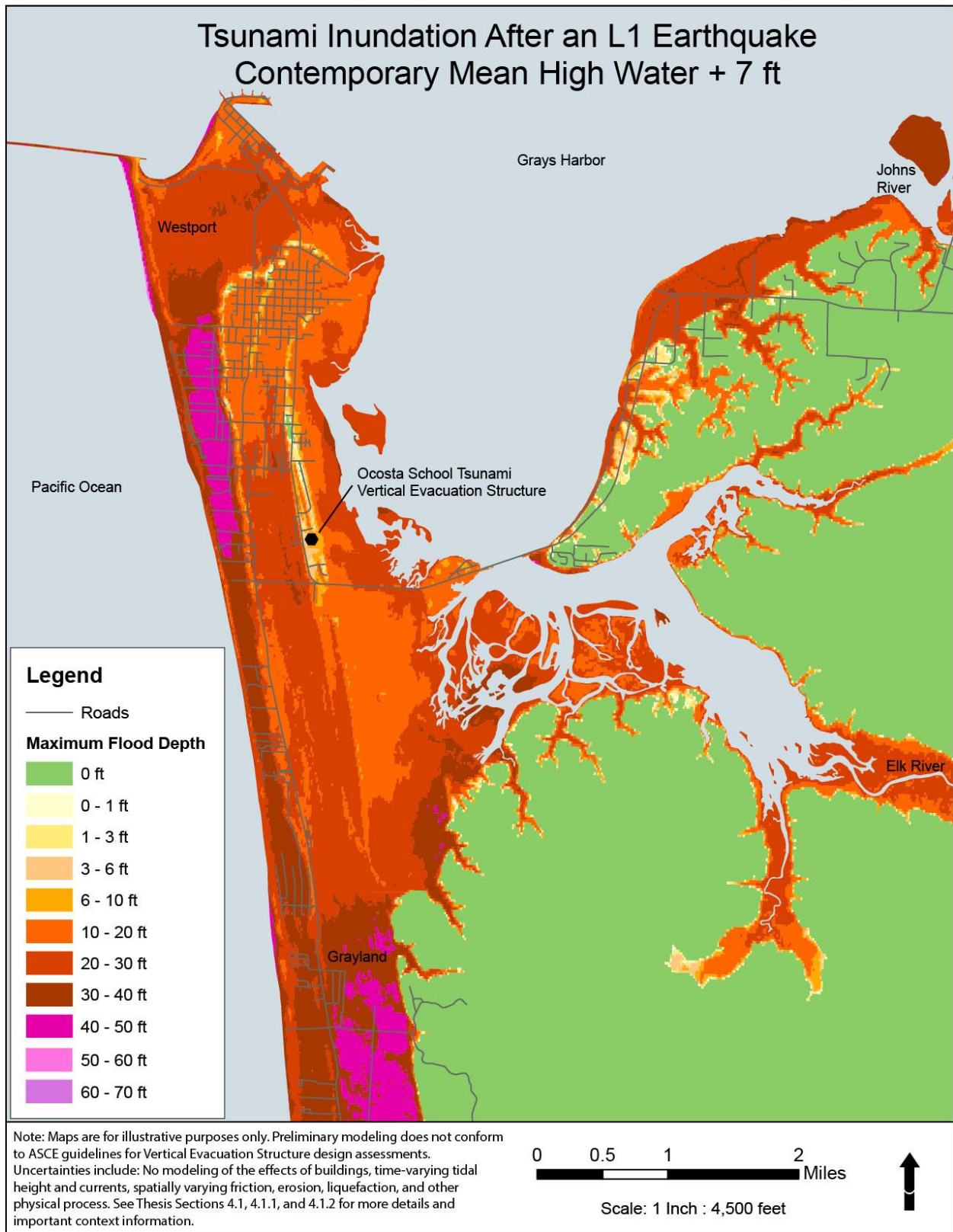


Figure A.10. Tsunami inundation map for L1 earthquake scenario at background water level contemporary mean high water +7 feet

