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NATURAL HAZARDS

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3.9 NATURAL HAZARDS

Introduction

Coos County has inventoried the following natural hazards:

- **Flood Hazards**
    - **Riverine flooding**
    - **Coastal flooding**
- **Landslides and Earthquakes**
    - **Landslide Susceptibility**
    - **Liquefaction potential**
    - **Fault lines**
- **Tsunamis**
- **Erosion**
    - **Riverine streambank erosion**
    - **Coastal**
        - **Shoreline and headlands**
        - **Wind**
- **Wildfire**

Purpose Statements:
Coos County shall regulate development in known areas potentially subject to natural disasters and hazards, so as to minimize possible risks to life and property. Coos County considers natural disasters and hazards to include river and coastal flooding, landslides, liquefaction potential due to earthquakes, fault lines, tsunamis, river bank erosion, coastal erosion along shorelines and headlands, coastal erosion due to wind, and wildfires, including those areas affected by gorse.

This strategy shall be implemented by enacting special protective measures through zoning and other implementing devices, designed to minimize risks to life and property associated with new development and substantial improvements. The determination of whether a property is located in one of the above referenced potentially hazardous areas shall be made by the reviewing body (Planning Director, Planning Commission, Board of Commissioners, or any designee based upon adopted inventory mapping). A specific site may not include the characteristics for which it is mapped.

Goal Requirements

The Statewide Planning Goals require that the comprehensive plan provide protection of life and property from natural disasters and hazards. Specifically, Goal 7 requires that:

> Developments subject to damage or that could result in loss of life shall not be planned nor located in known areas of natural disasters and hazards without appropriate safeguards.

Goal 17 (Coastal Shorelands) requires that programs be developed to "reduce the hazard to human life and property…resulting from the use and enjoyment of Oregon's coastal shorelands." The goal also requires that land use plans, implementing actions, and permit reviews "include consideration of…the geologic and hydrologic hazards associated with coastal shorelands."

Goal 18 (Beaches and Dunes) requires the reduction of "the hazard to human life and property from natural or man-induced actions" associated with beach and dune areas.

SECTION 3.9.100 FLOOD HAZARDS

The following section is the flood hazard study completed for Coos County.

NOTICE TO FLOOD INSURANCE STUDY USERS

Communities participating in the National Flood Insurance Program have established repositories of flood hazard data for floodplain management and flood insurance purposes. This Flood Insurance Study (FIS) report may not contain all data available within the Community Map Repository. Please contact the Community Map Repository for any additional data. The Federal Emergency Management Agency (FEMA) may revise any republish part or all of this FIS report at any time. In addition, FEMA may revise par of this FIS report by the Letter of Map Revision process, which does not involve republication or redistribution of the FIS report. Therefore, users should consult with the community officials and check the Community Map Repository to obtain the most current FIS report components.

Initial Countywide FIS Effective Date: September 25, 2019
Revised County wide FIS Dates: March 17, 2014 and December 7, 2018

December 7, 2018 Volume I

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Exhibit 2 – Flood Insurance Rate Map Index
Flood Insurance Rate Map

FLOOD INSURANCE STUDY
COOS COUNTY, OREGON AND INCORPORATED AREAS

1.0 INTRODUCTION

1.1 Purpose of Study

This Flood Insurance Study (FIS) revises and updates information on the existence and severity of flood hazards in the geographic area of Coos County, including the Cities of Bandon, Coos Bay, Coquille, Lakeside, Myrtle Point, North Bend and Powers; the unincorporated areas of Coos County (referred to collectively herein as Coos County); the Coquille Indian Tribe; and the Confederated Tribes of Coos, Lower Umpqua, and Siuslaw; and aids in the administration of the National Flood Insurance Act of 1968 and the Flood Disaster Protection Act of 1973. This study has developed flood-risk data for various areas of the community that will be used to establish actuarial flood insurance rates and to assist the community in its efforts to promote sound floodplain management. Minimum floodplain management requirements for participation in the National Flood Insurance Program (NFIP) are set forth in the Code of Federal Regulations at 44 CFR, 60.3.

1.2 Authority and Acknowledgments

The sources of authority for this FIS are the National Flood Insurance Act of 1968 and the Flood Disaster Protection Act of 1973.

Pre-Countywide Analyses

Coos County Unincorporated Areas. Flood Hazard Boundary Maps for Coos County, Oregon, were produced by the U.S. Department of Housing and Urban Development in September 1977 (community panel numbers 0001-0021).

City of Bandon. Flood Hazard Boundary Maps for City of Bandon, Coos County, Oregon, were produced by the U.S. Department of Housing and Urban Development in December 1973 and revised in April 1976 (community panel numbers 410043A 01-03).

City of Coos Bay. Flood Hazard Boundary Maps for City of Coos Bay, Coos County, Oregon, were produced by the U.S. Department of Housing and Urban Development in March 1977 (community panel numbers 410044 0001-0005).

City of Coquille. Flood Hazard Boundary Maps for City of Coquille, Coos County, Oregon, were produced by the U.S. Department of Housing and Urban Development in November 1973 and revised October 1975.

City of Myrtle Point. Flood Hazard Boundary Maps for City of Myrtle Point, Coos County, Oregon, were produced by the U.S. Department of Housing and Urban Development in November 1973 and revised December 1975.

City of North Bend. Flood Hazard Boundary Maps for City of North Bend, Coos County, Oregon, were produced by the U.S. Department of Housing and Urban Development in June 1974 (community panel numbers 410048A 01-03).

Coos County Unincorporated Areas. The detailed riverine and estuarine hydrologic and hydraulic analyses for this study were performed by CH2M Hill Northwest, Inc., for FEMA, under Contract No. EMW-C-0283. This work was completed in April 1982 and represents a portion of the original FIS performed for Coos County.

City of Bandon. The original FIS was revised to update coastal flood information from the south jetty to the southern city limit of Bandon. The work was performed by CH2M Hill, Inc., under FEMA Contract No. EMW-94-C-4526 and was completed in September 1995. Note that the present countywide update revises this area and supersedes this update.

Countywide Analyses

A countywide update and vertical datum conversion was performed by WEST Consultants, Inc., for FEMA, under Contract No. EMS-2001-CO-0068. This countywide update occurred under FEMA's Map Modernization program, the purpose of which was to create digital versions of the Flood Insurance Rate Maps (DFIRMs), create a single layout format for the entire area within the county, and compile a single FIS report that includes all FIS information and data for the entire county area. During this countywide update revised hydraulic data were incorporated for Pony Creek (in the cities of Coos Bay and North Bend). See Section 3.2 for more information about the hydraulic data revision for Pony Creek. Portions of Pony Creek, Coos Bay, and the Pacific Ocean flood zones were redelineated with 2 foot contours provided by the City of North Bend. Portions of the Pacific Ocean flood zones were also redelineated with LiDAR provided by NOAA. All other flood mapping was incorporated as-is from the original FIS. This update was completed in July 2008.

The present countywide update was performed by the Oregon Department of Geology and Mineral Industries (DOGAMI), for FEMA, under Contract No. EMS-2008-GR-0013. During this countywide update, revised detailed and approximate coastal hydrologic and hydraulic analyses were performed for the entire coastline. Revised approximate riverine hydrologic and hydraulic analyses were also performed for county where new, high quality topographic data (LiDAR) was available. Finally, revised mapping of detailed riverine and estuarine study areas (from original FIS) was performed by redelineating to LiDAR provided by the Oregon LiDAR Consortium. This redelineation work supersedes all similar work performed for the previous countywide analysis. This update was completed in March 2014.

Base map information shown on the Flood Insurance Rate Map (FIRM) was derived from LiDAR ground and first return digital elevation models produced at a scale of 1:2,300, from surveys conducted between June 8, 2008 and September 28, 2008. The projection used in the preparation of this map is Universal Transverse Mercator Zone 10 North, and the horizontal datum used is NAD 1983.

1.3 Coordination

An initial meeting is held with representatives from FEMA, the community, and the study contractor to explain the nature and purpose of a FIS, and to identify the streams to be studied or restudied. A final meeting is held with representatives from FEMA, the community, and the study contractor to review the results of the study.

The initial and final meeting dates for previous FIS reports for Coos County and its communities are listed in the following table:

Table 1. Initial, Intermediate, and Final CCO Meetings

Community	Initial CCO Date	Intermediate CCO Dates	Final CCO Meeting
Coos County (Unincorporated Areas)	May, 1979	--	November, 1980
Bandon, City of	May, 1979	March 22, 1983	August 23, 1983
Coos Bay, City of	May, 1979	--	August 24, 1983
Coquille, City of	May, 1979	--	July 20, 1983
Lakeside, City of	May, 1979	March 22, 1983	August 25, 1983
Myrtle Point, City of	May, 1979	--	December 4, 1980
North Bend, City of	May, 1979	--	August 24, 1983
Powers, City of	--[1]	--[1]	--[1]

[1] Information not available

Streams, lakes, estuarine and coastal areas requiring detailed study were identified at a meeting attended by the CH2M Hill Northwest, Inc., FEMA, and representatives of Coos County in May 1979. The U.S. Geological Survey (USGS), the U.S. Army Corps of Engineers (USACE), and the Coos-Curry Council of Governments were contacted for information used in the initial study.

Streams, lakes, estuarine and coastal areas requiring revision were identified at a meeting attended by the CH2M Hill Northwest, Inc., FEMA, and representatives of the City of Bandon on March 22, 1983. The USGS was contacted for hydrologic information. The USACE, the Bandon Historical Society, and the Port of Coquille were contacted for information on past flooding in the city.

An initial community coordination meeting for Coos County was held on March 14, 2006, to address the first-time countywide update and vertical datum conversion. This meeting was attended by representatives of the cities and county, State of Oregon, FEMA and WEST Consultants.

The results of the update were reviewed at the final Consultation Coordination Officers' meeting held on November 5, 2008, and attended by representatives of FEMA, the City of Coos Bay, the City of Coquille, the City of Lakeside, the City of Myrtle Point, the City of North Bend, Coos County, the Oregon Department of Land and Development (DLCD) and DOGAMI.

<u>Present Countywide Update</u>
The initial meeting was held on January 7, 2009, and attended by representatives of FEMA, Coos County, the City of Bandon, the City of Coos Bay, the City of North Bend, the City of Coquille, the Coquille Indian Tribe, DLCD, and DOGAMI.

The results of the study were reviewed at the final meeting held on June 7, 2011, and attended by representatives from the Coquille Indian Tribe, the Cities of Bandon, Coos Bay, Lakeside, Myrtle Point, and North Bend, and representatives from DOGAMI, STARR, DLCD, and FEMA. All problems raised at that meeting have been addressed.

2.0 AREA STUDIED

2.1 Scope of Study

This FIS covers the geographic area of Coos County, Oregon, including the incorporated communities listed in Section 1.1. The areas studied by detailed methods were selected with priority given to all known flood hazards and areas of projected development or proposed construction through 1987, determined during scoping of the original FIS.

The following flooding sources were studied by detailed methods in this FIS report:

Table 2. Summary of Flooding Sources Studied by Detailed Methods

Flooding Source	Limits of Detailed Study
Tenmile Creek	From Lake Front Road bridge to Tenmile Lake within the City of Lakeside
Tenmile Lake	Within corporate limits (as of 1982) of the City of Lakeside
North Tenmile Lake	Within corporate limits (as of 1982) of the City of Lakeside
Millicoma River	From river mile (RM) 8.2 to the confluence of the East and West Forks Millicoma River
East Fork Millicoma River	From its confluence with West Fork Millicoma River to RM 10.7
West Fork Millicoma River	From its confluence with East Fork Millicoma River to RM 2.0
Coquille River	Within the corporate limits (as of 1982) of the City of Bandon, from RM 16 to RM 17 at Riverton, from RM 23 to RM 27.5 at the City of Coquille, and from RM 32 to RM 33 at Arago
South Fork Coquille River	From RM 36.4 to RM 38.4 at the City of Myrtle Point
Pony Creek	From the Virginia Avenue bridge in the City of North Bend to Ocean Boulevard in the City of Coos Bay
Cunningham Creek	Within corporate limits (as of 1982) of the City of Coquille
Calloway Creek	Within corporate limits (as of 1982) of the City of Coquille

Table 2. Summary of Flooding Sources Studied by Detailed Methods (continued)

Flooding Source	Limits of Detailed Study
Ferry Creek	From its confluence with Coquille River to upstream of Harlem Avenue within the City of Bandon
Coos River	From its confluence with Coos Bay to 2 miles upstream (area of tidal influence)
Cooston Channel	From its confluence with Coos Bay to its confluence with Coos River
Catching Slough	Within corporate limits (as of 1982) of the City of Coos Bay
Coos Bay	From its confluence with the Pacific Ocean to its confluence with Coos River and Cooston Channel
Isthmus Slough	From its confluence with Coos Bay to 0.3 miles upstream of Coos-Summer Lane bridge
Coalbank Slough	From its confluence with Isthmus Slough to Shinglehouse Road
Pony Slough	From its confluence with Coos Bay to its confluence with Pony Creek within the City of North Bend
Haynes Inlet	From its confluence with Coos Bay to its confluence with Larson and Palouse Sloughs
North Slough	From its confluence with Coos Bay to the Highway 101 bridge near North Bay Road at Hauser

Table 2. Summary of Flooding Sources Studied by Detailed Methods
(continued)

Flooding Source	Limits of Detailed Study
South Slough	From its confluence with Coos Bay to Valino Island

This revision used LiDAR to re-delineate Special Flood Hazard Areas (SFHAs) to the flood elevations determined by detailed methods in the original FIS. This approach was applied in all detailed study areas listed above.

The following flooding sources are studied by revised detailed methods in this FIS report:

Table 3. Summary of Flooding Sources Studied by Revised Detailed Methods

Flooding Source	Limits of Revised Detailed Study
Pacific Ocean	From the north jetty at Coos Bay to Sunset Bay, and from the south jetty at Coquille River to the southern extent of the City of Bandon Urban Growth Boundary

The limits of detailed study are indicated on the Flood Profiles (Exhibit 1) and on the FIRM (Exhibit 2).

Approximate analyses were used to study those areas having low development potential or minimal flood hazards. These areas were adopted from previously effective flood hazard boundary maps (U.S. Department of Housing and Urban Development, 1977). The scope and methods of study were proposed to and agreed upon by FEMA, the communities, and the study contractor, DOGAMI.

The following flooding sources are studied by revised approximate methods in this FIS report:

Table 4. Summary of Flooding Sources Studied by
Revised Approximate Methods

Flooding Source
Pacific Ocean, excluding areas studied by revised detailed methods

Table 4. Summary of Flooding Sources Studied by Revised Approximate Methods (continued)

<u>Flooding Source</u>

Tenmile Creek Basin, including these tributaries and lakes:

> Saunders Creek, Clear Lake, Saunders Lake, Eel Creek, Eel Lake, Tenmile Lake, North Tenmile Lake, Murphy Creek, Big Creek, Noble Creek, Alder Gulch, Benson Creek, Roberts Creek, Johnson Creek, Adams Creek, Shutter Creek

Lakes of the Oregon Dunes National Recreation Area:

> Lyons Reservoir, Snag Lake, Sandpoint Lake, Spirit Lake, Horsfall Lake

Coos River Basin, including these tributaries and lakes:

> Winchester Creek, John B Creek, Talbot Creek, Talbot Slough, Elliott Creek, Joe Ney Slough, North Fork Joe Ney Slough, South Fork Joe Ney Slough, Tarheel Creek, Fourth Creek, First Creek, Chickses Creek, Lower Empire Lake, Upper Empire Lake, North Slough, Palouse Slough, Palouse Creek, Larson Slough, Larson Creek, Kentuck Slough, Kentuck Creek, Mettman Creek, Willanch Slough, Willanch Creek, Johnston Creek, Coalbank Creek, C. A. Smith Reservoir, Noble Creek, Delmar Creek, Davis Slough, Upper Isthmus Slough, Ross Slough, Catching Slough, Catching Creek, Millicoma River, Marlow Creek, East Fork Millicoma River (Not Revised), Glenn Creek (Not Revised), West Fork Millicoma River, Elk Creek, South Fork Coos River, Williams River

Coquille River Basin, including these tributaries and lakes:

> Ferry Creek, Fahy's Creek, Fahy's Lake, Sevenmile Creek, Bear Creek, Lampa Creek, Hatchet Slough, Beaver Creek, Fat Elk Creek, Calloway Creek, Cunningham Creek, Rink Creek, Fishtrap Creek, Hall Creek, North Fork Coquille River, East Fork Coquille River, Elk Creek, Brummit Creek (Not Revised), Middle Creek, Cherry Creek, Evans Creek, Woodward Creek, Catching Creek, Middle Fork Coquille River, Big Creek, Myrtle Creek, Rock Creek, Sandy Creek

Table 4. Summary of Flooding Sources Studied by Revised Approximate Methods (continued)

Flooding Source

New River Basin, including these tributaries and lakes:

Fourmile Creek, Laurel Creek, Laurel Lake, Lost Lake, Davis Creek, Muddy Lake, Croft Lake, Conner Creek, Bethel Creek, New Lake, Butte Creek, Morton Creek

Threemile Creek

Twomile Creek

Cut Creek Basin, including Chrome Lake and Round Lake

Johnson Creek

Crooked Creek

China Creek Basin, including Bradley Lake

Twomile Creek Basin, including Lower and South Twomile Creeks

2.2 Community Description

Coos County is located in southwest Oregon. The county is bounded on the west by the Pacific Ocean, on the south by Curry County, and on the east and north by Douglas County. Coos County is about 66 miles long, 36 miles wide, and covers an area of 1,629 square miles. About one-third of the county is publicly owned. The U.S. Bureau of Land Management, the U.S. Forest Service, the U.S. Fish and Wildlife Service, and the Oregon State Land Board own most of the public lands (Sidor and Brown, 1967). Only about 1 percent of the area in the county has been urbanized or built up. The county was founded on December 22, 1853. According to the U.S. Census Bureau, Coos County's population was 63,043 in 2010 (U.S. Department of Commerce, 2010). In 1990, the population was 60,273 (U.S. Department of Commerce, 2010). The Coos County economy is based on tourism, agriculture, forest products, and fishing (Coos County Emergency Management Department, 2005).

The Coquille River basin, with a drainage area of 1,058 square miles, covers most of the southern two-thirds of the county. Flow from the basin enters the Pacific Ocean at Bandon. Upstream at RM 36.3, about a mile south of Myrtle Point, the river branches into the South Fork and North Fork Coquille Rivers. The South Fork Coquille River has a drainage area of 598 square miles and a length of 62.8

miles. The North Fork Coquille River has a drainage area of 289 square miles and a length of 53.3 miles (Pacific Northwest River Basins Commission, 1968). Both forks begin in the Coast Range Mountains. The cities of Myrtle Point and Powers are located on the South Fork Coquille River, and the cities of Coquille and Bandon are located on the main stem of the Coquille River. Tidal influences extend as far upstream as Myrtle Point on the South Fork Coquille River. About 70% of the Coquille River basin is forested. Private industrial forest holdings make up 40% of the watershed. The remaining 30% of forested lands are federal, state, and county lands. (Coos County Emergency Management Department, 2005) Two federal agencies, the Bureau of Land Management (BLM) and the U.S. Forest Service (USFS), administer the largest of these public holdings.