Appendix B. Land Loss Maps

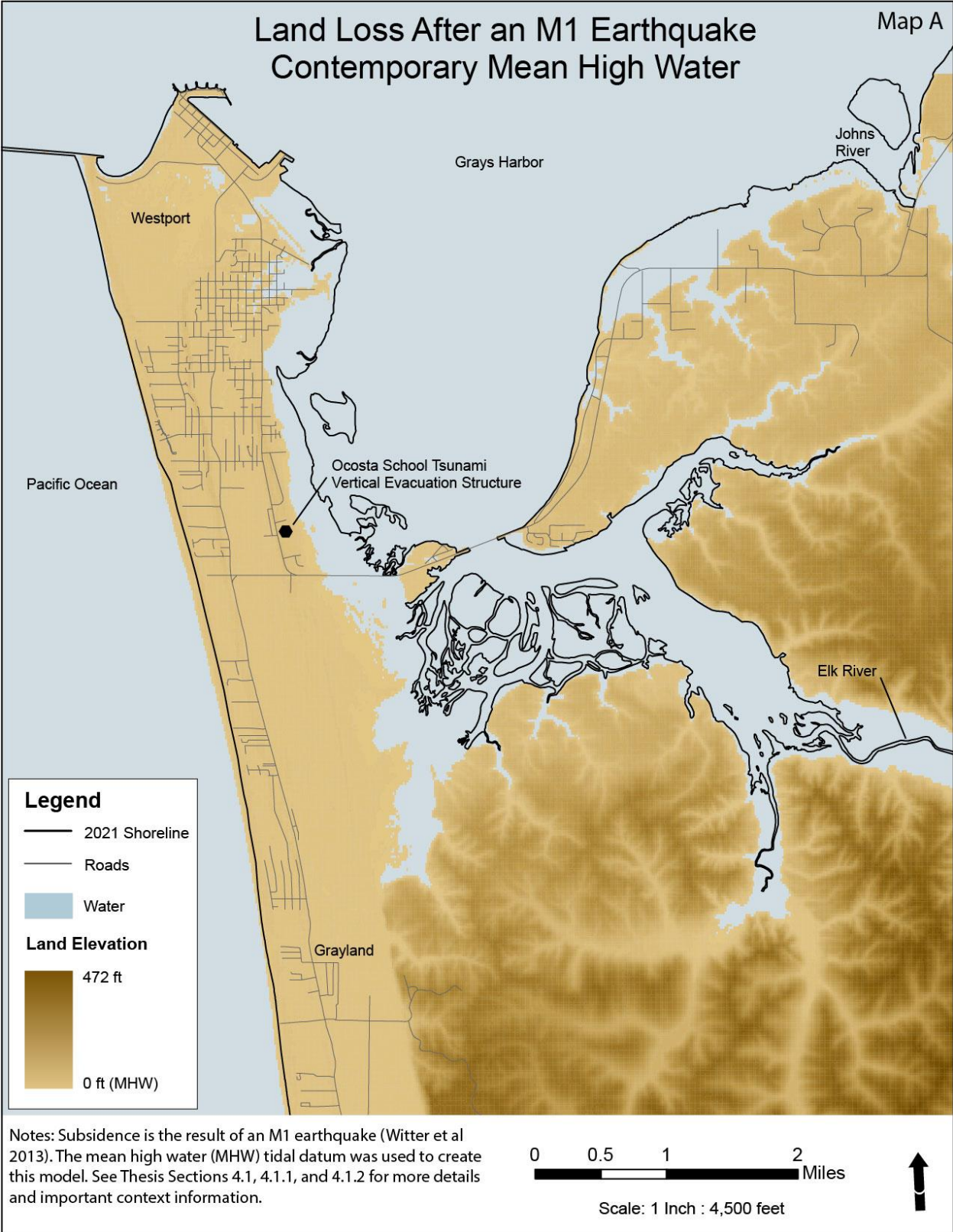


Figure B.1. Land loss map for M1 earthquake scenario at water level contemporary mean high water

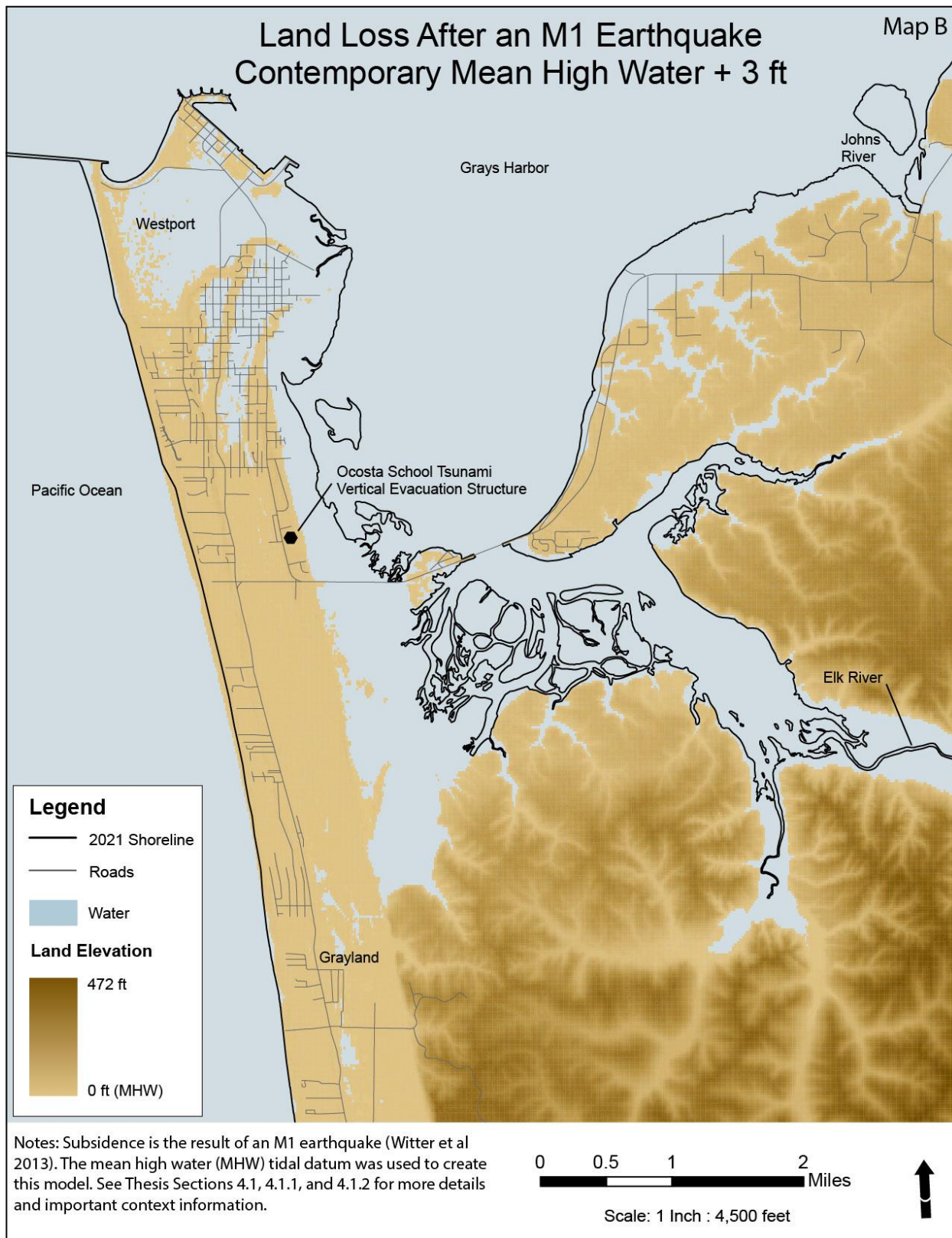


Figure B.2. Land loss map for M1 earthquake scenario at water level contemporary mean high water + 3 feet