The Coos River basin, with a drainage area of 415 square miles covers most of the northeast corner of the county. The Coos River flows into Coos Bay at the City of Coos Bay. Upstream at RM 5.5, the Coos River branches into the Millicoma River and the South Fork Coos River. The Millicoma River has a drainage area of 151 square miles while the South Fork Coos River has a drainage area of 254 square miles. The Millicoma River branches into the East Fork and West Fork Millicoma Rivers at RM 8.1. Tidal influences extend upstream to Dellwood on the South Fork Coos River and to the confluence of the East and West Forks on the Millicoma River. The East Fork Millicoma River has a drainage area of 79 square miles and a length of 23.9 miles. The West Fork Millicoma River has a drainage area of 55 square miles and a length of 34.9 miles (Pacific Northwest River Basins Commission, 1968). About 80% of the Coos River basin is forested.

Coos Bay, located in the west-central part of Coos County, is the largest estuary in Oregon. The bay covers an area of about 17 square miles and drains a total of 605 square miles (Percy and Sutterlin, 1974). Tributaries such as the South Slough, North Slough, Larson and Palouse Creeks, Isthmus Slough, and Catching Slough account for 190 square miles of the drainage area. The Coos River accounts for the remaining 415 square miles. The Cities of Coos Bay and North Bend are located on the bay.

The original natural estuarine environments of Coos Bay have been altered by the community's dependence on wetland and estuarine resources and the need for flat, dry land. Diking, draining, and filling of marshes began in the 1870's to create the present city of Coos Bay, expand rail and road routes, and accommodate more ranches and homes. In 1970, when only 15% of the original marsh remained, state and federal laws slowed the conversion process (Coos County Emergency Management Department, 2005).

The eastern two-thirds of the Coos River basin is sparsely populated and made up of steep forested slopes. This area has been managed exclusively for time since the late 1800's. About 36,000 people live in the basin, with the bulk of the population clustered about the eastern half of the estuary and lower riverbanks. Until the late 1980's the area was heavily reliant on natural resource extraction, such as timber production, fishing, and agriculture. Many family wage jobs have been lost as these industries saw a decline in the availability of resources. The area is struggling with a transition to utilize other economic opportunities, such as tourism (Coos County Emergency Management Department, 2005).

The Tenmile Creek basin, with a drainage area of about 86 square miles, covers most of the northwest corner of the county. Tenmile Creek flows generally west for 5.1 miles from the outlet of Tenmile Lake at Lakeside to the Pacific Ocean. The drainage area above the outlet of Tenmile Lake is 70.6 square miles. This drainage area includes North Tenmile Lake which is connected to Tenmile Lake by a 0.4-mile-long canal. The drainage area above the outlet of North Tenmile Lake is 29.0 square miles. North Tenmile Lake and Tenmile Lake cover about 980 and 1,350 acres, respectively (Sidor and Brown, 1967). Most of the steep forested slopes in the upper basin are found in the Elliott State Forest, which is managed by the Oregon Department of Forestry (Coos County Emergency Management Department, 2005).

The native fishery in the Tenmile Creek basin was primarily Coho salmon, steelhead, and sea-run cutthroat trout. In the 1930's, yellow perch, small mouth bass, brown bullhead catfish and other non-native fish were introduced to the lakes. In 1996, the lakes in the Tenmile Creek basin were placed on the Department of Environmental Quality's list for water quality problems with bacteria, aquatic weeds, temperature, and algae (Coos County Emergency Management Department, 2005).

Coos County has a temperate marine climate with typically mild temperatures, wet winters, and dry summers. The average temperature in January is about 50°F and in July, about 60°F. The average annual temperature ranges from 50 to 54°F. The average yearly rainfall along the coast is about 60 inches. Further inland in the Coast Range, average yearly rainfall may reach 100 inches or more, depending on the location and elevation. Approximately 75 percent of the rainfall occurs from November through March. In coastal areas prevailing winds during March through October are from the northwest with an average speed of 17 miles per hour. During November through February, prevailing winds are from the southwest with an average speed of 15 miles per hour (Sidor and Brown, 1967).

The topography of Coos County is predominately steep and mountainous. The Coast Range Mountains begin near the coastline and rise to average peak elevations of 2,500 to 3,500 feet at the crest of the Coast Range. The Coast Range in Coos County is predominately composed on marine sedimentary rock with some igneous and metamorphic rock occurring in the southern end of the county. The sedimentary rock is composed of alluvium, siltstone, mudstone, sandstone, shale, and conglomerates. The igneous rock is composed of basalt, breccia, tuff, diorite, and peridotite. The metamorphic rock is composed of gneiss, schist, and serpentine. Soils in the county are generally clayey (Sidor and Brown, 1967).

Land located in the river valleys of Coos County is used predominately for agriculture.

City of Bandon

The City of Bandon is located on the Pacific Ocean at the mouth of the Coquille River in southwestern Coos County. Bandon is located 23 miles southwest of Coos Bay along U.S. Highway 101, 27 miles north of Port Orford along U.S. Highway 101, and 18 miles southwest of Coquille along State Highway 42S. The city was incorporated in 1891. According to the U.S. Census Bureau, the population of Bandon was 3,066 in 2010 (U.S. Department of Commerce, 2010). In 1990, the population was 2,215 (U.S. Department of Commerce, 2010).

The Coquille River flows through the northwestern corner of Bandon and empties into the Pacific Ocean. Most of the city is located on a high bluff overlooking the ocean and river estuary. The Coquille River is 99 miles long from the beginning of the South Fork Coquille River to the Pacific Ocean, and drains an area of 1,058 square miles covering most of the southern two-thirds of Coos County (City of Bandon, 1977). The average annual precipitation over the Coquille River basin is 66 inches (Beaulieu and Hughes, 1975).

Ferry Creek flows through the southeast corner of Bandon to the Coquille River. Ferry Creek is 3.8 miles long and drains an area of 5.2 square miles.

The corporate limits of Bandon enclose 3.2 square miles. Most of this area is lightly developed. The two most densely developed areas are along U.S. Highway 101 and near Harbor Lights High School. All of the flood plain areas studied are lightly developed and predominantly residential areas, except for the old downtown area between U.S. Highway 101 and the Coquille River. Development within the old downtown area is mainly commercial, with some industrial development, including a fish processing plant and a lumber mill.

The average annual rainfall at Bandon is approximately 60 inches. The mean temperature in January is approximately 50° F, and in July, approximately 60° F. From May through August, the prevailing winds are from the northwest, while the prevailing winds in winter are from the southwest. Winter winds are usually less than those experienced during the summer except during an occasional winter storm (Coos County Emergency Management Department, 2005).

Soils in the City of Bandon are predominantly sandy loams. The coastal cliffs and offshore rocks are a mixture of sandstone, siltstone, volcanic rock, chert, and blue schist. In undeveloped areas of Bandon south of the Coquille River estuary, vegetation includes salal, wild rhododendron, pine, cypress, and gorse. The Bandon tidal marsh covers approximately 25 percent of the Coquille River estuary (City of Bandon, 1978).

Bandon is served by U.S. Highway 101 and State Highway 42S.

City of Coos Bay

The City of Coos Bay is located in western Coos County at the southern end of a peninsula that extends north into the Coos Bay estuary. The City of Coos Bay is located approximately 4 miles east of the Pacific Ocean, approximately 27 miles south of Reedsport, and approximately 17 miles north of Coquille. The City of Coos Bay is bounded by the City of North Bend to the north, the Coos Bay estuary to the east and west, and Coos County to the south. The city covers 16.1 square miles. The city was incorporated in 1874. According to the U.S. Census Bureau, the population of Coos Bay was 15,967 in 2010 (U.S. Department of Commerce, 2010). In 1990, the population was 15,076 (U.S. Department of Commerce, 2010).

The downtown area of the City of Coos Bay is located on Isthmus Slough, which enters the Coos Bay estuary near the intersection of Date Avenue and Front Street. Coalbank Slough follows the southeast corporate limits and enters Isthmus Slough east of the intersection of Hall Avenue and Front Street. Isthmus Slough and Coalbank Slough drain an area of 33.3 square miles south of the bay.

The Coos River, the major tributary of Coos Bay, flows into the bay through the Marshfield and Cooston Channels east and north of the developed portion of the City of Coos Bay. The Coos River drains an area of 415 square miles and has several forks including the Millicoma River, the East and West Fork Millicoma Rivers, the South Fork Coos River, and the Williams River. Catching Slough also flows into Coos Bay through the Marshfield Channel and has a drainage area of 25.2 square miles above the southern corporate limits of the City of Coos Bay.

Pony Creek has its headwaters in the hills southwest of the City of Coos Bay and flows north to the Coos Bay estuary. Pony Creek drains the central portion of the peninsula on which Coos Bay and North Bend are located. The creek has a length of 5.6 miles and a drainage area of 6.4 square miles above Virginia Avenue in North Bend. The Coos Bay North Bend Water Board operates two dams on Pony Creek for municipal water supplies. The drainage area above the upper dam is 2.9 square miles, while the drainage area above the lower dam is 3.9 square miles. At normal winter pool elevation, the storage volume in the reservoir behind the upper dam is 2,090 acre-feet, and the storage volume in the reservoir behind the lower dam is 123 acre-feet (CH2M HILL, 1978).

Blossom Creek has its headwaters in the hills between the Pony Creek basin and downtown Coos Bay, and drains an area of 1.0 square mile above 10th Street. At 10th Street, Blossom Creek enters the Mill Slough Box, a major storm sewer that drains several smaller systems in downtown Coos Bay and then discharges into Isthmus Slough 3,200 feet downstream of 10th Street.

Average annual precipitation at Coos Bay is approximately 60 inches. The majority of the rainfall occurs from November through March (Erichsen et al., 1966). In January, the coldest month, the mean temperature is approximately 46.6°F, and in July, the warmest month, the mean temperature is approximately 59.0°F. From May through August, prevailing winds are from the northwest, while in winter prevailing winds are from the southwest. Winter winds are usually milder than those during the summer, except during an occasional winter storm.

Soils in Coos Bay are predominantly sandy loams. In areas affected by tidal action along the bay, Coalbank and Isthmus Slough, and Pony Creek, the soils range from silty clay loams to sandy loams (U.S. Department of Agriculture, 1975). Most of Coos Bay is underlain by either coarse- to fine-grained sandstone of the Coaledo formation or Quartenary marine terrace deposits (Beaulieu and Hughes, 1975).

Most of the developed part of the City of Coos Bay that was formerly known as Eastside is underlain by the Bastendorff Formation consisting of shale and siltstone with minor sandstone interbeds (City of Eastside, 1978). A substantial amount of land north and west of the developed area has been, and will continue to be, filled with dredged material. Soils are predominantly silt loams where no fill has been placed.

A large portion of all land within the Coos Bay corporate limits is undeveloped or open lands including rights-of-way, city parks, and land owned by the Coos Bay-North Bend Water Board. Most residential areas are centered around downtown Coos Bay, in the Empire area, and along major arterials such as Southwest Boulevard, Ocean Boulevard, and Newmark Street (Coos Bay City Council, 1981). Development in areas affected by flooding is predominantly commercial and industrial with only limited residential areas affected.

Coos Bay is served by U.S. Highway 101 and the Southern Pacific Railroad.

City of Coquille

The City of Coquille is located in western Oregon, in the south-central portion of Coos County. The closest incorporated community is the City of Myrtle Point, located 9 miles to the south along State Highway 42. The coastal community of Coos Bay is located approximately 18 miles to the north and is connected to Coquille by a branch line of the Southern Pacific Railroad. State Highways 42 and 42S are the major routes between the coast, Coquille, and inland areas. The city is bounded by the unincorporated areas of Coos County. The city was incorporated in 1885. According to the U.S. Census Bureau, the population of Coquille was 3,866 in 2010 (U.S. Department of Commerce, 2010). In 1990, the population was 4,121 (U.S. Department of Commerce, 2010).

The Coquille River forms the southwest boundary of Coquille and extends approximately 99 river miles inland from the coastal community of Bandon to the headwaters of the South Fork Coquille River. It drains a total of 1,058 square miles. Coquille occupies an area of high ground on the east bank of the river, between RM 23 and RM 25. Above the State Highway 42S bridge in Coquille, the Coquille River has a drainage area of 930 square miles. The Coquille River has two major tributaries, the North Fork Coquille River and the South Fork Coquille River that meet about 12 miles upstream of Coquille, near Myrtle Point. The North Fork Coquille River drains approximately 288 square miles, while the South Fork Coquille River drains 591 square miles (Pacific Northwest River Basins Commission, 1968). Tidal influences extend as far upstream as Myrtle Point on the South Fork Coquille River.

Cunningham Creek flows southwest through the City of Coquille to its confluence with the Coquille River at RM 24.0. The Cunningham Creek floodplain divides the developed portion of Coquille into two distinct areas that are joined by State Highway 42 (West Central Boulevard). Total drainage area of the Cunningham Creek basin at its confluence with the Coquille River is 14.2 square miles. Calloway Creek is a tributary of Cunningham Creek and has a drainage area of 2.7 square miles above its confluence with Cunningham Creek. Calloway Creek and Cunningham Creek share the flood plain for about 1,500 feet north of West Central Boulevard.

Total land area within the corporate limits of Coquille is 2.7 square miles. About 60 percent of the city is undeveloped. Approximately one-third of this undeveloped land is in the flood plain (City of Coquille and Coos-Curry Council of Governments, 1978a). Existing development in the City of Coquille has occurred mainly on the terraced area northeast of the Coquille River. Approximately two-thirds of the developed land is currently used for residential purposes. Commercial development, consisting almost entirely of service-oriented business, is concentrated in the central business district. At present, commercial development is expanding eastward along West Central Boulevard. Lands developed for industrial purposes are primarily outside the corporate limits and, in most cases, are near the river. Little development has occurred within the Coquille River and Cunningham Creek flood plains because of a lack of roadway access and the need for extensive fill.

The Coquille River valley is a productive agricultural area that also supports dairy and beef production. With the exception of the river valley, much of the land surrounding Coquille is hilly and wooded.

Annual precipitation at Coquille averages 55.2 inches (City of Coquille and Coos-Curry Council of Governments, 1978a). Rainfall is heaviest in December and January, when a series of frontal storms frequently pass through the area. These storms are formed when cold, polar air from the Aleutian region merges with the warm air of the Central Pacific. On average, only about 4 percent of the total annual rainfall occurs in June, July, and August. The average annual temperature in Coquille is approximately 50 to 55°F.

Most of Coquille is underlain by Quaternary fluvial terrace deposits. Flood plain areas along Cunningham Creek and the Coquille River are underlain by unconsolidated deposits of sand, silt, clay, and mud (City of Coquille and Coos-Curry Council of Governments, 1978b).

City of Lakeside

The City of Lakeside is located in the northwestern corner of Coos County on Tenmile and North Tenmile Lakes. Lakeside is approximately 15 miles north of Coos Bay, 15 miles south of Reedsport, and 3 miles west of the Pacific Ocean. The city was incorporated in 1974. According to the 2010 U.S. Census, the population of Lakeside was 1,699 in 2010 (U.S. Department of Commerce, 2010). In 1990, the population was 1,437 (U.S. Department of Commerce, 2010).

The southwest corner of North Tenmile Lake, the west end of Tenmile Lake, and 1.2 miles of Tenmile Creek are within the city limits of Lakeside. North Tenmile Lake and Tenmile Lake cover approximately 980 acres and 1,350 acres, respectively (Sidor and Brown, 1967). The drainage area above the North Tenmile Lake outlet near the North Lake Road Bridge is 29.0 square miles. North Tenmile Lake drains into Tenmile Lake through a 0.4-mile-long canal. The drainage area above the Tenmile Lake outlet and near the Hilltop Drive Bridge is 70.6 square miles. Tenmile Creek flows west from Tenmile Lake for 5.1 river miles before entering the Pacific Ocean. Above the Wildwood Drive Bridge and the confluence of Tenmile and Eel Creeks, Tenmile Creek drains an area of 97 square miles.

Several recreation areas border Lakeside: William M. Tugman State Park is to the north, and the Oregon Dunes National Recreation Area and the Siuslaw National Forest are to the west. Both Tenmile Lake and North Tenmile Lake are known for their sports fishing. U.S. Highway 101 and the Port of Coos Bay Railway serve the area, and Lakeside Municipal Airport is located in Lakeside.

The City of Lakeside covers 2.3 square miles. Development is primarily residential with most commercial development located along North 8th and South 8th Streets. Development in the flood plain includes a tourist resort on North Tenmile Lake, several residences along Tenmile Creek, and the city's sewage treatment plant.

Average annual precipitation at Lakeside is approximately 70 inches (Pacific Northwest River Basins Commission, 1969). Approximately 80 percent of the rainfall occurs between October and March. January is the coldest month, with an average temperature of approximately 45°F. August is the warmest month, with an average temperature of approximately 60°F. The predominant soil type found in Lakeside is composed of loamy sand, sand, and fine sand formed in wind-deposited material. Gravelly loams and silty loams formed from weathered sedimentary rock occur around Tenmile and North Tenmile Lakes (U.S. Department of Agriculture, 1975).

City of Myrtle Point

The City of Myrtle Point is located in the south-central portion of Coos County. The closest incorporated community is the City of Coquille, located 9 miles to the north along State Highway 42. The coastal community of Coos Bay is located approximately 27 miles to the north and is connected to Myrtle Point by a branch line of the Southern Pacific Railroad. The city is bounded by the unincorporated areas of Coos County. The city was incorporated in 1887. According to the U.S. Census Bureau, the population of Myrtle Point was 2,514 in 2010 (U.S. Department of Commerce, 2010). In 1990, the population was 2,712 (U.S. Department of Commerce, 2010).

The South Fork Coquille River flows along the western boundary of Myrtle Point. The City of Myrtle Point occupies an area of high ground on the east bank of the South Fork Coquille River, between RM 37.0 and RM 38.0 (Pacific Northwest River Basins Commission, 1968). The confluence of the South Fork Coquille River and the North Fork Coquille River is at RM 36.4, a short distance downstream of Myrtle Point. State Highway 42 is the major highway between the coast, Myrtle Point, and inland areas. A bridge, roadway, and overflow bridge have been constructed across the South Fork and its floodplain at Spruce Street (RM 37.4) to serve access to a secondary highway to Bandon.

Total land area within the corporate limits of Myrtle Point is 1.6 square miles. The majority of residential and commercial development in the City of Myrtle Point is located on a plateau some 75 feet above the river valley. Scattered residential and industrial development exists within and along the fringes of the floodplain boundary. Commercial development includes a wide spectrum of retail- and service-oriented businesses centered along State Highway 42 and Spruce and Maple Streets. Limited light industrial development exists close to the Southern Pacific Railroad tracks along the western edge of the city.

The Coquille River valley is a productive agricultural area that also supports dairy and beef production. With the exception of the river valley, much of the land surrounding Myrtle Point is hilly and wooded.

Annual precipitation at Myrtle Point averages 56 inches. Rainfall is heaviest in December and January, when a series of frontal storms frequently pass through the area. On average, only about 4 percent of the total annual rainfall is received in June, July, and August. The average daily temperature in Myrtle Point is 62°F. Temperature extremes have been recorded as low as 0°F in winter and over 100°F in summer (City of Myrtle Point and Coos-Curry Council of Governments, 1979).

Sandstone, basalt, poorly sorted gravel, sand, silt, and clay are the predominate rock and soil types found in the area (Beaulieu and Hughes, 1975).

City of North Bend

The City of North Bend is located in western Coos County. The city lies on the northern end of a peninsula that extends north into Coos Bay estuary. North Bend is located approximately 2 miles west of the Pacific Ocean, approximately 25 miles south of Reedsport, and approximately 19 miles north of Coquille. North Bend is bounded by Coos Bay to the north and east, and by the City of Coos Bay to the south and west. The City of North Bend covers 5.1 square miles. The elevation in North Bend varies below sea level in the bay to approximately 160 feet at the western city limits. The city was incorporated in 1903. According to the U.S. Census Bureau, the population of North Bend was 9,695 in 2010 (U.S. Department of Commerce, 2010). In 1990, the population was 9,614 (U.S. Department of Commerce, 2010). The economy of North Bend is based on shipping, retail trade, and tourism.

Pony Creek flows north through the center of North Bend to the Coos Bay estuary, and drains the central portion of the peninsula on which the Cities of Coos Bay and North Bend are located. The creek has a length of 5.6 miles and a drainage area of 6.4 square miles above Virginia Avenue. As previously mentioned, the Coos Bay-North Bend Water Board operates two dams on Pony Creek for municipal water supplies.

The average annual rainfall at North Bend is 61.2 inches (Pacific Northwest River Basins Commission, 1968). The mean temperature in January, the coldest month, is approximately 46.6°F and in July, the warmest month, the mean temperature is approximately 59.0°F. In winter, the prevailing winds are from the southwest, while from May through August, the prevailing winds are from the northwest. Winter winds are usually milder than those during the summer except during an occasional winter storm.

Development in the floodplain is clustered around the Pony Creek and includes a shopping mall on Virginia Avenue and several businesses along Broadway Avenue. Some residential developments are also in the floodplain.

Soils in North Bend are predominantly sands and sandy loams. In areas affected by tidal action along the bay and Pony Creek, the soils range from silty clay loams to sandy loams (U.S. Department of Agriculture, 1975). Most of North Bend is underlain by coarse- to fine-grained sandstone of the Coaledo formation (Beaulieu and Hughes, 1975).

North Bend is served by U.S. Highway 101, the Union Pacific Railroad, and is the site of the Southwest Oregon Regional Airport.

City of Powers

The City of Powers is located in southern Coos County. The closest incorporated community is the City of Myrtle Point, located 21 miles to the north along State Highway 42. The coastal community of Coos Bay is located approximately 42 miles to the north. The city is bounded by the unincorporated areas of Coos County. The city was incorporated in 1945. According to the U.S. Census Bureau, the population of Powers was 689 in 2010 (U.S. Department of Commerce, 2010). Total land area within the corporate limits of Powers is approximately 416 acres.

The South Fork Coquille River flows through the center of Powers. Powers is located 28 miles upstream of the confluence of the South and North Forks of the Coquille River. Although the City of Powers participates in the National Flood Insurance Program, a Flood Insurance Study had not been previously developed.

2.3 Principal Flood Problems

Riverine and Estuarine

Most flooding in Coos County occurs on the Coquille River and its tributaries. The Coquille River at Coquille and the South Fork Coquille River at Myrtle Point typically exceed flood stage at least once each winter. Most other rivers and streams in the county flood less frequently. Riverine flooding usually occurs from November through February when storms moving inland off the Pacific Ocean cause heavy rainfall.

In the lower reaches of the Coquille River, higher than normal tides combining with high runoff can cause extensive flooding. Storm runoff is high because of moderately steep to steep terrain and the characteristic low soil permeability in the upper Coquille River valley. A natural constriction in the Coquille River valley downstream of Riverton and tidal influences control the flood elevations at the City of Coquille. The river valley at Coquille is flooded an average of 3 months each year (City of Coquille and Coos-Curry Council of Governments, 1978a). Natural levees along the riverbanks result in poor drainage from overbank areas as floodwaters recede. The worst flooding occurs when high tides combine with high runoff and onshore winds during major winter storms.

Flood stage at Coquille is 21 feet while the flood stage at Myrtle Point is 33 feet (National Oceanic and Atmospheric Administration [NOAA], 2010). Extreme riverine floods have occurred in February 1890, December 1955, December 1964, and November 1996. Major flooding occurred in the Coquille River valley in December 1951, January 1953, November 1953, January 1971, January 1974, December 1980, December 1981, January 1995, and December 2005.

The largest observed flood in the basin, in February 1890, crested at 23 feet at the State Highway 42S Bridge in Coquille. In both December 1955 and December

1964, the river crested at 21.1 feet at Coquille with an estimated discharge of 120,000 cubic feet per second (cfs) (City of Myrtle Point and Coos-Curry Council of Governments, 1979). The estimated return period for both the 1955 and 1964 floods is 200 years. During floods of this magnitude, an estimated 300,000 acre-feet of water covers the Coquille River flood plain to an average depth of 15 feet. Damages to the Coquille River basin during the December 1964 flood totaled $3.1 million. About one-half of the damages were agricultural (USACE, 1969). Flooding in the Coquille River basin during the February 1999 flood totaled $5 million in crop damage (Coos County Emergency Management Department, 2005).

Flood stage in the Myrtle Point area is higher than in the areas downstream because of a natural constriction in the flood plain immediately downstream of the confluence of the North and South Forks of the Coquille River. In December 1964, the Spruce Street Bridge staff gage at Myrtle Point, indicated that the South Fork Coquille River crested at approximately 11 feet above flood stage (bankfull discharge) (City of Myrtle Point, 1964) with an estimated discharge of 100,000 cfs. This flow has a return period greater than 500 years. Stream Gage No. 14325000 on the South Fork Coquille River at Powers recorded a peak flow of 48,900 cfs. This flow has a return period of about 500 years.

Flooding on the North Fork Coquille River is often affected by backwater from the South Fork Coquille River. However, a localized storm system could cause flooding on the North Fork with resulting water-surface elevations that are not significantly affected by South Fork flows. During the December 1964 flood, the North Fork Coquille River near Myrtle Point (Stream Gage No. 14327000) peaked at 38,400 cfs. This flow has a return interval of 55 years (Beaulieu and Hughes, 1975).

Flooding on Cunningham Creek and Calloway Creek is affected by backwater from the Coquille River, During the December 1964 flood, flow from Cunningham and Calloway Creeks was 1 to 1.5 feet deep over West Central Boulevard in the City of Coquille.

Most flooding on Ferry Creek, located within the corporate limits of Bandon, results from high tides and storm surge in the Coquille River estuary backing up flow in the creek. During the 1955 flood, there were 18 inches of water in the Bandon Cheese Cooperative building on the west bank of Ferry Creek between U.S. Highway 101 and 3rd Street E. In December 1981, the creek overflowed near the intersection of 3rd Street E. and Grand Avenue. Water was 18 inches deep in one building southeast of the intersection. The overflow traveled down 3rd Street E. and Fillmore Avenue to the Coquille River estuary.

In December 1964, the flow at the only stream gage in the Coos River basin, No. 14324500, on the West Fork Millicoma River near Allegany, peaked at 5,560 cfs. This flow has a return period of only two years. The peak recorded flow at the

Allegany gage was 8,100 cfs in November 1960. This flow has a return period of about 8 years.

Until 1980, the flood plain along Pony Creek, located in the cities of North Bend and Coos Bay, had not been developed. As development occurs in this area, the potential for flood damage could increase substantially. In December 1980, water levels almost reached the Woodland Medical Village on Pony Creek east of Broadway Avenue after a period of heavy rainfall. The peak flow recorded at USGS Stream-Gage No. 14324580 below the lower Pony Creek dam for December 1980 was 73 cfs. The peak flow of record at the gage was 181 cfs in December 1981.

Flooding on North Tenmile Lake, Tenmile Lake, and Tenmile Creek in Lakeside usually occurs from October through March, during periods of heavy rainfall. Major floods in Lakeside typically have occurred in December or January. The largest recorded flood on Tenmile Creek came in December 1964 during a period of extensive flooding throughout western Oregon. The peak recorded flow at the USGS gage, Number 14323200, Tenmile Creek near Lakeside, was 3,330 cfs. This flow has a return frequency of approximately 36 years. The maximum elevation of Tenmile Lake during the 1964 flood was 18.8 feet measured at a staff gage maintained by the USGS near the outlet of Tenmile Lake. This elevation has a return frequency of approximately 17 years. East of South 8th Street, floodwaters almost reached North Lake Avenue. The Lakeside Division of Bohemia Lumber Company was flooded. West of North 6th Street floodwaters reached the second step of the Northlake Resort grocery store.

In January 1953, before the Tenmile Creek stream gage and Tenmile Lake staff gage were installed, Tenmile Lake reached an elevation of 19.8 feet. This elevation has a return frequency of approximately 53 years. Other major floods have occurred in 1969, 1977, and 1982 as a result of heavy rainfall. Flooding in December 1982 was close to what would be expected during the 1-percent-annual-chance event.

There is limited development along the shoreline of the Coos Bay estuary except in the incorporated areas of Coos Bay and North Bend, and in the unincorporated communities of Barview, Charleston, and Glasgow. Flooding in Coos Bay is most likely to occur from November through March, when rainfall is greatest and major storms are most likely to occur. In the past, most severe flooding in the City of Coos Bay has been caused by high tides in the Coos Bay estuary occurring during periods of high rainfall and runoff. In December 1964, a high tide of 6.1 feet combined with strong southerly winds to flood Bayshore Drive and several homes along Front Street to a depth of 6 inches. In December 1965, high water flooded the lobby of the Fitzpatrick Building, the basement of the old City Hall, and the intersection of South Broadway and Hall Avenue. In January 1966, December 1967, December 1968, December 1969, and December 1972, high tides of approximately 6 feet caused flooding along South Broadway and U.S.

Highway 101. In January 1973, several businesses along Front Street and North Bayshore were flooded. Development in Eastside, North Bend, Barview, and Glasglow has generally occurred in areas unaffected by flooding. Flooding in Charleston has reached some of the lower-lying commercial areas in the past when storm surge combined with high tides.

Coastal

The Coos County shoreline is the product of a variety of processes that have helped shape the morphology of the beaches and shorelines over the past several thousand years. These include the effects from great earthquakes associated with the Cascadia subduction zone that produced giant tsunamis that inundated significant areas of the coast as well as having lowered the coastal land elevations, thereby initiating a new sequence of shoreline evolution. More recent effects are due to humans, including the construction of the jetties at the mouth of the Coquille and Coos estuaries, and indirectly through the introduction of non-native dune grasses that have stabilized significant stretches of the coast, enhancing the growth of dunes and dramatically changing the character of the coast.

Beach morphodynamics along the Bandon shoreline today is a function of the response of the coast to the most recent Cascadia subduction zone earthquake (1700), with the coast now being emergent due to tectonic uplift, and human effects associated with the construction of the Coquille jetties. The primary sediment sources for the Bandon beaches are fine sands that are carried down the Coquille River and gravels (sand to pebbles) supplied by the erosion of Blacklock Point, located to the north of Cape Blanco in northern Curry County. Sand has also been lost from this stretch of shore due to Aeolian processes that have carried the finer sand inland where it has accumulated and formed dunes, a loss that is particularly significant south of Bradley Lake near Bandon where a field of dunes has formed. Sand dunes have also accumulated at the back of the beach along the length of the New River Spit, a ridge of foredunes that separates the ocean beach from the channel of the river.

Erosion of Blacklock Point north of Cape Arago is actively contributing coarser sediments to the beach system. Analyses of changes in the position of the bluff-top using historical aerial photos indicate that the bluffs along Blacklock Point are eroding at rates of ~0.09 m per year (Komar et al., 2001). These coarser sediments move along the shore in a predominantly northward direction, where they have mixed with the finer sands contributed by the Coquille River, producing a longshore variation in beach sediment grain-sizes along this shore. Pebbles dominate the beach sediments along the southern portion of the New River Spit, while the sand content decreases away from the Coquille River southward toward the southern end of the New River Spit; this southward decrease of sand in the beach reflects both the increasing distance away from the Coquille River, its source, as well as the loss of the sand inland to form dunes. The general patterns of sediment movement identified by Komar et al. (2001) does not reflect any prevailing net longshore sediment transport in any one particular direction, since within the "pocket beach" littoral cells of the Oregon coast the net transport is effectively zero (Komar, 1997). Nevertheless, sand and gravel derived from the mixing of these two sediment sources has enabled the New River Spit to prograde as the mouth of the river has slowly migrated to the north in recent decades, and with the elevations of the foredunes having increased with time, aided by the introduction of European dune grass. Over approximately 1.5 km near the tip of the Spit nearest the present day position of the river's mouth, the beach is characterized by intermittent clumps of low dunes, separated by zones where winter storm waves actively wash over the Spit. With increasing distance southward, the dunes become progressively higher and more effective at preventing overwash during storms.

In the north along the Bandon bluffs, the beach and shoreline is considered to be stable and appears geomorphically to be unchanged from photographs taken in the early 1900s. The bluffs are covered by dense vegetation, mainly impenetrable brush, such as salal and gorse, and have not been subject to wave-induced toe erosion during the 140 years of settlement of Bandon (Komar et al., 1991).

The Bandon jetties were constructed in the late 1800s at the mouth of the Coquille River, and this locally resulted in significant changes in the shorelines. Construction of the jetties was initiated in December 1883 and the response of the shoreline is documented in Figure 1, derived from periodic surveys undertaken by USACE (Komar et al., 1976). As can be seen in Figure 1, the shoreline response in 1884 indicates rapid accretion that took place south of the jetty. This occurred as a sand spit that grew northward where it became attached to the south jetty. East of the spit, the northward advance of the spit effectively trapped a low area within the accreted land, forming a lagoon shown in the 1891 survey that still exists today (Figure 1). Aside from the build-up of sand south of the south Coquille jetty, sand also began to aggrade in the north adjacent to the north jetty. Based on this evidence and from similar studies undertaken elsewhere on the coast, this type of response demonstrates the existence of a seasonally reversing longshore sediment transport, northward during the winter and to the south in the summer, but with the long-term net transport being effectively zero (Komar et al., 1976).

The shoreline adjacent to the Coquille jetties have been broadly stable for some decades, although the dunes and low lying land characteristic of this area remain susceptible to both dune erosion and flooding from extreme ocean waves coupled with high tides (Figures 2 and 3). Figure 4 is an historical 1939 aerial photo of the 'triangle' adjacent to the jetties. Included in the figure is a dashed line that demarcates blowouts in the foredune that is likely to have been caused by a recent major storm(s), possible an event in January 1939 (Figure 4). Evidence for the blowouts includes significant amounts of logs and flotsam that have been carried well inland from the coast. The January 1939 storm resulted in extensive erosion elsewhere on the Oregon coast and is thought to be one of the most significant events to affect the coast in historical times (Dr. Paul Komar, Emeritus Professor, Oregon State University, December 2009). According to Dr. Komar, the 1939 aerial photographs were flown by USACE to document the effects of the storm, and is the first coastwide suite of aerial photographs of the Oregon coast. A comparison of the shoreline mapped in 1939 with the 2009 shoreline indicates little difference in the general position, reaffirming the fact that there has been little net change in the position of the shoreline over the past 70 years.

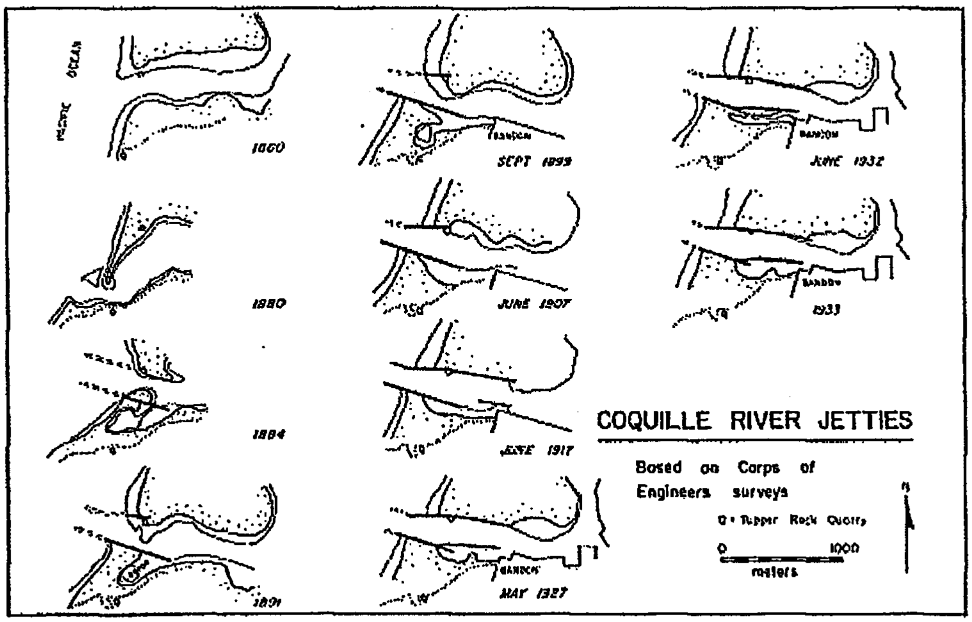


Figure 1 - USACE Coquille River Survey Lines at Bandon
Survey line drawings prepared by USACE prior to and during construction of the Coquille jetties adjacent to Bandon (Komar et al., 1991).

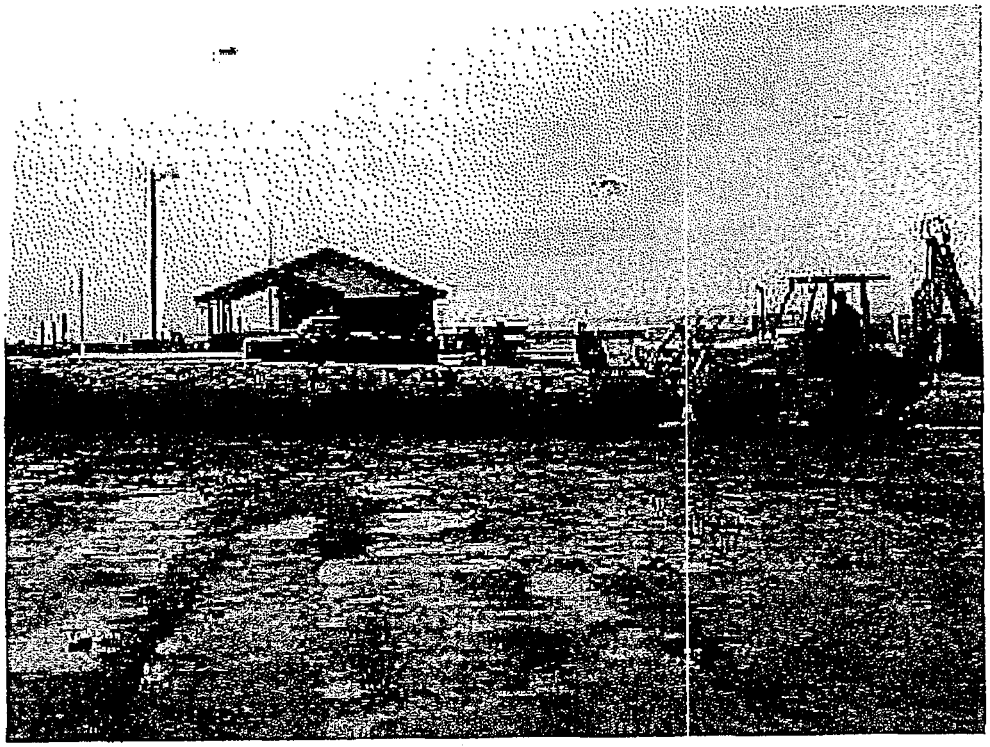


Figure 2 - December 22, 2000 Coastal Flooding Debris at Bandon
High wave runup and overtopping during a major storm (December 22, 2000) near the south Coquille jetty at Bandon carried logs onto the main parking lot, adjacent to a public restroom (Photo courtesy of Dr. J. Marra, pers. comm., May 2010).