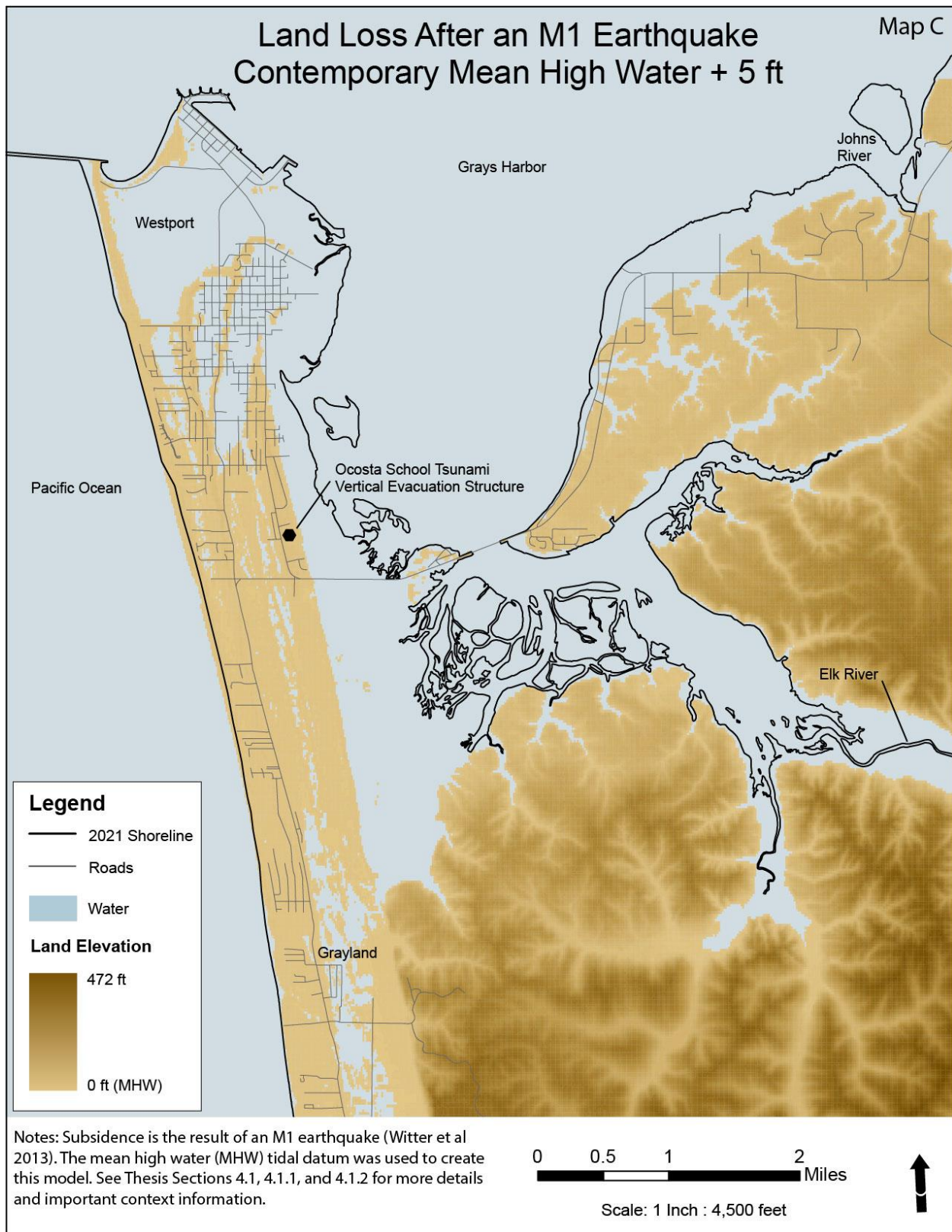


Figure B.3. Land loss map for M1 earthquake scenario at water level contemporary mean high water +5 feet

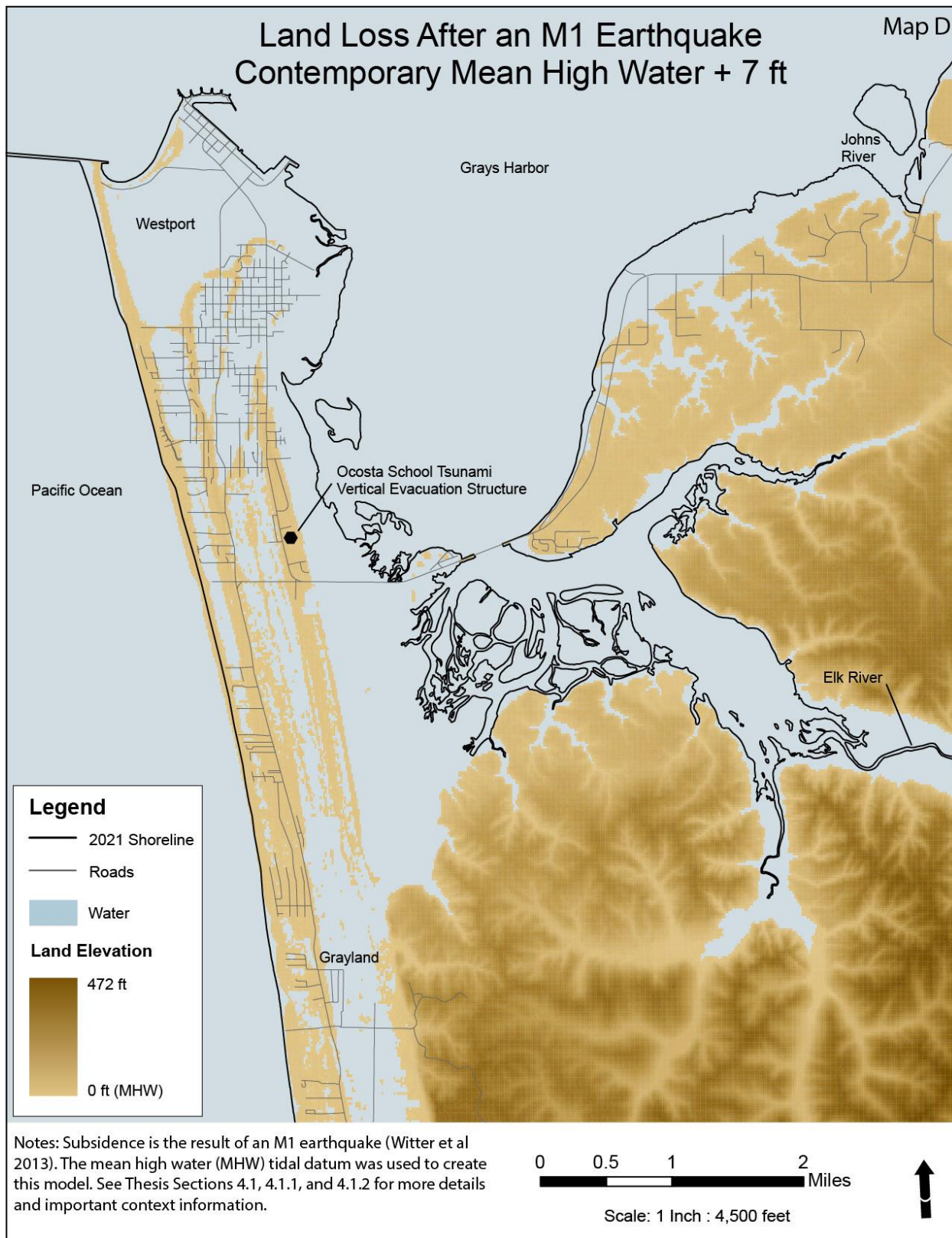


Figure B.4. Land loss map for M1 earthquake scenario at water level contemporary mean high water + 7 feet