Figure 3 - December 22, 2000 Wave Runup at Bandon
Wave overtopping during a major storm (22 December, 2000) surrounds the restroom and covers the parking lot adjacent to the south Coquille jetty at Bandon (Photos courtesy of Dr. J. Marra, pers. comm., May 2010).

Figure 4 - 1939 Aerial Photo of Wave Blowouts at Bandon
1939 aerial photograph of the Bandon 'triangle' adjacent to the Coquille jetties showing evidence of blowouts in the developing foredune that likely occurred during a major storm in January 1939.

As part of the revised FIS undertaken in Bandon, CH2MHILL (1996) compiled a history of past flood events. These are summarized in Table 5, while Figures 2 and 3 highlight the effects of several recent storms along the Bandon 'triangle'. For example, one local resident described one storm between 1945 and 1977, which generated ocean flooding near the Bandon triangle that reached an estimated 5.6 m (NAVD88) elevation at the shore.

Table 5. History of Coastal Flooding Events at South Jetty Area of Bandon, Oregon (CH2MHILL, 1998)

Date	Comments	(Note 1) Observed Tide Level (ft. NGVD)	(Note 2) Estimated Return-Period of Tide Level (yrs)
2/9/60	Beach erosion at foot of South Jetty with drift logs 1-2 ft. dia. and stumps (est. from photos) washed est. 200' into parking lot.	NHT	---
11/20/60	62 mph southwest winds at Bandon with high tides and surf. No reported flooding, but flood damage at Newport and Tillamook.	NHT	---
10/12/62	Columbus Day wind storm "hurricane-like" winds caused much wind damage but no reported flooding.	5.45	2
1/18/64	Stormy SW wind. Seafoam 2-3 ft. deep drifted into parking lot at S. Jetty.	NHT	---
12/1/67 – 12/2/67	Very high tides and "ferocious" winds wash logs into S. Jetty parking lot and jetty access road. 10.1 ft tide (no datum reported) associated with flooding.	NHT	---
1/17/73	S. Jetty Road and top of S. Jetty littered with stumps 2-3 ft. dia. and 1 ft. (est.) logs. Sand deposited on S. Jetty Road.	6.05	< 1
11/9/75	Worst windstorm since 10/12/62. 145 mph gusts at C. Blanco. 100 mph W-NW gusts Bandon airport. No flooding mentioned.	MD	---
10/28/77	Highest waves in years. "Water surged 9.5 feet (?) instead of normal 1 foot in Bandon Harbor." Drift logs 1-2 ft. dia. washed into S. Jetty parking lot approximately 200 feet.	4.63	< 1
12/13/77	Foam and sheets of water surge over foot of S. Jetty.	NHT	---
2/7/78	3 ft. dia. drift logs and sand on S. Jetty Road from high tide and breaking waves	6.25	18
11/22/79	2-3 ft. diameter stumps and sand washed onto S. Jetty Road. High waves reported.	NHT	---
11/13/81 - 11/14/81	Est. 100 mph gusts at Bandon. Much wind damage. No reported flooding.	5.91	7
1/28/83 - 1/29/83 (dates approx.)	Waves wash across S. Jetty Road opposite Bandon lighthouse into freshwater pond. Coos County in process of placing rock along road shoulder to prevent further damage.	6.90	141
11/22/88	High tides and waves scattered foam over S. Jetty parking lot.	5.24	1.1
1/29/90	62-98 mph wind gusts. Driftwood tossed into S. Jetty parking lot. "[Significant] waves measured at 26 feet " at wave buoy 5 miles off Bandon's Bar.	NHT	---

Table 5. History of Coastal Flooding Events at South Jetty Area of Bandon, Oregon (CH2MHILL, 1998) (continued)

Date		Comments	(Note 1) Observed Tide Level (ft. NGVD)	(Note 2) Estimated Return-Period of Tide Level (yrs)
1/30/92 1/31/92	-	"Huge piles" of driftwood washed up on beach at the S. Jetty.	NHT	—
12/10/92 12/11/92	-	"Heavy surge" cuts through the bank behind Bandon Boatworks Restaurant with new channel cut to Redman Pond. Small driftwood logs (4" dia.) deposited next to 2 houses immediately south of parking lot.	5.28	1.2
12/9/93 12/10/93	-	Ocean waves and river erode backshore shoreline vicinity of Redman Pond	N/A	---

Notes:
1. Tide elevations based on observed tides at Crescent City, which is the primary reference station for tides at Bandon. Elevations shown are for recorded monthly maximums. NHT = not highest monthly tide observed at Crescent City. MD = Missing data for month. N/A = Not available as of late 1994 from NOAA.

Beach morphodynamics along Bastendorff Beach are similar to those observed along the Bandon shore. Prior to construction of the Coos Bay jetties, the entrance to Coos Bay reflected a rocky stretch of coast along its south bank, while an extensive barrier spit was located to the north that protected the Coos Bay estuary from the direct effects of ocean waves. Jetty construction was initiated first on the north spit and by the beginning of the 20th century the shoreline had prograded seaward by about 1 km (~3000 ft), while the shoreline had straightened significantly as sand piled up against the north jetty. With the construction of the south jetty early in the 20th century, a similar response was observed in the south (Figure 5). Sand accreted against the jetty and against the rocky shore and the shoreline began to prograde seaward. As can be seen in Figure 5, the shoreline rapidly prograded seaward up until the 1960s. Since 1967, however, the shoreline has essentially remained much the same as it is today suggesting that the beach has reached a quasi-equilibrium state with the sediment transport processes. With the shoreline progradation having all but ceased by 1967, the back shore portion of the beach rapidly became stabilized due to the introduction of non-native beach grasses, particularly European Beach grass, and from growth of shore pines immediately landward of the primary dune (Figures 6 and 7). This type of response is characteristic of the entire length of Bastendorff Beach. Further south at Lighthouse Beach, the shoreline in the 1920's is essentially unchanged from its position in 1967 and again in 2008. This indicates that the effects of jetty construction did not extend south of Bastendorff Beach and furthermore that the shoreline has been broadly stable over the past 80-90 years.

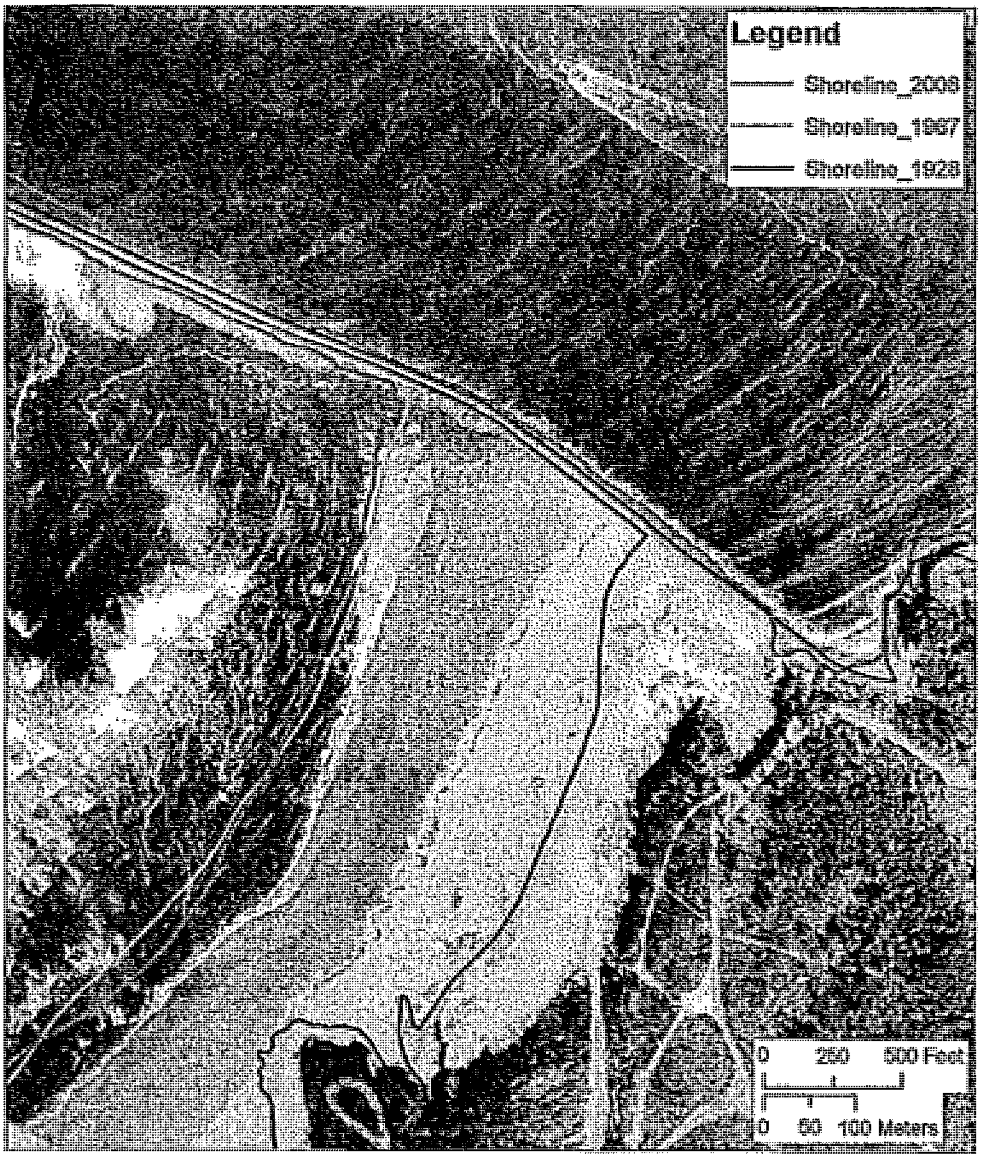


Figure 5 - Historical Shorelines at Bastendorff Beach Overlaid on 1939 Aerial Photo
Historical shoreline changes at Bastendorff Beach adjacent to the Coos Bay jetties. The photo is of the beach in 1939.

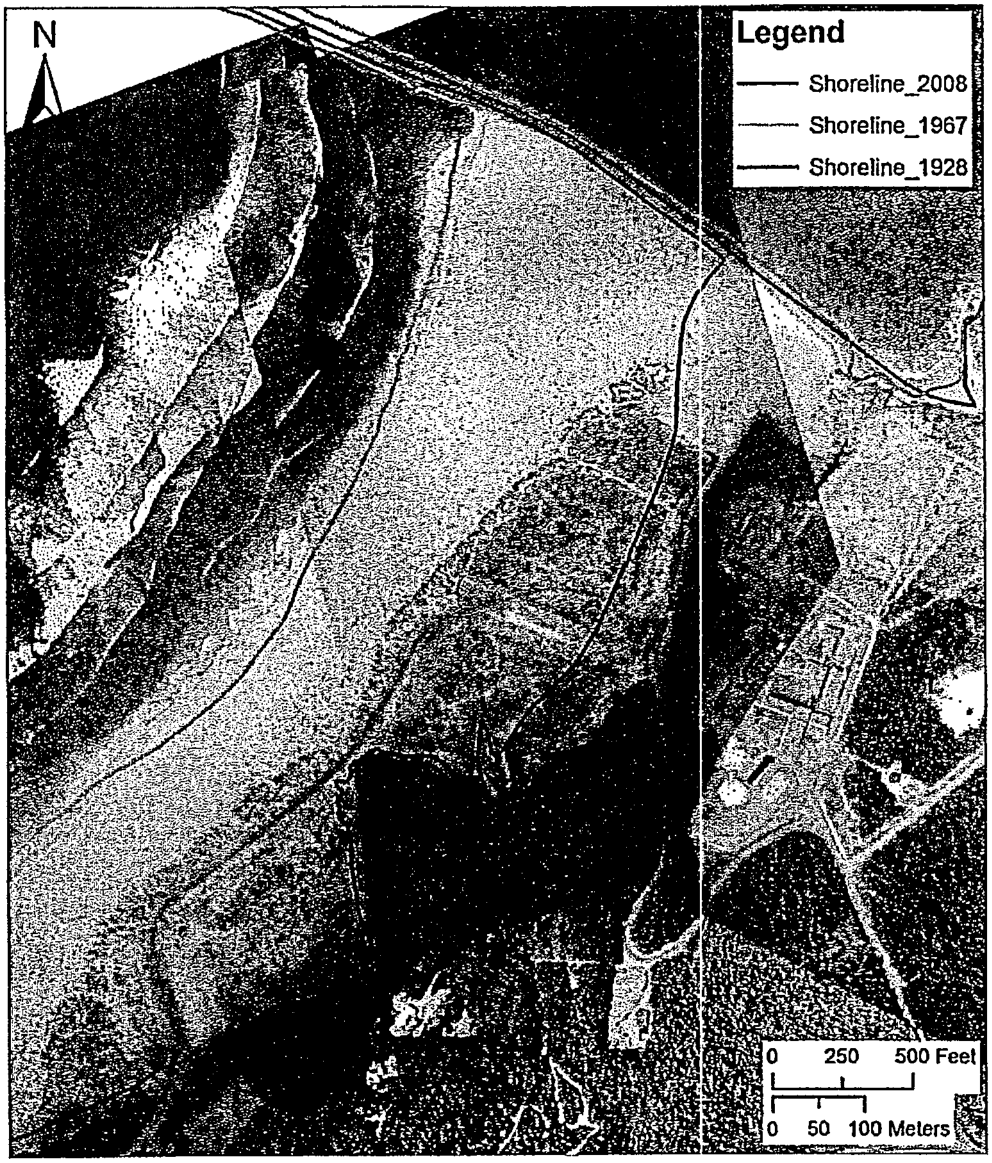


Figure 6 - Historical Shorelines of Bastendorff Beach Overlaid on 1967 Aerial Photo
Historical shoreline changes at Bastendorff Beach adjacent to the Coos Bay jetties. The photo is of the beach in 1967 and shows the degree to which the backshore has become stabilized due to introduction of European beach grass and from growth of shore pines.

Figure 7 - April 9, 2010 Photo of Bastendorff Beach Foredune
Photo of Bastendorff Beach on April 9th 2010 showing the well vegetated foredune and backshore. Photo taken by Jonathan Allan, DOGAMI.

2.4 Flood Protection Measures

Several structural measures providing flood protection have been taken in Coos County. The USACE stabilized the Coos Bay and Coquille River entrances by building jetties on either side of the entrance channels. The Coos Bay jetties were completed in 1929. The Coquille River jetties were completed in 1908. The USACE has also maintained navigation channels in Coos Bay, in the Coquille River estuary, and on the Coos and Millicoma Rivers. The Coos Bay navigation channel is maintained at 45 feet across the outer bar, at 35 feet from Coos Head to the junction of Coalbank and Isthmus Sloughs, and at 22 feet on Isthmus Slough between Coalbank Slough and the community of Millington. The Coquille River navigation channel is maintained at 13 feet between RM 0 and RM 1.3. The Coos River and Millicoma River navigation channels are maintained at 5 feet to RM 8.3 on the Millicoma and 8.8 on the South Fork Coos River. From RM 8.8 to RM 9.2, the South Fork Coos River navigation channel is maintained at 3 feet. All depths in the navigation channels are measured below mean lower low water.

Low-lying areas of Palouse and Larson Creeks, Kentuck Slough, and Willanch Slough have been diked with tide gates at their outlets. The tide gates prevent inundation of the low-lying areas by high tides in the bay. Most of these dikes and tide gates have been built by local drainage districts. Some areas along the South

Slough, Isthmus Slough, Coalbank Slough, Catching Slough, and the Coos River have also been diked. Most of these dikes are not high enough to completely prevent flooding. In the Coos Bay estuary, 2,000 acres of tidelands have been diked for agricultural use (Beaulieu and Hughes, 1975).

Since 1920, 1,500 acres of tidelands have been filled (Beaulieu and Hughes, 1975). Many of these fills are not high enough to completely prevent flooding. Major fills have occurred at the mouth of Pony Slough, at the mouths of Coalbank and Isthmus Sloughs, in the area north of the developed part of eastern Coos Bay (formally known as Eastside), and at Graveyard Point along the Coos River. The first three fill areas will be flooded to some extent during a 1-percent-annual-chance event.

Since the downtown area has flooded so frequently in the past, the City of Coos Bay has taken several structural measures to reduce flood damage. A dike was built along Isthmus Slough from Commercial Avenue to Coalbank Slough to protect the downtown area during high tides. The dike is frequently checked for damage and settling. The dike provides limited protection because the lowest dike elevation is 7.6 feet NGVD (11.2 feet NAVD) and in places the dike would be overtopped during a 10-, 2-, or 1-percent-annual-chance tide in the bay. During a 0.2-percent-annual-chance tide, the entire length of dike would be overtopped.

To minimize ponding behind the dike when high local runoff occurs during a high tide, the City of Coos Bay has built two pumping stations. One pumping station is located near the intersection of Front Street and Johnson Street and protects most of the area bounded by Golden Avenue to the north, 4th Street to the west, Kruse Avenue to the south, and the dike to the east. The other pumping station is located at the intersection of Commercial Avenue and 3rd Street and protects most of the area bounded by Commercial Avenue on the north, 4th Street to the west, Curtis Avenue to the south, and North Broadway to the east. These pumps can only provide complete protection when there is little or no overtopping of the dike.

Several storm sewer systems in the City of Coos Bay, including the Mill Slough Box that drains Blossom Creek, have tide gates at their outlets to prevent high tides from backing up into the systems. During periods of high tide combined with high runoff, ponding will occur behind the tide gates.

Some flood protection is provided on Pony Creek because flow downstream of Ocean Boulevard is regulated by two reservoirs operated by the Coos Bay-North Bend Water Board for municipal water supplies. The reservoirs are not operated for flood control, but some flood control is provided because runoff is stored during the rainy season for use during the dry season. Typically, the upper reservoir reaches its lowest level in late fall and refills during the rainy season. Once the water level reaches an elevation of 82 feet (85.6 feet NAVD88), the pool level will be maintained until mid-March, and no more runoff will be stored. During the winter, the lower reservoir is operated with free flow over the spillway because of dam safety considerations. Unless the reservoir has been drawn down below the spillway lip during the dry season, no storage volume will be available to store runoff.

The South Fork Coquille River stream gage at Powers, the staff gage at Coquille, and the staff gage at Myrtle Point are three of 15 key stations in Subregion 10 of the Flood Forecasting System operated by the National Weather Service (Pacific Northwest River Basins Commission, 1971). Subregion 10 covers coastal systems in Oregon and part of Washington. Flood warnings are issued when forecasts indicate that near bankfull stages are expected. When flood stage is reached, bulletins are issued at 12-hour intervals until the streams recede and the danger has passed.

In the City of Bandon, several property owners along the Pacific Ocean have placed berms and riprap around their homes to protect them from wave action.

The Portland Weather Forecast Office issues storm tide warnings indicating expected tidal flooding along low-lying coastal areas. Warnings include expected tidal stages above mean lower low water or departure from normal high tide, degree of flooding, possible wave or surf battering, and significant beach erosion.

The U.S. Coast and Geodetic Survey prepared warnings and advisories of tsunamis. Local officials have the responsibility for advising the local population.

The Cities of Bandon, Coos Bay, Coquille, Lakeside, Myrtle Point, North Bend, Powers, and Coos County participate in the National Flood Insurance Program and each have a floodplain ordinance approved by FEMA for controlling development in flood hazard areas.

Levees exist in the study area that provide the county with some degree of protection against flooding. However, it has been ascertained that some of these levees may not protect the community from rare events such as the 1-percent-annual-chance flood. The criteria used to evaluate protection against the 1-percent-annual-chance flood are 1) adequate design, including freeboard, 2) structural stability, and 3) proper operation and maintenance. Levees that do not protect against the 1-pecent-annual-chance flood are not considered in the hydraulic analysis of the 1-percent-annual-chance floodplain.

3.0 ENGINEERING METHODS

For the flooding sources studied by detailed methods in the community, standard hydrologic and hydraulic study methods were used to determine the flood hazard data required for this study. Flood events of a magnitude that are expected to be equaled or exceeded once on the average during any 10-, 50-, 100-, or 500-year period (recurrence interval) have been selected as having special significance for floodplain management and for flood insurance rates. These events, commonly termed the 10-, 50-, 100-, and 500-year floods, have a 10-, 2-, 1-, and 0.2-percent chance, respectively, of being equaled or exceeded during any year. Although the recurrence interval represents the long-term, average period between floods of a specific magnitude, rare floods could occur at short intervals or even within the same year. The risk of experiencing a rare flood increases when periods greater than 1 year are considered. For example, the risk of having a flood that equals or exceeds the 1-percent-annual-chance (100-year) flood in any 50-year period is approximately 40 percent (4 in 10); for any 90-year period, the risk increases to approximately 60 percent (6 in 10). The analyses reported herein reflect flooding potentials based on conditions existing in the community at the time of completion of this study. Maps and flood elevations will be amended periodically to reflect future changes.

3.1 Hydrologic Analyses

Hydrologic analyses were carried out to establish peak discharge-frequency relationships for each flooding source studied by detailed methods affecting the community.

Hydrology for Detailed Riverine Studies

Regionalized flood prediction equations were developed for the 10-, 2-, 1-, and 0.2-percent-annual-chance floods based on statistical analysis of the data recorded at USGS stream gages listed in Table 6. The statistical analyses of these gages followed the standard log-Pearson Type III method as outlined by the U.S. Water Resources Council (1977).

Table 6. USGS Stream Gages Used for Statistical Analysis

Gage Number	Location	Years of Record[2]
14299000[1]	South Fork Necanicum River near Seaside	16
14301500	Wilson River near Tillamook	46
14302500[1]	Trask River near Tillamook	37
14303600	Nestucca River near Beaver	11
14305500	Siletz River at Siletz	60
14306100	North Fork Alsea River at Alsea	18
14306400	Five Rivers near Fisher	14
14306500	Alsea River near Tidewater	37
14324500	West Fork Millicoma River near Allegany	25

Table 6. USGS Stream Gages Used for Statistical Analysis (continued)

Gage Number	Location	Years of Record[2]
143246001	South Fork Coquille River above Panther Creek, near Illahe	14
14324700[1]	South Fork Coquille River near Illahe	18
14324900[1]	South Fork Coquille River near Powers	14
14325000	South Fork Coquille River at Powers	60
14326500[1]	Middle Fork Coquille River near Myrtle Point	17
14326800[1]	North Fork Coquille River near Fairview	16
14327000[1]	North Fork Coquille River near Myrtle Point	22

[1] Discontinued gages

[2] As of 1982

Flow records for 23 other gages were initially considered but were not used in this study for several reasons. These reasons included significant regulation by lakes, stream flow records from abnormally dry periods, and gauging of watersheds less than 10 square miles where local hydrologic conditions are not representative of regional conditions.

Flood flows for the Coquille River, South Fork Coquille River, Millicoma River, East Fork Millicoma River, and West Fork Millicoma River were calculated using the regional flow equation:

$$Q=KA^n$$

"Q" and "A" are the discharge in cubic feet per second (cfs) and drainage area in square miles at the study site, respectively. The constant "K" and the exponent "n" were determined for each flood using logarithmic plots of drainage area versus frequency-discharge relationship of the stream gages given in Table 4. The values determined for "K" and "n" are 550 and 0.71 for the 10-percent-annual-chance flood, 661 and 0.73 for the 2-percent-annual-chance flood, 708 and 0.74 for the 1-percent-annual-chance flood, and 830 and 0.74 for the 0.2-percent-annual-chance flood. These equations are only valid when the drainage area at the site is greater than 10 square miles.

Drainage areas at points in the study area were measured on USGS topographic maps or taken from the River Mile Index for Coastal Tributaries (Pacific Northwest River Basins Commission, 1975).

Flood flows on Calloway, Cunningham and Ferry Creeks were determined using the USGS regional method presented in Magnitude and Frequency of Floods in Western Oregon (Harris et al., 1979). Ferry Creek has been gaged near the fish hatchery by the Oregon Department of Water Resources since 1977 (No. 14327120) (Oregon Department of Water Resources, 1978). This gage has a drainage area of 4.2 square miles. At the time of the original study (1983), the gage record was too short to produce accurate estimates of low-frequency flood flows. Flows from a log-Pearson Type III frequency analysis done by the USGS (1980) on Gieger Creek flows, when transferred to the mouth of Ferry Creek were only slightly lower than those determined using regional equations.

The USGS operated the Tenmile Creek gage, Number 14323200 from August 1957 to September 1976. Because of a shifting rating curve and regulation by the two lakes, the USGS discontinued operation of the gage.

Storage volume analyses were carried out to determine the 10-, 2-, 1-, and 0.2-percent-annual-chance outflows from Tenmile Lake and the resulting elevation of Tenmile and North Tenmile Lakes.

The 10-, 2-, 1-, and 0.2-percent-annual-chance, 24-hour precipitation values (Miller et al., 1973) were used to generate inflow hydrographs to the lakes. Most major storms in this area have durations longer than 24 hours. The 24-hour precipitation amounts were used because the analyses showed peak outflow from Tenmile Lake was not very sensitive to duration and because precipitation records for longer durations were not available. Hourly precipitation amounts during a 24-hour storm were calculated using the U.S. Soil Conservation Service Type 1A precipitation distribution (U.S. Department of Agriculture, 1970). Precipitation excess was calculated assuming near-saturation conditions with a constant infiltration rate of 0.02 of an inch per hour. Snyder's unit hydrograph method was used to generate inflow hydrographs from precipitation excess.

Base flow at the Tenmile Lake outlet was set equal to 680 cfs. The respective base flows for North Tenmile and Tenmile Lake inflow hydrographs were estimated using ratios of the tributary drainage areas to the total drainage area.

The infiltration rate, base flow, and lag times were assumed to be equal for the 10-, 2-, 1-, and 0.2-percent-annual-chance events. The infiltration rate, base flow, and lag times were determined by calibrating a hydrograph, generated from precipitation at Reedsport and Allegany recorded during the December 1964 flood (USACE, 1966; U.S. Department of Commerce, 1965), to the recorded flood hydrograph at the Tenmile Creek gage (City of Myrtle Point, 1964). The 24-hour precipitation was taken as the only variable for the 10-, 2-, 1-, and 0.2-percent-annual-chance events.

The USACE HEC-1 flood hydrograph computer program (USACE, 1973) was used to generate the inflow hydrographs from precipitation and to route the hydrographs through the lakes. Routing through the lakes required storage-capacity curves that were developed from USGS topographic maps (Harris et al., 1979). The outflow rating curve for Tenmile Lake was developed from a backwater analysis on Tenmile Creek. The outflow rating curve for North Tenmile Lake was approximated by a normal depth calculation for a canal cross section at the North Lake Avenue Bridge.

The peak lake elevation for Tenmile Lake was determined from its outflow rating curve using the peak 10-, 2-, 1-, and 0.2-percent-annual-chance outflows. A backwater analysis on the short canal between the two lakes showed that North Tenmile Lake would peak at the same elevation as Tenmile Lake regardless of the flow through the canal connecting the lakes. These analyses reflect stillwater levels (SWLs) only. A summary of the elevation-frequency relationship for the two lakes is shown in Table 8, "Summary of Elevations".

Flows in Pony Creek downstream of Ocean Boulevard are regulated by two Coos Bay – North Bend Water Board water-supply reservoirs. For this reason, the USACE HEC-1 computer program was used to generate inflow hydrographs through the reservoirs downstream to the former location of the tide gates at Crowell Lane.

Inflow hydrographs were generated from the 10-, 2-, 1-, and 0.2-percent-annual-chance, 24-hour precipitation (Miller et al., 1973) for each drainage subarea along Pony Creek. The precipitation was distributed over a 24-hour period using the U.S. Soil Conservation Service's Type 1A precipitation distribution (U.S. Department of Agriculture, 1970). Excess precipitation was calculated using an infiltration rate of 0.43 inches per hour estimated from local soil data (U.S. Department of Agriculture, 1975).

Peak flows from the upper reservoir inflow hydrographs were compared to peak flows transferred from the USGS Geiger Creek Gage No. 14327100 near Bandon using the relationship

$$Q=Q_g(A/A_g)^{0.92}$$

Where:

Q is the flow in cubic feet per second at the study site.
A is the drainage area in square miles at the study site.
Q_g is the flow in cubic feet per second at the gage.
A_g is the drainage area in square miles at the gage.

The USGS performed a log-Pearson Type III frequency analysis on the Geiger Creek flows following the U.S. Water Resources Council Guidelines (1977). The hydrograph lag time was adjusted until the two frequency-discharge relationships were in close agreement.

The upper reservoir inflow hydrographs were then routed through the upper reservoir assuming the water level was initially at 82 feet (85.6 feet NAVD88). The upper reservoir outflow rating curve was developed from spillway geometry with stop logs placed to elevation 82 feet (85.6 feet NAVD88). The storage-capacity curve was taken from a CH2M HILL Pony Creek Water Supply report (1978). The outflow hydrographs were combined with local inflow between the two reservoirs and routed through the lower reservoir assuming the water level was initially at the spillway lip elevation of 28.4 feet (32 feet NAVD88). The lower reservoir outflow rating curve was developed from the spillway geometry with no stop logs in place. The storage capacity curve was taken from the Pony Creek Water Supply report (CH2M HILL, 1978).

Downstream of the lower reservoir, local inflow hydrographs were generated from precipitation. Urbanization was accounted for in each drainage subarea. The percent of impervious area and the extent of storm sewers in each subarea were used to determine hydrograph coefficients for the Denver Urban Storm Drainage Criteria Manual (Wright-McLaughlin Engineers, 1969). The extent of storm sewered areas was determined using a storm sewer study for the City of North Bend (Pacific Northwest River Basins Commission, 1968) and a storm sewer master plan for the City of Coos Bay (Erichsen et al., 1975). The percent of impervious area was estimated using aerial photographs at a scale of 1:12,000 (CH2M HILL, 1980). Local inflow hydrographs were combined with the lower reservoir outflow hydrographs and routed to Crowell Lane using storage-outflow relationships developed from preliminary step-backwater calculations. Drainage areas for Pony Creek were measured on USGS 7.5-Minute topographic maps (USGS, various years).

Hydrology for Approximate Riverine Studies (Revised)

Stream flow data for revised approximate studies of riverine flooding in Coos County were provided by the USGS web tool StreamStats for Oregon (Cooper, 2005). Discharges were acquired for the 1-percent-annual-chance peak flow at each stream confluence and downstream terminus (i.e. the Coquille River's confluence with the Pacific Ocean).

There were several exceptions where StreamStats for Oregon was not used to acquire stream flow data. Due to the unsuitability of using StreamStats for reaches downstream of large water bodies, stream flow data for the approximate study sections of Tenmile Creek was acquired from the hydrologic model prepared by CH2M HILL for the detailed study of Tenmile Creek. Coastal lakes in the Oregon Dunes National Recreation Area (Lyons Reservoir, Snag Lake, Sandpoint Lake, Spirit Lake, Horsfall Lake) are not hydrologically connected to any riverine flooding source and were therefore re-delineated to a representative 1-percent-annual-chance flooding elevation based on the previous mapping. The Empire Lake reservoirs and Tarheel Lake reservoir were mapped to a 1-percent-annual-chance flooding elevation equal to the elevation of dam-overtopping.

Hydrology for Detailed Estuarine Studies

The methodology developed by CH2M HILL for study of Pacific Northwest storms was used to study the coastal flooding influence on estuaries in Coos County. This method involves statistical analysis of the various components of ocean flooding caused by storms and a combined probability analysis to determine the effect of these components on flood levels. It is applicable to detailed study areas in the cities of Bandon, Coos Bay, North Bend, and Lakeside where static base flood elevations have been determined for Coquille River, Ferry Creek, Coos Bay, South Slough, Pony Slough, North Slough, Haynes Inlet, Coalbank Slough, Blossom Creek, Isthmus Slough, Catching Slough, Coos River, North Tenmile Lake, and Tenmile Lake.

High astronomical tides are a major component of ocean flooding. Predicted astronomical tides were calculated on an hourly basis for the study areas based on the National Oceanic and Atmospheric Administration (NOAA) Tide Tables (1980). The hourly predicted tides were used to compute the astronomical tide height histogram (Brocherdt and Borgman, 1970).

Storm surge, or the rise in water from wind stress and low atmospheric pressure, is also a common component of flooding. Significant storm surge-producing events were selected from 3-hour surface weather maps for the period 1942 to 1980. The storm surge heights were computed for these events and grouped into three winds direction classes. Storm-surge frequency distributions were computed from a population of the highest storm surges for each class.

Waves are another component of ocean flooding. A wave forecasting computer program was used to compute wind-generated wave height (Oregon State University, 1976). The program uses wind speed, direction, and fetch data from the surface weather maps to compute significant wave height and period at 6-hour intervals. Frequency curves were plotted for the three wind direction classes of both sea waves and swell wave heights.

The peak SWL at the entrance to Coos Bay and inflow to the bay from major streams are the main causes of flooding in the Coos Bay estuary. A series of normal winter tide cycles with the 10-, 2-, 1-, and 0.2-percent-annual-chance peak SWLs superimposed on one cycle were used in the detailed estuary analysis. Subsequently, these tide cycles will be referred to as the 10-, 2-, 1-, and 0.2-percent-annual-chance tide cycles.

SWL is a function of two components. The first component, astronomical tide, is caused by the gravitational forces exerted on the earth by the sun and the moon. The second component, storm surge, is the rise in water level due to wind stress and low atmospheric pressure.

A peak SWL-frequency curve was developed for the Coos Bay entrance using 47 years of observed tide data from an open-coast tide gage at Crescent City, California, and 12 years of observed tide data from a tide gage located in Coos Bay at Charleston. The Crescent City gage is located 100 statute miles south of the Charleston gage but both gages were found to respond similarly to major storms monitored at both gages. A frequency curve developed for the Crescent City gage was transferred to the Coos Bay entrance by adjusting for datum and location differences and compared with an elevation-frequency curve developed for the Charleston gage. The Charleston curve was then adjusted slightly to show the effects of a longer period of record the Crescent City frequency curve. SWLs at the Coos Bay entrance were then taken from the revised Charleston frequency curve.

The peak SWLs were superimposed on one cycle of a series of normal winter tide cycles predicted using the West Coast of North and South America Tide Tables (1980). It was assumed that the surge component would cause an increase in water level above the normal predicated tide level for a period of 12 hours, and that the largest increase in water level would occur half-way through that period.

Peak inflows to the Coos Bay estuary from the South Slough, North Slough, Palouse and Larson Creeks, Isthmus Slough, Catching Slough, and the Coos River were determined using the regional flow equation given previously. Triangular hydrographs were then developed using the peak inflows and assumed times to peak. A time of 20 hours was used for the Coos River basin. A time of 4 hours was used for the South Slough, Isthmus Slough, Catching Slough, Larson and Palouse Creeks, and the North Slough. The peak inflows are summarized in Table 6.

Estuary elevation-frequency curves were developed assuming a combination of riverine and tidal influences. Inflow hydrographs for the major streams entering Coos Bay were developed for the detailed estuary analysis. The peak hydrograph flows were calculated using regional flood prediction equations. These equations were developed for the 10-, 2-, 1-, and 0.2-percent-annual-chance flows based on statistical analysis of the data recorded at the USGS stream gages listed in Table 6. The statistical analyses at these gages followed the standard log-Pearson Type III method outlined by the U.S. Water Resources Council (1977).

Drainage areas for each stream used in the estuary analysis were measured on a South Coast Drainage Basin Map (Oregon State Water Resources Board, 1971) or taken from the River Mile Index for Coastal Tributaries (Pacific Northwest River Basins Commission, 1968).

Hydrology for Detailed Coastal Studies (Revised)

Measurements of tides on the Oregon coast are available from various tide gages operated by the National Ocean Service (NOS). Hourly tidal records are available from the following long-term (30+ years) coastal sites: the Columbia River (Astoria, #9439040), South Beach (Newport, #9435380), Port Orford (#9431647), and at Charleston (#9432780) located midway along the Coos County shoreline. Long-term tidal records are also available from the Crescent City tide gage (#9419750), located in northern California, and have been used in previous FIS carried out in Coos County (e.g. CH2MHILL, 1995). For the purposes of this study, we have based our SWL and wave runup calculations on the Charleston tide gage due to its central proximity along the Coos County coast and importantly because of its relatively long record (38 years). All hourly tide data were purchased from the NOS and were processed using various scripts developed in Matlab. In addition to the measured tides, hourly tide predictions were calculated for all years using the NOS tide prediction program, NTP4.

Tides along the Oregon coast are classified as moderate, with a maximum range of up to 14 ft and an average range of about 6 ft (Komar, 1997). There are two highs and two lows each day, with successive highs (or lows) usually having markedly different levels (Figure 8). Tidal elevations are given in reference to the mean of the lower low water levels (MLLW), and can be easily adjusted to the NAVD88 vertical datum. As a result, most tidal elevations are positive numbers with only the most extreme lower lows having negative values. Figure 8 shows the tidal elevation statistics derived from the Charleston tide gage (#9432780), with a mean range of 5.69 ft and a diurnal range of 7.62 ft. The highest tide measured at Charleston reached 11.18 ft, recorded in January 1983 during the peak of the strong 1982-83 El Niño.

The actual level of the measured tide can be considerably higher than the predicted level provided in standard Tide Tables, and is a function of a variety of atmospheric and oceanographic forces, which ultimately combine to raise the mean elevation of the sea. These latter processes also vary over a wide range of timescales, and may have quite different effects on the coastal environment. For example, strong onshore winds coupled with the extreme low atmospheric pressures associated with a major storm can cause the water surface to be locally raised along the shore as a storm surge, and have been found in tide-gage measurements to be as much as 4.9 ft along the Pacific Northwest coast (Allan and Komar, 2002). However, during the summer months these processes can be essentially ignored due to the absence of major storms systems.

On the Oregon coast, tides tend to be enhanced during the winter months due to warmer water temperatures and the presence of northward flowing ocean currents that raise water levels along the shore, persisting throughout the winter rather than lasting for only a couple of days as is the case for a storm surge. This effect can be seen in the monthly averaged water levels derived from the Charleston tide gage, but where the averaging process has removed the water-level variations of the tides, yielding a mean water level for the entire month. Based on 38 years of data, the results show that on average monthly-mean water levels during the winter are nearly 0.7 ft higher than in the summer. Water levels are most extreme during El Niño events, due to an intensification of the processes, largely enhanced ocean sea surface temperatures offshore from the Oregon coast. This occurred particularly during the unusually strong 1982-83 and 1997-98 El Niños. Water levels during those climate events were approximately 0.8 ft higher than the seasonal peak, and as much as 1.6 ft higher than during the preceding summer, enabling wave swash processes to reach much higher elevations on the beach during the winter months, with storm surges potentially raising the water levels still further.