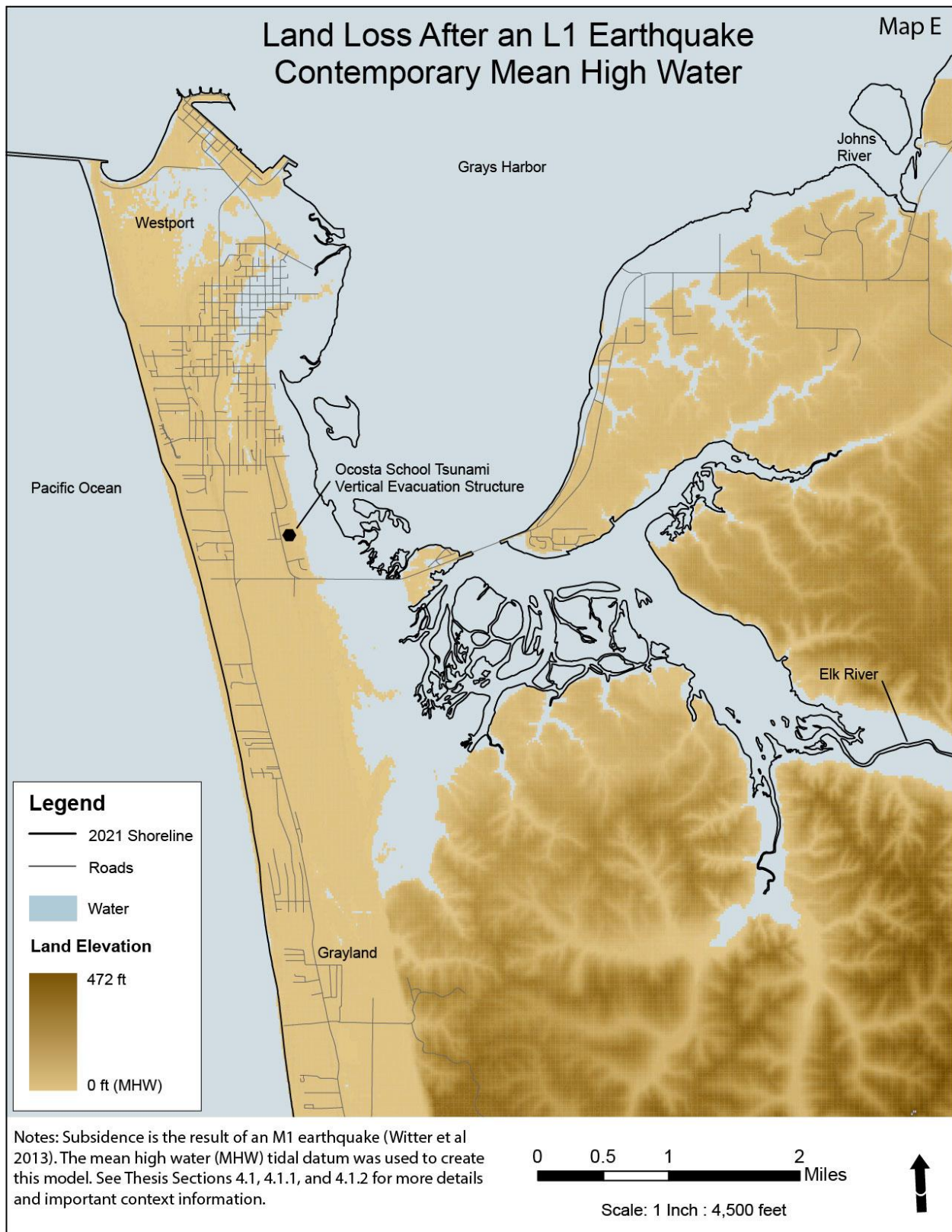


Figure B.5. Land loss map for L1 earthquake scenario at water level contemporary mean high water