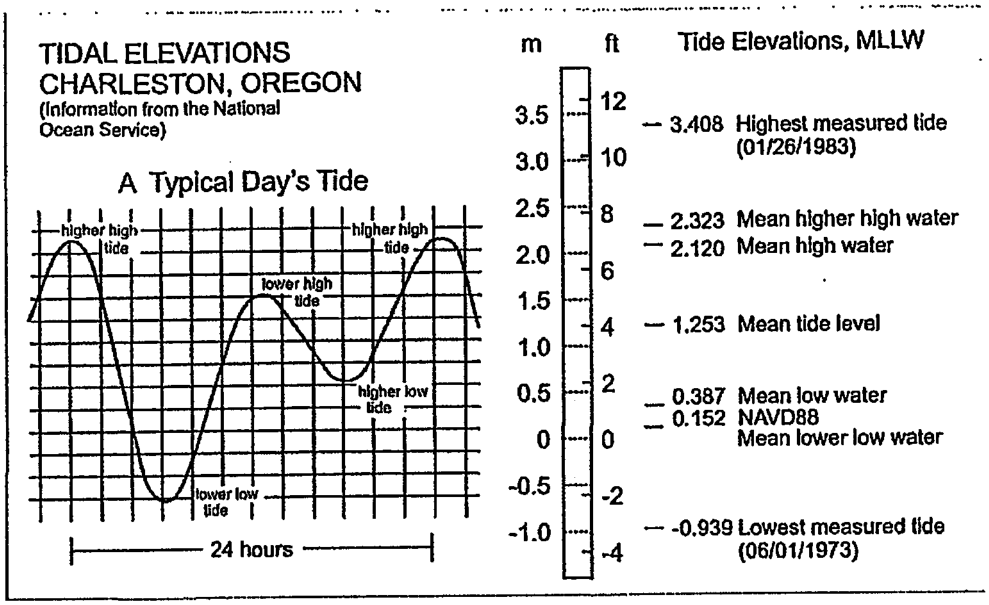


Figure 8 - Daily Tidal Elevations Measured at Charleston
Daily tidal elevations measured at Charleston on the southern Oregon coast. Data from the National Ocean Service.

Figure 9 presents results of the generalized extreme value analyses for the Charleston tide gage. In constructing this plot, a threshold of 9.2 ft was used. The calculated SWLs in Figure 9 project to the 1-percent-annual-chance event. As can be seen in Figure 9, the 1-percent-annual-chance SWL calculated for the Charleston gage is 11.2 ft, relative to MLLW. When adjusted to the NAVD88 vertical datum, this value becomes 10.7 ft; note the adjustment from NAVD88 to MLLW is 0.5 ft. The 0.2-percent-annual-chance SWL is estimated to be 10.9 ft NAVD88. As observed previously, the highest tide measured at the Charleston gage reached 10.7 ft NAVD88. Of interest, the SWL identified in the original flood mapping calculations at Bandon, based on the Crescent City tide gage (and compared with the Charleston tide gage) indicated a SWL of 10.6 ft, close to the current estimate.

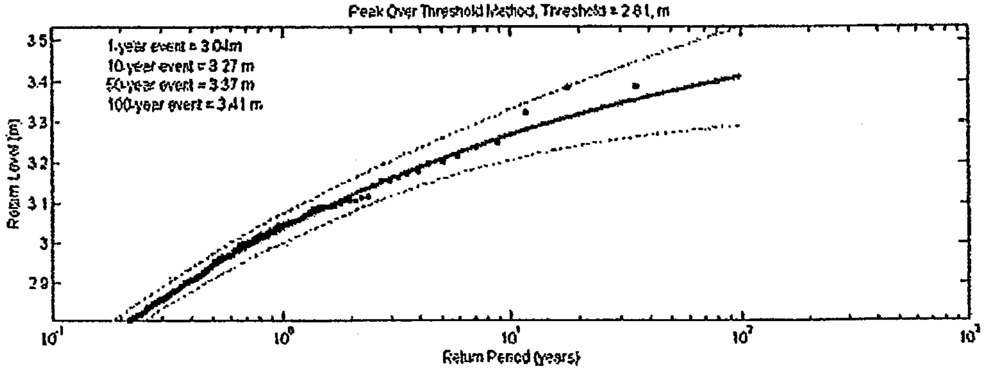


Figure 9 - Extreme-Value Analyses of SWL at Charleston Tide Gauge
Extreme-value analyses of the stillwater level (SWL) determined for the Charleston tide gage.

Flood elevations are summarized in Table 8, "Summary of Elevations". Peak discharge-drainage area relationships for each stream studied in detail are shown in Table 7, "Summary of Discharges".

Table 7. Summary of Discharges

		Peak Discharges (cubic feet per second)			
Flooding Source and Location	Drainage Area (square miles)	10-Percent-Annual-Chance	2-Percent-Annual-Chance	1-Percent-Annual-Chance	0.2-Percent-Annual-Chance
Blossom Creek					
At inlet to Mill Creek Slough Box	1.0	130	170	190	240
Calloway Creek					
Above Central Boulevard	2.7	280	400	440	530
Catching Slough					
At east side of Coos Bay corporate limits	25.2	5,440	6,970	7,710	9,040
Coos River					
At mouth	415	39,700	53,900	61,300	71,800
Coquille River					
Confluence with Pacific Ocean	1,058	77,200	107,000	122,000	143,000
At Riverton	980	73,100	101,000	116,000	136,000
At Coquille	930	70,500	97,100	111,000	130,000
At Arago	902	69,000	95,000	109,000	128,000
Confluence of North and South Forks	879	67,700	93,200	107,000	125,000
Cunningham Creek					
At mouth	14.2	1,360	1,860	2,020	2,410
Above Central Boulevard	2.7	280	400	440	530
East Fork Millicoma River					
At confluence with West Fork	79	12,200	16,000	18,000	21,000
Ferry Creek					
Confluence with Coquille River	5.2	640	890	980	1,220
Above Highway 241 bridge	25	5,410	6,930	7,660	8,980

Table 7. Summary of Discharges (continued)

		Peak Discharges (cubic feet per second)			
Flooding Source and Location	Drainage Area (square miles)	10-Percent-Annual-Chance	2-Percent-Annual-Chance	1-Percent-Annual-Chance	0.2-Percent-Annual-Chance
Millicoma River					
Below Woodruff Creek	137	18,100	24,000	27,000	31,600
North Slough					
Above Highway 101 bridge	11.3	3,080	3,880	4,260	4,990
Pony Creek					
At Ocean Boulevard	3.9	84	140	180	290
At Woodland Drive	4.9	260	350	400	480
At Crowell Lane	6.2	320	420	480	590
South Fork Coquille River					
Confluence with North Fork at Myrtle Point	598	51,100	69,700	79,600	93,300
Tenmile Creek					
At Wildwood Drive	71.2	2,640	3,480	3,900	4,870
West Fork Millicoma River					
At confluence with East Fork	55	9,460	12,300	13,700	16,100

Table 8. Summary of Elevations

	Peak Water Surface Elevations (Feet NAVD88)			
Flooding Source	10-Percent-Annual-Chance	2-Percent-Annual-Chance	1-Percent-Annual-Chance	0.2-Percent-Annual-Chance
Blossom Creek				
City of Coos Bay	8.6[1]	11.6[2]	12.6[3]	13.3[3]
Coos Bay				
South Slough	10.4	11.0	11.2	11.7
Ponding in the City of Coos Bay	11.2[4]	12.3[3]	12.6[3]	13.3[3]
West corporate limit of North Bend	11.2	11.8	12.1	12.6
Pony Slough	11.3	12.0	12.2	12.8
North Slough	11.5	12.1	12.4	13.0
Haynes Inlet	11.5	12.1	12.4	13.0
Southeast corporate limit of North Bend	11.6	12.3	12.6	13.3
Isthmus Slough at downtown Coos Bay	11.7	12.3	12.6	13.3
Isthmus Slough at Millington	11.8	12.4	12.7	13.4
Coalbank Slough	11.9	12.5	12.8	13.4
Coos River	12.3	13.1	13.5	14.5
Coquille River				
City of Bandon	12.6	14.5	15.2	17.0
Ferry Creek				
City of Bandon	12.6	14.5	15.2	17.0

[1] Peak elevation is controlled by volume of Blossom Creek hydrograph that must be stored.

[2] Peak elevation is controlled by the total volume of flow over the dike stored in downtown Coos Bay and Blossom Creek areas.

[3] Peak elevation is controlled by elevation in slough.

[4] Limited flow over city dike will fill low areas of downtown Coos Bay.

Table 8. Summary of Elevations (continued)

	Peak Water Surface Elevations (Feet NAVD88)			
Flooding Source	10-Percent-Annual-Chance	2-Percent-Annual-Chance	1-Percent-Annual-Chance	0.2-Percent-Annual-Chance
North Tenmile Lake				
At City of Lakeside	21.8	23.2	23.8	25.0
Pacific Ocean				
Bastendorff/Lighthouse Beach Profile 1	--	--	23.8	25.1
Bastendorff/Lighthouse Beach Profile 2	--	--	24.0	25.5
Bastendorff/Lighthouse Beach Profile 3	--	--	22.6	24.6
Bastendorff/Lighthouse Beach Profile 4	--	--	21.6	23.3
Bastendorff/Lighthouse Beach Profile 5	--	--	23.7	25.5
Bastendorff/Lighthouse Beach Profile 6	--	--	23.4	25.2
Bastendorff/Lighthouse Beach Profile 7	--	--	36.2	39.0
Bastendorff/Lighthouse Beach Profile 8	--	--	31.6	34.0
Bastendorff/Lighthouse Beach Profile 9	--	--	33.2	35.7
Bastendorff/Lighthouse Beach Profile 10	--	--	31.3	33.3
Bastendorff/Lighthouse Beach Profile 11	--	--	26.5	27.9
Bastendorff/Lighthouse Beach Profile 12	--	--	29.0	30.9
Bandon Profile 1	--	--	30.1	31.6
Bandon Profile 2	--	--	32.6	34.2
Bandon Profile 3	--	--	29.9	31.2
Bandon Profile 4	--	--	29.4	30.7
Bandon Profile 5	--	--	25.3	26.4
Bandon Profile 6	--	--	23.7	24.5
Bandon Profile 7	--	--	22.5	23.5
Bandon Profile 8	--	--	21.5	22.6
Bandon Profile 9	--	--	22.9	24.6
Bandon Profile 10	--	--	23.0	24.6
Bandon Profile 11	--	--	23.1	25.1
Bandon Profile 12	--	--	32.8	34.1
Bandon Profile 13	--	--	36.2	40.4
Bandon Profile 14	--	--	31.5	32.9
Bandon Profile 15	--	--	22.2	23.7
Bandon Profile 16	--	--	20.8	22.1
Bandon Profile 17	--	--	20.8	22.0
Bandon Profile 18	--	--	20.6	21.9
Bandon Profile 19	--	--	30.6	31.3
Bandon Profile 20	--	--	26.7	29.3
Bandon Profile 21	--	--	31.6	32.1
Tenmile Lake				
At City of Lakeside	21.8	23.2	23.8	25.0

3.2 Hydraulic Analyses

Analyses of the hydraulic characteristics of flooding from the sources studied were carried out to provide estimates of the elevations of floods of the selected recurrence intervals. Users should be aware that flood elevations shown on the FIRM represent rounded whole-foot elevations and may not exactly reflect the elevations shown on the Flood Profiles or in the Floodway Data Table in the FIS report. Flood elevations shown on the FIRM are primarily intended for flood insurance rating purposes. For construction and/or floodplain management purposes, users are cautioned to use the flood elevation data presented in this FIS report in conjunction with the data shown on the FIRM.

Cross sections for backwater analyses of the Coquille River at Coquille and Arago and the South Fork of Coquille River at Myrtle Point were obtained by digitizing aerial photographs at a scale of 1:12,000. The underwater sections were obtained by field measurement. Cross sections for Tenmile Creek, the Millicoma River, the West Fork Millicoma River, the East Fork Millicoma River, and the Coquille River at Riverton were obtained by field measurement. Bridges were field checked to obtain elevation data and structure geometry.

Cross sections for backwater analyses of Calloway Creek and Cunningham Creek were measured on City of Coquille topographic maps at a scale of 1:1,200 with a 5-foot contour interval. The channel geometry was based on field observation. Culvert geometry was determined using state and county bridge plans.

Cross sections for the backwater analysis of Pony Creek were scaled from City of North Bend and City of Coos Bay topographic maps at a scale of 1:1,200 with 2-foot contour intervals (Chickering-Green Empire Inc., 1976). Channel sections, obtained by field measurements, were used with the scaled cross sections. All bridges were field checked to obtain elevation data and structural geometry.

Cross sections for the backwater analysis of the Coquille River estuary were scaled from City of Bandon topographic maps at a scale of 1:2,400 (Chickering, 1973), a USACE pre-dredge survey map at a scale of 1:2,000 (1979), and a NOAA nautical chart at a scale of 1:10,000 (1981). Cross sections for Ferry Creek were scaled from the Bandon topographic maps (Chickering, 1973) with the channel section obtained by field measurement. All bridges and culverts were field checked to obtain elevation data and structural geometry. Starting water surface elevations for the Coquille River and Ferry Creek were initially calculated using the slope-area method. When the 10-, 2-, 1-, and 0.2-percent-annual-chance elevations for the Coquille River were compared with the 10-, 2-, 1-, and 0.2-percent-annual-chance ocean elevations, it was found that backwater from the ocean would control the flood elevation in the estuary. It was also found that backwater from the Coquille River estuary would control the flood elevation in Ferry Creek; therefore, no flood profiles for the Coquille River and Ferry Creek are presented.

Channel roughness factors (Manning's "n") used in the hydraulic computations were chosen by engineering judgment and based on field observation of the river channel and flood plain. The range of roughness values for all floods is shown in Table 9. The acceptability of all assumed hydraulic factors, cross sections, non-effective flow areas, and hydraulic structure data was checked by hydraulic computations that were calibrated against historic floodwater profiles.

Table 9. Range of Manning's Roughness Values

Flooding Source	Channel "n"	Overbanks "n"
Calloway Creek	0.040-0.060	0.040-0.080
Cunningham Creek	0.040-0.060	0.040-0.080
Coquille River	0.080-0.100	0.040-0.080
Coquille River Estuary	0.030	0.030-0.035
East Fork Millicoma River	0.045	0.050-0.080
Ferry Creek	0.035-0.040	0.040-0.070
Millicoma River	0.040	0.040-0.080
Pony Creek	0.030-0.060	0.035-0.080
South Fork Coquille River	0.050-0.060	0.040-0.080
Tenmile Creek	0.030-0.085	0.060-0.120
West Fork Millicoma River	0.045	0.040-0.080

Water surface elevations of floods of the selected recurrence intervals were computed through use of the USACE HEC-2 step-backwater computer program (USACE,1976).

Flood profiles were drawn showing computed water-surface elevations for floods of the selected recurrence intervals. Starting water-surface elevations for Tenmile Creek were estimated using the relationship between peak recorded flow and elevation at the Tenmile Creek gage. Starting water-surface elevations for the Millicoma River, the Coquille River at Riverton, Cunningham Creek and Calloway Creek were determined using the slope-area method. Starting water-surface elevations for the West Fork Millicoma River and the East Fork Millicoma River were taken from the Millicoma River profiles. It was assumed that the West Fork and East Fork Millicoma Rivers would peak at about the same time. To determine starting water-surface elevations for the Coquille River at Coquille, Arago, and at the confluence of the North and South Forks Coquille River, the backwater analysis was continued between detailed study areas using cross sections scaled from 1:24,000 USGS topographic maps (USGS, various dates).

Downstream of Crowell Lane the estuary elevations control the flood elevations. Between Crowell Lane and Newmark Street, the flood elevations are controlled by the volume of water that must be stored behind the tide gates when the gates are closed.

A series of outflow rating curves were developed for the Crowell Lane culverts and tide gates assuming a range of tidal elevations downstream. A storage-capacity curve for the area above the tide gates was developed using the City of North Bend topographic maps (Chickering-Green Empire Inc., 1976).

Using the outflow rating and storage-capacity curves, several frequency hydrographs were routed through the area above the tide gates balancing inflows and outflows with changes in the volume of stored water. The storage routing was conducted over tide cycles predicted for the mean annual event and the 10-percent-annual-chance event.

On log-probability paper, the maximum elevations resulting from the storage routing for a mean annual tide cycle were plotted against the probability of the mean annual tide cycle occurring during each runoff event. A curve was drawn through the plotted points. The maximum elevations resulting from the routing for a 10-year tide cycle were plotted against the probability of the 10-year tide cycle occurring during each runoff event. A second curve was then drawn through these points. An enveloping curve was then drawn tangent to the two curves. This resulted in a peak elevation-frequency curve valid for other combinations of inflows and tide cycles. During this analysis, it was reasoned and demonstrated that the highest elevations behind the tide gates would occur when the inflow hydrograph and tide cycle peaks coincided. This condition was assumed in the original analysis.

During the community coordination meeting held on March 14, 2006, it was learned that the above tide gates on Pony Creek located at Crowell Lane had been removed and that the portion of Pony Creek upstream is now subject to flooding due to tidal and storm surge conditions. The flood profile and FIRM have been updated to reflect this condition.

Calloway Creek and Cunningham Creek run along the edge of a very flat area. At flood stage, the two creeks form one floodplain in the study area. Approximately 30 percent of the flood flow in Cunningham Creek will pass through the culvert under Fairview Road. The remaining flow is forced across the floodplain toward the Calloway Creek bridge at West Central Boulevard. On the downstream side of West Central Boulevard, approximately half of the combined flow of Calloway Creek and Cunningham Creek overflows in the area near the Cunningham Creek Bridge. The remaining flow continues down the normal channel alignment. Although a separate floodway was developed for the Cunningham Creek Overflow channel, a flood profile was not developed as the entire reach is backwatered by the Coquille River.

The profile baselines depicted on the FIRM represent the hydraulic modeling baselines that match the flood profiles on this FIS report. As a result of improved topographic data, the profile baseline, in some cases, may deviate significantly from the channel centerline or appear outside the Special Flood Hazard Area.

The hydraulic analyses for this study were based on unobstructed flow. The flood elevations shown on the Flood Profiles (Exhibit 1) are thus considered valid only if hydraulic structures remain unobstructed, operate properly, and do not fail.

Locations of selected cross sections used in the hydraulic analyses are shown on the Flood Profiles (Exhibit 1). For stream segments for which a floodway was computed (Section 4.2), selected cross section locations are also shown on the FIRM (Exhibit 2).

Hydraulics for Detailed Estuarine Studies

Tsunami and storm flood events were considered to be independent events because tsunami waves can occur at any time during the year and storm waves are seasonal. Because of the uncertainties involved in combining these events, no probabilistic mapping of tsunami hazard was undertaken in this study.

Peak elevation frequency curves were developed for the Coos Bay estuary using a computer model that simulated the hydraulic response of the estuary to the 10-, 2-, 1-, and 0.2-percent-annual-chance tidal conditions at the entrance to the bay and to the 10-, 2-, 1-, and 0.2-percent-annual-chance inflows from major streams entering the bay. The hydrodynamic algorithm of the Dynamic Estuary Computer Model (Water Resources Engineers Inc. and CH2M HILL, 1977; Federal Water Quality Administration, 1975) was used for the hydraulic simulation.

A junction and channel grid network was constructed using the NOAA Nautical Chart for Coos Bay at a scale of 1:20,000 (1980), to represent the geometric flow pattern in the estuary. A total of 50 junctions and 78 interconnecting channels were used to model the estuary and adjoining sloughs within the detailed study limits.