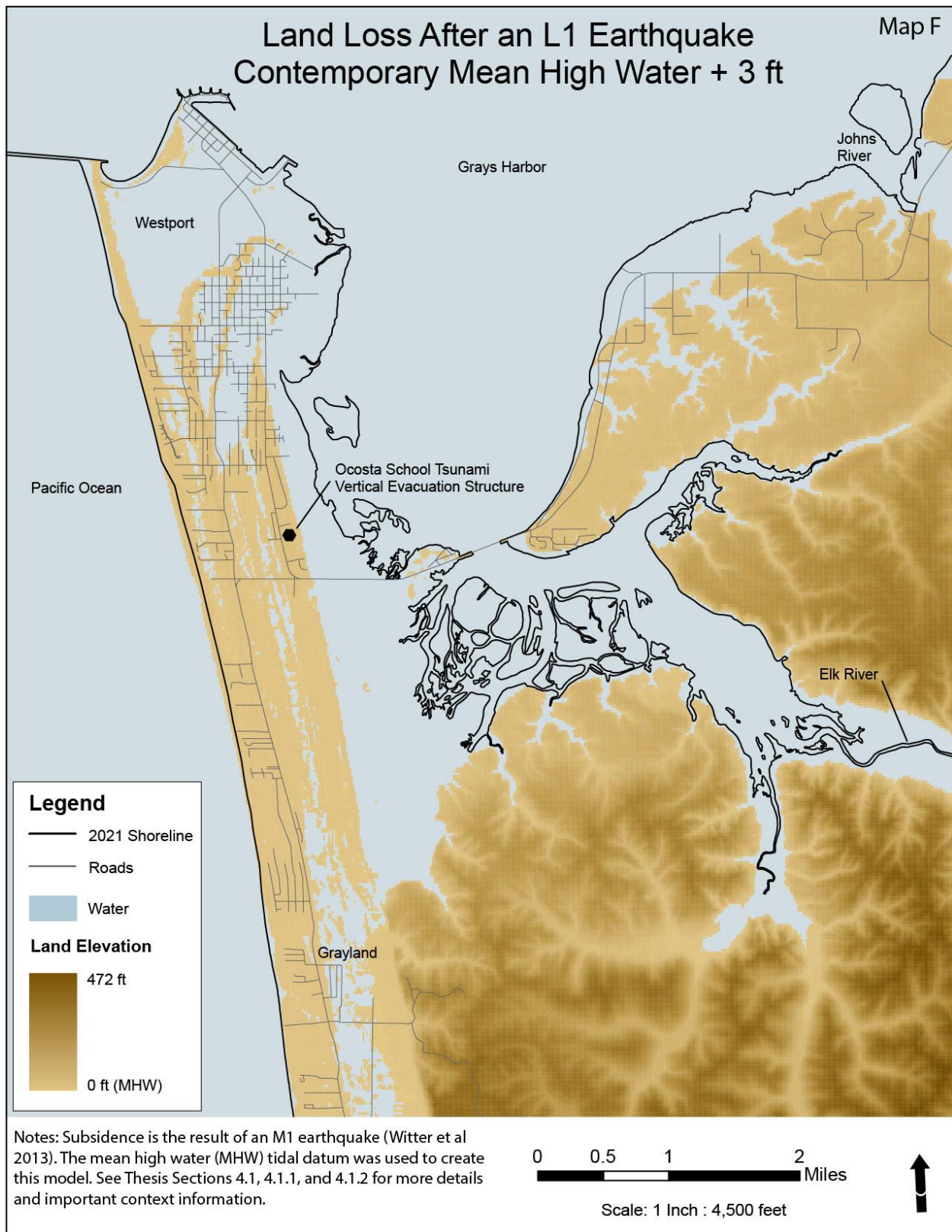


Figure B.6. Land loss map for L1 earthquake scenario at water level contemporary mean high water + 3 feet