Inputs to the hydraulic model included surface area and depth for the area represented by each junction, channel length, width, and roughness factors (Manning's "n"), and tidal and riverine inflow boundary conditions. For the Coos Bay network, channel widths ranged from 150 to 2,000 feet and lengths ranged from 3,200 to 8,300 feet. Channel roughness values varied from 0.023 to 0.035.

The Dynamic Estuary Model computed stage and channel velocities at each junction for each time step throughout several complete tide cycles by simultaneously solving one-dimensional equations of motion and continuity. Output from the hydraulic simulation summarizes the hourly stage and channel velocity at each junction.

The estuary computer model was calibrated to historical tide cycles recorded from November 8-12, 1976. Coincident records for those days were available for tide gages located throughout the bay (Water Resources Engineers Inc. and CH2M HILL, 1977; Federal Water Quality Administration, 1975). No significant storm activity occurred during this period. The simulated tide cycles at the junctions agreed with recorded tide cycles. The range of computed velocities correlated with velocity surveys conducted by the USACE in a similar study of Coos Bay during the period October 14-22, 1976 (USACE, 1978).

Combined tidal and riverine inflows effects were used to establish the 10-, 2-, 1-, and 0.2-percent-annual-chance flood elevations within the estuary. Hydraulic simulations were made using the 10-, 2-, 1-, and 0.2-percent-annual-chance tide cycles combine with the 10-percent-annual-chance inflow hydrographs for major stream inflows. It was assumed that the inflow hydrograph peak would coincide with the peak tidal stillwater levels (SWLs), because high estuary elevations will occur when they coincide.

Hydraulic simulations were also run with the 10-year tide cycle combined with the 10-, 2-, 1-, and 0.2-percent-annual-chance stream inflows. The resulting estuary elevations were compared to those determined using the 2-, 1-, and 0.2-percent-annual-chance tide cycles. The higher computed elevation at each junction for each frequency was used. Flood profiles are not applicable for areas of tidal flooding; therefore, no flood profiles are shown for Coos Bay or the Coos River.

The estuary elevations are SWLs resulting from tidal conditions at the Coos Bay entrance. They do not include any contributions from wind setup in the estuary or from wave action. Calculations for wind setup suggested the contribution was insignificant, while the increase in flood hazard from wave action will be less than 1 foot.

Peak flood elevation in downtown Coos Bay results from high water in Isthmus Slough overtopping the city dike. Peak flood elevations in Blossom Creek are controlled by the volume of water entering the creek when the tide is high enough to prevent any outflow past the tide gates.

During the 1- and 0.2-percent-annual-chance events, the volume of water overtopping the dike along Isthmus Slough will be great enough to fill Blossom Creek and the downtown area to be same elevation as the Slough. During the 2-percent-annual-chance event, the volume of water overtopping the dike will be great enough to fill the downtown area to the same elevation as the slough, but a constriction at 6th Street between Central and Bennett Avenues will limit the volume of water reaching Blossom Creek. While the dike is being overtopped, the water level will reach an elevation of approximately 7 feet (10.6 ft NAVD) in Blossom Creek. After the bay elevation recedes to below the top of the dike, there will continue to be a hydraulic gradient causing water to flow from the downtown area into Blossom Creek. This will continue until the total volume of water that overtopped the dike reaches a constant elevation of 8 feet (11.6 ft NAVD) throughout both areas.

Whenever the tide gates are closed and the water level in the downtown area is greater than the water level in Blossom Creek area, the backflow will tend to equalize the water levels in the two areas.

During the 10-percent-annual-chance event, only a small volume of water will flow over the dike and pond in the lowest areas of downtown Coos Bay. No dike overflows will reach Blossom Creek. The 10-percent-annual-chance peak flood elevation is Blossom Creek was determined assuming that the greatest 4-hour volume under the 10-percent-annual-chance inflow hydrograph would occur during a high tide in the bay and have to be stored. This results in a 10-percent-annual-chance peak elevation of approximately 5 feet (8.6 ft NAVD).

Storage capacity curves for Blossom Creek and the downtown area of Coos Bay were developed using the City of Coos Bay topographic maps (Chickering-Green Empire Inc., 1976). Peak flood elevations in downtown Coos Bay and Blossom Creek are summarized in Table 5.

Hydraulics for Approximate Riverine Studies (Revised)

Cross sections were developed from aerial LiDAR surveys performed in the summer of 2008 (Oregon LiDAR Consortium, 2009). LiDAR was collected at a nominal density of 8 points per square meter. On flat surfaces the average vertical accuracy of the LiDAR point cloud is within 5 centimeters of true elevation. A 1-meter resolution digital elevation model (DEM) representing ground points was derived from the LiDAR point cloud. No hydro-enforcement was applied to the LiDAR DEM (e.g. the stream water surface during the time of survey was included in the DEM).

Cross sections were developed directly from the LiDAR DEM at regularly spaced intervals along straight channels. Where channels change direction significantly or engineered structures (e.g. bridges) are present, cross sections were spaced more closely.

Cross sections, overbank flow lines, banks, and stream centerlines were developed using the HEC-GeoRAS extension (USACE, 2010) for ArcGIS Desktop 9.3.1. A representative "Manning's N" value of 0.04 was applied to all studied reaches.

Normal depth was calculated to produce output flood zone polygons. Output polygons were then checked to assure flood zones had hydraulic connection to the main channel. Output polygons were removed where no reasonable connection could be established.

Hydraulics for Detailed Coastal Studies (Revised)

Field surveys were undertaken during the 2008-09 winter along the two beach study sites (Bandon, and Bastendorff and Lighthouse Beach) in Coos County. The purpose of these surveys was to provide measurements of the beach in its most eroded state (e.g. most eroded winter profile) in order to define the morphology, elevation, and slope of the beach face for use in subsequent wave runup and overtoping computations. Surveying at Bandon was carried out over a period of three days on February 8-10, 2009, and on March 8-10, 2009 at Bastendorff and Lighthouse Beach. In both cases, the surveys were completed late in the winter season when Oregon beaches are typically in their most eroded state (Aguilar-Tunon and Komar, 1978; Komar, 1997; Allan and Komar, 2002b; Allan and Hart, 2008). A total of 21 transects were established along the Bandon shoreline, while 11 transects were established between Sunset Beach State Park and Bastendorff Beach, adjacent to the mouth of Coos Bay (Figure 10).

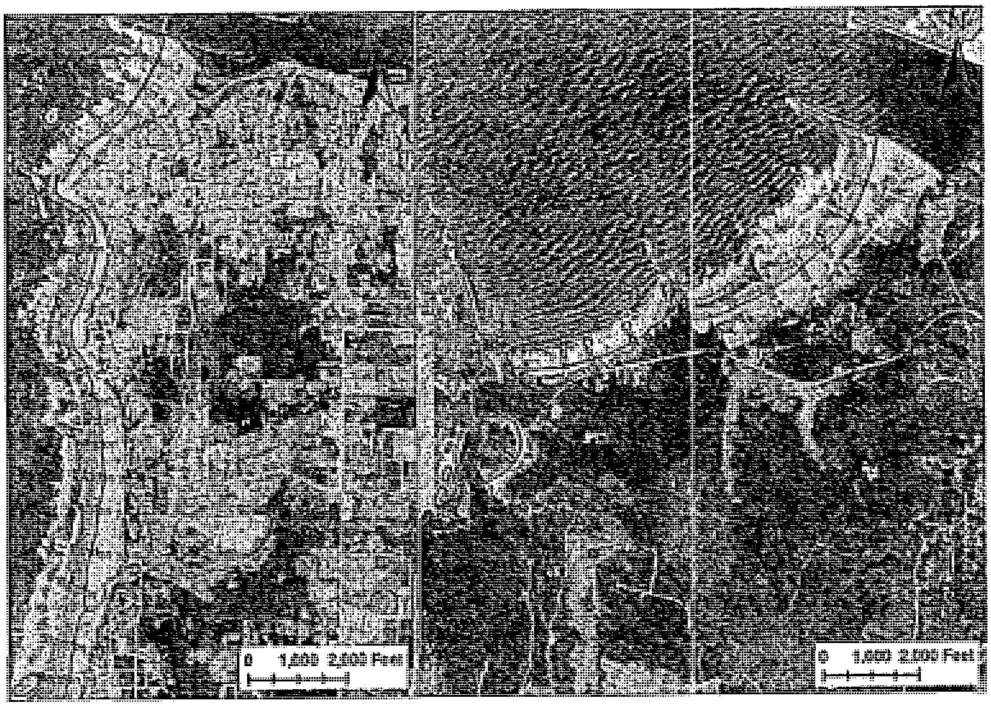


Figure 10 - Location Map of Beach Transects for Detailed Coastal Studiess *Location map of beach profiles measured at Bandon (left) and at Bastendorff/ Lighthouse Beach (right) in Coos County.*

Wave runup is the culmination of the wave breaking process whereby the swash of the wave above the SWL is able to run up the beach face, where it may encounter a dune, structure or bluff, potentially resulting in the erosion (Figure 11), or overtopping and flooding of adjacent land. Runup, "R", or wave swash is generally defined as the time-varying location of the intersection between the ocean and the beach, and summarized as a function of several key parameters. These include the deepwater wave height, peak spectral wave period and the wave length (specifically the wave steepness), and through the breaker parameter (or Iribarren number), which accounts for the slope of a beach or an engineering structure and the steepness of the wave.

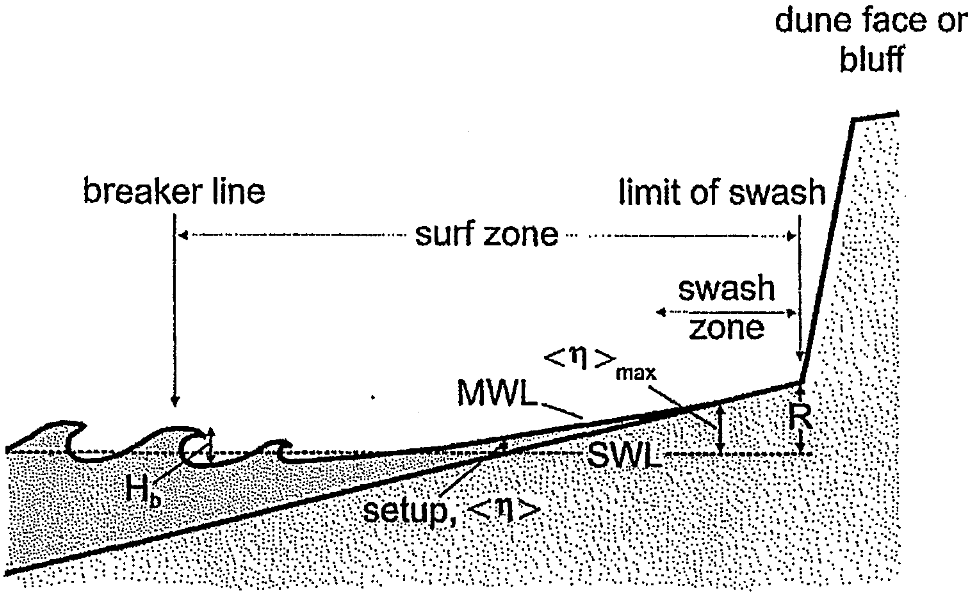


Figure 11 - Conceptual Model of Wave Runup
Conceptual model showing the components of wave runup associated with incident waves (modified from Hedges and Mase, 2004).

The total runup, "R", produced by waves includes three main components:

- wave setup, <η>;
- a dynamic component, η^; and,
- incident wave runup, R_{inc}

$$R = \langle\eta\rangle + \eta\hat{}+R_{inc}$$

Along the Pacific Northwest Coast of Oregon and Washington, the dynamic component of runup, η^, has been demonstrated to be a major component of the total wave runup due to infragravity energy becoming trapped in the surf zone, allowing the swash to reach to much higher elevations at the shore.

A variety of models have been proposed for calculating wave runup on beaches (Ruggiero et al., 2001; Hedges and Mase, 2004; NHC, 2005; Stockdon et al., 2006). DOGAMI employed the runup model developed by Stockdon et al. (2006) due to its demonstrated ability to best represent beach environments in Coos County when compared to other models.

For calculating wave runup on barriers (e.g. bluffs) the method developed by the Technical Advisory Committee for Water Retaining Structures (TAW) was employed. Tables 10 and 11 provide the barrier runup reduction factors used for those selected profile sites along the Bandon and Bastendorff/Lighthouse beach shorelines. In the case of bluff roughness along the Bandon shore, we used a value of 0.6 due to the highly vegetated nature of the Bandon bluffs. These bluffs are located at their stable angle of repose and are covered with salal plants, where it forms a deep, nearly impenetrable thicket. Wave direction reduction factors presented in Table 10 and Table 11 are the mean values determined for all storms for each transect site.

Table 10. Barrier Runup Reduction Factors Used for Calculating Runup (Bandon)

Bandon Profile	Roughness	Berm	Wave Direction	Description
1	N/A	N/A	N/A	Dune-backed
2	N/A	N/A	N/A	Dune-backed
3	N/A	N/A	N/A	Dune-backed
4	N/A	N/A	N/A	Dune-backed
5	N/A	N/A	N/A	Dune-backed
6	N/A	N/A	N/A	Dune - Bluff-backed
7	0.6	1.0	0.81	Dune - Bluff-backed
8	0.6	1.0	0.89	Bluff-backed
9	0.6	1.0	0.90	Bluff-backed
10	0.6	1.0	0.99	Bluff-backed
11	0.6	1.0	0.98	Bluff-backed
12	0.6	1.0	0.99	Bluff-backed
13	0.6	1.0	1.0	Bluff-backed
14	0.6	1.0	1.0	Bluff-backed
15	N/A	N/A	N/A	Dune - Bluff-backed
16	N/A	N/A	N/A	Dune - Bluff-backed
17	N/A	N/A	N/A	Dune - Bluff-backed
18	N/A	N/A	N/A	Dune - Bluff-backed
19	0.6	1.0	0.96	Dune - Bluff-backed
20	0.6	1.0	1.0	Dune - Bluff-backed
21	0.6	1.0	1.0	Dune - Bluff-backed

Table 11. Barrier Runup Reduction Factors Used for Calculating Runup (Bastendorff/Lighthouse Beach)

Coos Profile	Roughness	Berm	Wave Direction	Description
1	N/A	N/A	N/A	Dune-backed
2	N/A	N/A	N/A	Dune-backed
3	N/A	N/A	N/A	Dune-backed
4	N/A	N/A	N/A	Dune-backed
5	N/A	N/A	N/A	Dune-backed
6	N/A	N/A	N/A	Dune-backed
7	1.0	1.0	0.73	Bluff-backed
8	1.0	1.0	0.74	Bluff-backed
9	1.0	1.0	0.72	Bluff-backed
10	1.0	1.0	0.68	Bluff-backed
11	1.0	1.0	0.64	Bluff-backed
11	N/A	N/A	N/A	Dune - Bluff-backed

For both beach and barrier models, the calculated runup is combined with the appropriate measured tides to develop the total water level (TWL) conditions used to generate the 1- and 0.2-percent-annual-chance events. These extreme flood hazard statistics were calculated using the Stockdon et al. (2006) runup model at all 21 profiles at the Bandon focus site and 12 profiles along Bastendorff/Lighthouse Beach. Where applicable (Bandon 7-14 and 19-21 profile sites and for the Bastendorff/Lightbouse 7-11 profiles) these same statistics were calculated using the TAW method. TWLs produced from both the Stockdon et al. method and the TAW method are shown as the 1- and 0.2-percent-annual-chance in Table 8, "Summary of Elevations". Most TWLs come from the Stockdon et al. method. However, where the TAW method produced higher TWLs than the Stockdon et al. method (for bluff-backed beaches only), the TAW method TWLs are shown.

Overtopping of natural features such as foredunes, spits and coastal engineering structures and barriers occurs when the wave runup superimposed on the tide exceeds the crest of the foredune or structure (Figure 12). Based on TWL calculations, only Bandon profiles 1-6 and Bastendorff/Lighthouse profiles 1-5 and 12 experience overtopping during the 1-percent-annual-chance event.

Mapping flood inundation zones requires an estimate of the velocity, "*V*", or discharge, "*q*", of the water that is carried over the crest, the envelope of the water surface that is defined by the water depth, "*h*", landward of the barrier crest, and the inland extent of green water and splash overtopping. According to NHC (2005) these hazard zones are ultimately defined based on the following two derivations:

- Base Flood Elevations (BFEs) are determined based on the water surface envelope landward of the barrier crest; and

- Hazard zones are determined based on the landward extent of green water and splash overtopping, and on the depth and flow velocity in any sheet flow areas beyond that, defined as $hV^2 = 200\,ft^3/s^2$.

A distinction can be made between whether green water (or bore) or splash overtopping predominates at a particular location, dependent on the ratio of the calculated wave runup height, "R", relative to the barrier crest elevation, "Z_c" (Figure 11). When $1 < R/Z_c < 2$, splash overtopping dominates and for $R/Z_c > 2$, bore propagation occurs. In both cases, R and Z_c are relative to the 2% Dynamic Water Level ($DWL_{2\%}$) at the barrier (NHC, 2005).

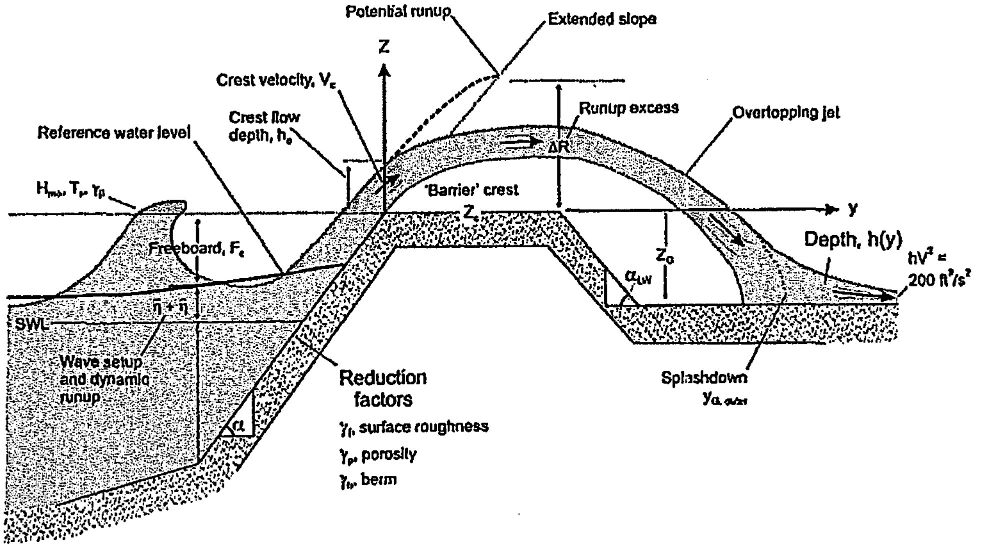


Figure 12 - Nomenclature of Wave Runup Parameters
Nomenclature of overtopping parameters available for mapping base flood elevations (BFEs) and flood hazard zones (after NHC, 2005).

Prior to calculating the mean overtopping rate at the barrier crest, it is necessary to first distinguish between four contrasting types of wave breaking situations that may impact a particular barrier or dune overtopping situation. The four conditions include (1) non-breaking or (2) breaking on normally sloped barriers, and (3) reflecting or (4) impacting on steeper barriers. Of these, the only one that applies to the Coos County detailed coastal study sites is the breaking wave situation (2), where the waves have already broken across the surf zone and are reforming as bores prior to swashing up the beach face or barrier.