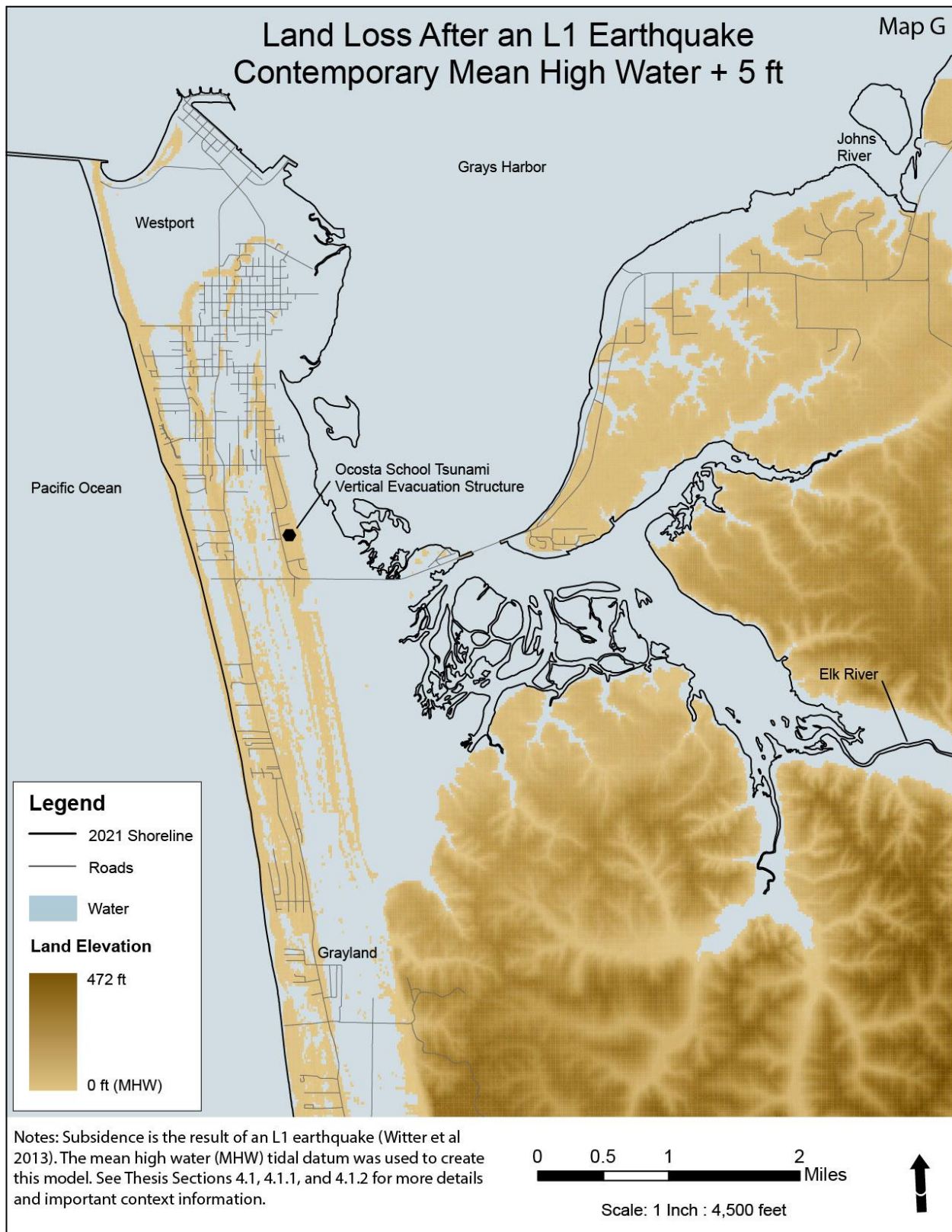


Figure B.7. Land loss map for L1 earthquake scenario at water level contemporary mean high water + 5 feet

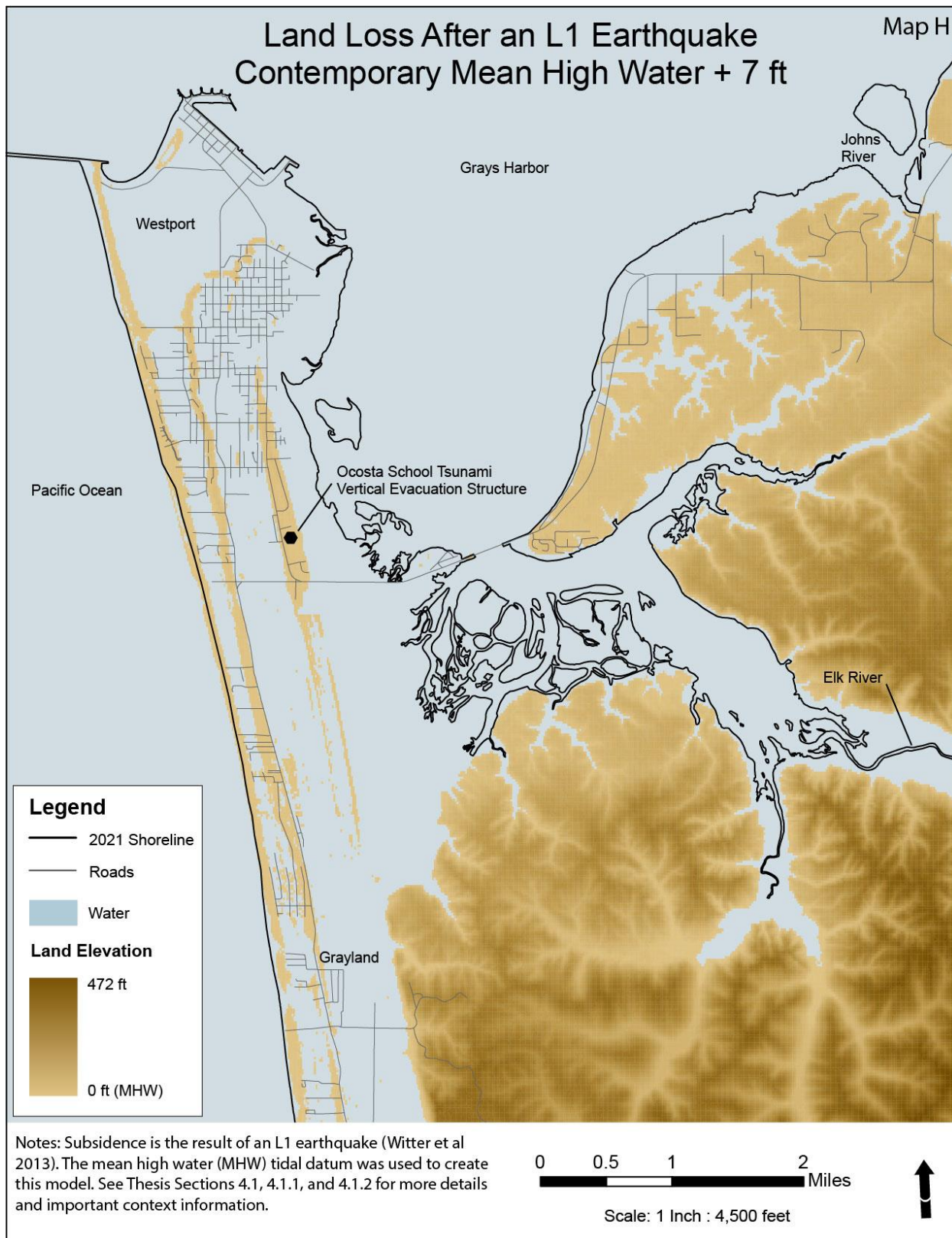


Figure B.8. Land loss map for L1 earthquake scenario at water level contemporary mean high water + 7 feet

Appendix C. Digital Shoreline Analysis System Summary Report

File name: DSAS_Summary_transect_20210309_193545.txt
Timestamp of rate calculation: 03/09/2021 19:35:49
DSAS version: 5.0.20200527.0200
ArcGIS version: 10.7
Rate types run: SCE, NSM, EPR, LRR, WLR
Baseline layer: T2016_vector
Shoreline layer: shoreline_merged
Shoreline dates used: 1/1/1860, 1/1/1911, 1/1/1926, 1/1/1941, 1/1/1954, 1/1/1989, 1/1/2006
Shoreline threshold: 6
Confidence Interval (CI) selected: 90
Default Uncertainty: 10.8
Transect spacing length: 500
Smoothing distance: 2500
Coordinate system: NAD_1983_StatePlane_Washington_South_FIPS_4602
Is bias applied: NO

All rates reported are in meters/year, distance values are in meters.

DISTANCE: SCE (Shoreline Change Envelope, m)

SCE OVERALL AVERAGES:

total number of transects: 39
average distance: 700.94
maximum distance: 2027.38
maximum distance transect ID: 36
minimum distance: 69.6
minimum distance transect ID: 10

DISTANCE: NSM (Net Shoreline Movement, m)

NSM OVERALL AVERAGES:

total number of transects: 39
average distance: 327.22
number of transects with negative distance: 9
percent of all transects that have a negative distance: 23.08%
maximum negative distance: -788.1

maximum negative distance transect ID: 29
average of all negative distances: -233.87
number of transects with positive distance: 30
percent of all transects that have a positive distance: 76.92%
maximum positive distance: 1582.24
maximum positive distance transect ID: 36
average of all positive distances: 495.55

RATE: EPR (End Point Rate, m/yr)

EPR OVERALL AVERAGES:

total number of transects: 39
average rate: 2.24
average of the confidence intervals associated with rates: 0.11
reduced n (number of independent transects): 6
uncertainty of the average rate using reduced n: 0.05
average rate with reduced n uncertainty: 2.24 +/- 0.05

number of erosional transects: 9
percent of all transects that are erosional: 23.08%
percent of all transects that have statistically significant erosion: 17.95%
maximum value erosion: -8.3
maximum value erosion transect ID: 29
average of all erosional rates: -2.27

number of accretional transects: 30
percent of all transects that are accretional: 76.92%
percent of all transects that have statistically significant accretion: 74.36%
maximum value accretion: 10.84
maximum value accretion transect ID: 36
average of all accretional rates: 3.59

RATE: LRR (Linear Regression Rate, m/yr)

LRR OVERALL AVERAGES:

total number of transects: 39
average rate: 2.17

average of the confidence intervals associated with rates: 4.14
reduced n (number of independent transects): 5
uncertainty of the average rate using reduced n: 1.89
average rate with reduced n uncertainty: 2.17 +/- 1.89

number of erosional transects: 8
percent of all transects that are erosional: 20.51%
percent of all transects that have statistically significant erosion: 7.69%
maximum value erosion: -7.18
maximum value erosion transect ID: 28
average of all erosional rates: -2.13

number of accretional transects: 31
percent of all transects that are accretional: 79.49%
percent of all transects that have statistically significant accretion: 23.08%
maximum value accretion: 9.58
maximum value accretion transect ID: 30
average of all accretional rates: 3.28

RATE: WLR (Weighted Linear Regression, m/yr)

WLR OVERALL AVERAGES:

total number of transects: 39
average rate: 2.17
average of the confidence intervals associated with rates: 4.14
reduced n (number of independent transects): 5
uncertainty of the average rate using reduced n: 1.89
average rate with reduced n uncertainty: 2.17 +/- 1.89

number of erosional transects: 8
percent of all transects that are erosional: 20.51%
percent of all transects that have statistically significant erosion: 7.69%
maximum value erosion: -7.18
maximum value erosion transect ID: 28
average of all erosional rates: -2.13

number of accretional transects: 31
percent of all transects that are accretional: 79.49%

percent of all transects that have statistically significant accretion: 23.08%
maximum value accretion: 9.58
maximum value accretion transect ID: 30
average of all accretional rates: 3.28

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