At the beach or barrier crest, the relative freeboard, "F_c", (Figure 11), is a particularly important parameter since changing these two parameters controls the volume of water that flows over the barrier crest. For example, increasing the wave height or period increases the overtopping discharge, as does reducing the ‘beach or barrier crest height or raising the water level.

A variety of prediction methods are available for calculating the overtopping discharge and are almost entirely based on laboratory experiments based on a range of structure slopes (slopes between 1:1 and 1:8, with occasional tests at slopes around 1:15 or lower). Factors that reduce the potential overtopping discharge include the barrier surface roughness, “γ_f”, the presence of a berm, “γ_b”, wave approach directions, “γ_β”, and the porosity of the barrier, “γ_p” (Figure 11). Of the four reduction parameters, only the angle of wave attack was used to reduce the overtopping discharge along the Coos County detailed study sites. The presence of a berm can be ignored since berms are non-existent in a most eroded winter profile. The surface roughness was ignored since the beach face and backshore is composed of sand and hence has only a nominal effect on reducing overtopping. Porosity was also ignored as the beach is characterized by medium to coarse sand and during major storms the beach is typically in a saturated state due to the combination of high runup and the storm duration, such that the beach is less capable of taking up additional water.

Initial computations of the landward extent of wave overtopping using the prescribed method (NHC, 2005) yielded narrow hazard zones for Coos County. To calibrate the method for realistic application on the Coos County coast, wave overtopping calculations were performed for a site on the northern Oregon coast where field observations of wave overtopping had been observed. The site is Cape Lookout State Park located on the northern Oregon coast in Tillamook County (Allan and Komar, 2002a; Komar et al., 2003; Allan et al., 2006). The southern portion of Cape Lookout State Park is characterized by a wide, gently sloping, dissipative sand beach, backed by a moderately steep gravel berm and ultimately by a low foredune that has undergone significant erosion since the early 1980’s (Komar et al., 2000).

In March 1999, the crest of the cobble berm/dune at Cape Lookout State Park was overtopped during a major storm; the significant wave heights reached 14.1 m (46.3 ft), while the peak periods were 14.3 seconds (Allan and Komar, 2002b). Wave overtopping of the dune and flooding extended 230 ft into the park (Dr. P. Komar, Emeritus Professor, College of Oceanic and Atmospheric Sciences, pers. comm., 2010), evidence for which included photos and field evidence including pock-marks at the base of the tree trunks located in the park. These pock-marks were caused by cobbles having been carried into the park from the beach by the overtopping waves, where they eventually slammed into the base of the trees as ballistics. Since the average beach slopes at Cape Lookout State park are analogous to those observed along the shore near the Bandon south jetty and that large wave events associated with extra-tropical storms affect significant stretches (hundreds to thousands of miles) of the coast at any single point in time, these data are believed to provide a reasonable means in which to investigate a range of alpha values, "α", (Figure 11) that may be used to determine the landward extent of wave inundation at Cape Lookout State Park.

Using beach morphology data from Cape Lookout State Park and deepwater wave statistics from a nearby National Data Buoy Center (NDBC) wave buoy (#46050), a range of alpha values were experimented with in order to replicate the landward extent of the inundation. In order to emulate the landward extent of flooding observed at Cape Lookout State Park the analyses yielded an alpha of 0.58. Using this alpha value, the extent of the hazard zone was calculated where $hV^2(y) = 200\ ft^3/s^2$, which was found to be approximately 34 meters from the crest of the cobble berm/dune, consistent with damage to facilities in the park.

Table 12 presents the results of the calibrated splashdown distances, "$y_{G\ outer}$", (Figure 11) and the landward extent of the flow, "hV^2", (Figure 11) where the flows approach $200\ ft^3/s^2$. The calculated splashdown distances, "$y_{G\ outer}$", (Table 12) were based on an enhanced wind velocity of 64.3 ft/s. This enhanced wind velocity was determined from an analysis of wind speeds measured by the Cape Arago C-MAN station located adjacent to the mouth of Coos Bay. The range of wind speeds identified at Cape Arago was examined for each storm event defined for this study and revealed a wide range of values, with the maximum being 64.3 ft/s. Since the measured wind speeds reflect a 2-minute average such that higher wind speeds have been measured throughout the entire record (e.g. the maximum 2-minute average wind speed is 96 ft/s, while the maximum 5-second wind gust reached 125.0 ft/s), it is considered justified to use the more conservative enhanced wind velocity of 64.3 ft/s rather than the default of 44 ft/s prescribed by NHC (2005).

The Bastendorff/Lighthouse Beach profile 2 site presents a situation where the calculated 1-percent-annual-chance TWL of 24 ft approximately equals the beach/dune crest elevation of 23.9 ft, suggesting that overtopping would probably not occur; in this situation the landward location of the primary frontal dune (PFD) would determine the width of the hazard zone.

Table 12. Splashdown and Flood Zone Limits for Detailed Coastal Profiles

Profile	# of Wave Overtopping Events, and Events where $hV^2 > 200$ ft^3/s^2	Maximum Splashdown $y_{G\,outer}$ (ft)	Maximum $hV^2(y) = 200\ ft^3/s^2$ (ft)	Maximum Width of Hazard Zone (ft)	Distance from Profile Benchmark (ft)
Bandon Profile Sites					
1	127 / 11	4.3	149.3	153.2	529.2
2	115 / 15	11.2	193.6	204.7	432.4
3	103 / 12	11.2	165.0	176.2	524.9
4	83 / 15	13.5	183.7	197.2	367.5
5	55 / 1	4.9	29.2	33.5	274.9
6	101 / 3	6.2	69.2	75.1	152.2
Bastendorff/Lighthouse Beach Profile Sites					
1	6 / 0	2.0	-	2.0	998.7
2	0 / 0	-	-	-	-
3	3 / 0	10.2	-	10.2	631.2
4	105 / 25	14.8	149.9	164.7	602.0
5	14 / 0	8.5	-	8.5	829.9
12	132 / 132	5.6	373.7	379.3	-50.9

Mapping of the SFHA for bluff-backed beaches used TWLs shown in Table 8, "Summary of Elevations", and extended them into the bluff. The contour of interest was extracted from a 1-meter resolution DEM derived from LiDAR ground points surveyed in the summer of 2008 (Oregon LiDAR Consortium, 2009). In all cases, the calculated TWLs were rounded to the nearest whole foot. The landward extent of the SFHA (Zone VE) is defined by the contour representing the TWL calculated for each of the surveyed profiles. To define the landward extent of the SFHA (Zone VE) between profile locations professional judgment was used to establish appropriate zone breaks by identifying along-shore geomorphic barriers within which a particular TWL is valid. Slope and hillshade derivatives of the LiDAR DEM, as well as 1-meter orthophotos (Oregon Geospatial Data Clearinghouse, 2009), provided base reference. An effort was made to orient zone breaks perpendicular to the beach at the location of the geomorphic barrier. In all cases, the seaward extent of the SFHA (Zone VE) was inherited from the previous FIS.

Mapping of the SFHA for dune-backed beaches was performed by calculating the degree of wave overtopping at each profile location (Figure 11; Table 12). The furthest point landward of the dune crest that experiences coastal flooding due to overtopping and is ultimately controlled by the extent of the landward flow where it approaches 200 ft^3/s^2; values greater than 200 ft^3/s^2 are located within the Zone VE SFHA, while values that dissipate below that threshold are designated within the Zone AE SFHA. For SFHAs (Zone VE) seaward of the dune crest, TWLs shown in Table 8, "Summary of Elevations", were used. As with bluff-backed beaches, professional judgment was used to establish appropriate zone breaks between profile locations. This was achieved using the LiDAR DEM (Oregon LiDAR Consortium, 2009), supplemented by knowledge of the local geomorphology. Again, an effort was made to orient zone breaks perpendicular to the beach and the seaward extent of the SFHA (Zone VE) was inherited from the previous FIS. Elevations were identified from the LiDAR DEM to aid in establishing zone breaks due to changes in flood depth landward of the dune crest. Slope and hillshade derivatives of the LiDAR DEM, as well as 1-meter orthophotos (Oregon Geospatial Data Clearinghouse, 2009), provided base reference. Some interpretation was required to appropriately map the SFHA for the printed FIRM panel scale.

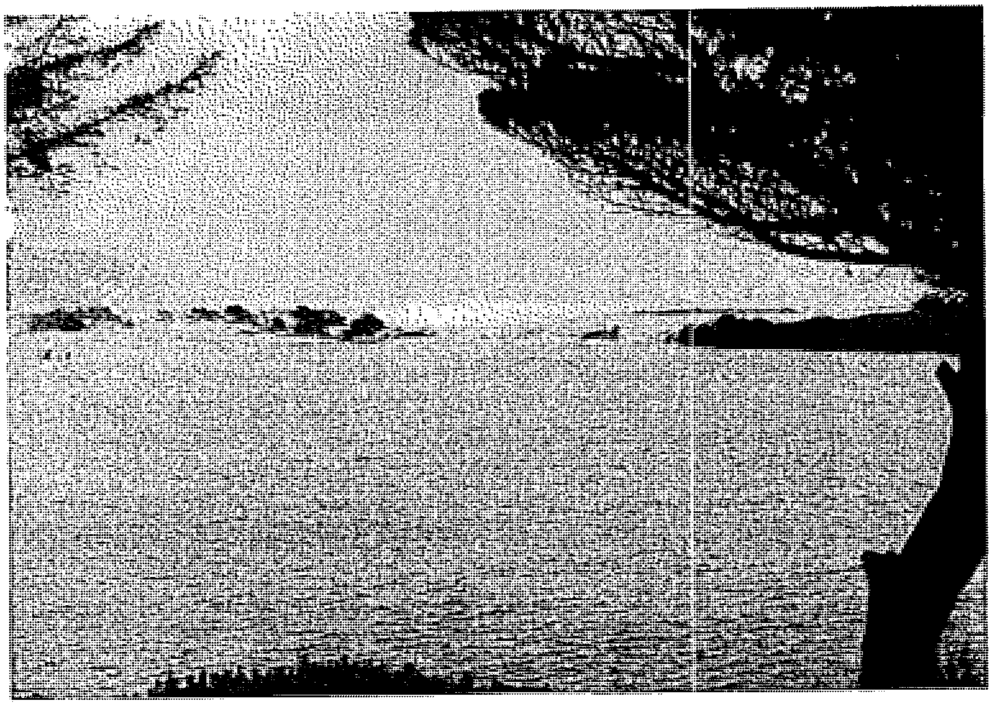


Figure 13 - Overtopping of Barrier Beach at Garrison Lake Near Port Orford
Overtopping of the barrier beach adjacent to Garrison Lake during a major storm on February 16, 1999 (Photo courtesy of a resident at Port Orford, Oregon).

Hydraulics for Approximate Coastal Studies (Revised)

FEMA guidelines direct that for mapping the SFHA in coastal areas where no detailed studies have occurred (Zone V), the location of the primary frontal dune

(PFD) be defined as the most landward extent of flooding. The PFD is defined as "a continuous or nearly continuous mound or ridge of sand with relatively steep seaward and landward slopes immediately landward and adjacent to the beach and subject to erosion and overtopping from high tides and waves during major coastal storms. The landward limit of the primary frontal dune, also known as the toe or heel of the dune, occurs at a point where there is a distinct change from a relatively steep slope to a relatively mild slope. The primary frontal dune toe represents the landward extension of the Zone VE coastal high hazard velocity zone" (Part 44 of the US Code of Federal Regulations, Section 59.1; FEMA Coastal Hazard Bulletin, No. 15).

The mapping approach developed by DOGAMI addresses three distinct geomorphic environments where the PFD variably discernible: (1) dune-backed beaches, (2) bluff-backed beaches, and (3) areas where streams drain into the Pacific Ocean.

The approach developed by DOGAMI to define the morphology of dune-backed beaches, including the location of the PFD, was based on detailed analyses of LiDAR elevation data measured by the USGS/NASA/NOAA in 1998 and 2002, and by the Oregon LiDAR Consortium (OLC) in the summer of 2008. However, because the LiDAR flown by the USGS/NASA/NOAA is of relatively poor resolution (nominal point spacing of 1 point per square meter) and reflects only a single return (i.e. includes vegetation where present) it was not used for mapping, only geomorphic time series analysis. OLC LiDAR is of much higher precision (nominal point spacing of 8 points per square meter) and was characterized by multiple returns enabling the development of a ground LiDAR DEM. Determination of the PFD was based entirely on analysis of the OLC LiDAR.

Profiles spaced 50 meters apart were cast perpendicular to the full length of the county coastline using the Digital Shoreline Analysis System (DSAS) developed by the USGS (Thieler et al., 2009). For each profile, 3D coordinates for the 1998, 2002 and 2008 LiDAR were extracted at 1-meter intervals along each profile.

Processing of the LiDAR was performed in Matlab using a custom beach profile analysis script developed by DOGAMI that interactively defines various morphological features, including the dune/bluff crest/top, bluff slope (where applicable), landward edge of the PFD, beach/dune juncture elevations for each year, and the slope of the beach foreshore.

Time series analysis of morphological features identified in the serial LiDAR indicate that erosion predominates along both the north Coos Spit and along much of the New River Spit, while much of the shore along Bullards Beach, located north of Bandon, appears to be accreting.

Due to uncertainties in identifying the PFD (as defined by FEMA), mapping of the SFHA for dune-backed beaches required that some professional judgment be employed. For example, where there was determined to be a high probability of erosion within ten years, the SFHA was mapped slightly landward of the PFD.

For bluff-backed beaches the landward extent of the SFHA was mapped at the top of the bluff, a readily identifiable feature in the 2008 OLC LiDAR.

Mapping of the SFHA in areas influenced by fluvial processes (e.g. near the mouth of Tenmile Creek) required professional judgment. Historical aerial photos and serial LiDAR were referred to for past evidence of flotsam and debris, wetlands, and channel migration.

3.3 Wave Height Analysis

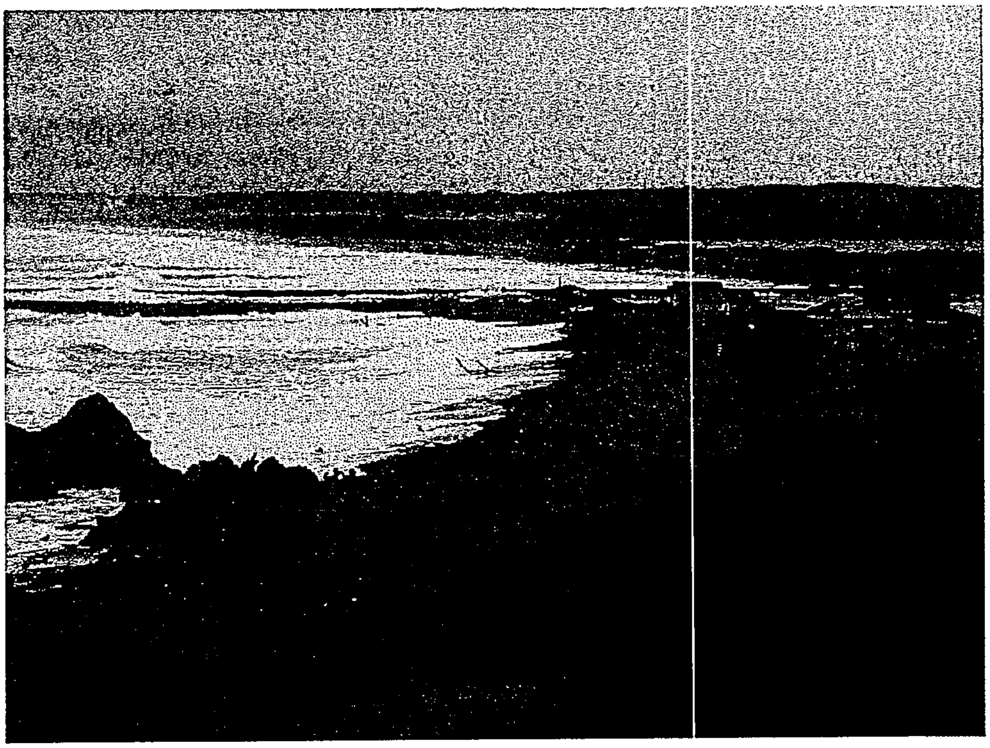


Figure 14 - February 9, 2009 Photo of Coquille Jetties During a Winter Storm Event
Looking north toward the Coquille River jetties in Bandon, Oregon during a typical winter storm on February 9, 2009 (Photo by Jon Allan, DOGAMI).

The wave climate offshore from the Oregon coast is one of the most extreme in the world, with winter storm waves regularly reaching heights in excess of several meters. This is because the storm systems emanating from the North Pacific travel over fetches that are typically a few thousand miles in length and are also characterized by strong winds, the two factors that account for the development of large wave heights and long wave periods (Tillotson and Komar, 1997). These storm systems originate near Japan or off the Kamchatka Peninsula in Russia, and typically travel in a southeasterly direction across the North Pacific towards the

Gulf of Alaska, eventually crossing the coasts of Oregon and Washington or along the shores of British Columbia in Canada.

Wave statistics (heights and periods) have been measured in the North Pacific using wave buoys and sensor arrays since the mid 1970's. These data have been collected by NOAA, which operates the National Data Buoy Center (NDBC) and by Scripps Institution of Oceanography, which operates the Coastal Data Information Program (CDIP). The buoys cover the region between the Gulf of Alaska and Southern California, and are located in both deep and in intermediate to shallow water over the continental shelf. The NDBC operates some 30 stations along the West Coast of North America, while CDIP has at various times carried out wave measurements at 80 stations. Presently there is one CDIP buoy operating offshore from Coos Bay (#46229), and two NDBC buoys (Oregon [#46002] and Port Orford [#46015]) located offshore from the southern Oregon coast. Wave measurements by NDBC are obtained hourly. CDIP provides measurements every 30 minutes. Measurements are transmitted via satellite to the laboratory for analysis of the wave energy spectra, significant wave heights and peak spectral wave periods (NOAA, 2009).

Analyses of the wave climate offshore from Coos County were performed at Oregon State University (OSU), and included numerical analyses of the 1-percent-annual-chance extreme storm wave event and the associated wave setup to determine the degree of coastal flood risk along the coast of Coos County.

OSU performed a series of analyses including wave transformations, empirical wave runup modeling, and TWL modeling. For the purposes of this study, OSU used the SWAN (Simulating Waves Nearshore) wave model to transform deepwater waves (for a range of 1-percent-annual-chance events) to the nearshore (typically the 65.6 ft [20 m] contour). The deep-water equivalent of these refracted nearshore waves was determined using the linear shoaling relation in order to calculate wave runup levels, which were then combined with the tidal component in order to estimate the flood risk along the Bandon shore and at Bastendorff/Lighthouse Beach.

All available NDBC and CDIP hourly wave buoy data were acquired for several wave buoys in the region. In addition, wave hindcast information on the deepwater wave climate determined through the Wave Information Studies (WIS) (Baird, 2005) was acquired for station 074, located adjacent to NDBC buoy #46002, the primary wave buoy used in this study due to its high quality long record of data (1975-present). However, since this buoy is located in 11,500 ft of water and is over 250 miles from the location of the shelf edge buoys (Port Orford #46015 and Umpqua Offshore #46229), it was necessary to develop a methodology to transform these 'off-shelf' waves to the 'shelf-edge' offshore boundary condition of the SWAN model. The wave climate observed at NDBC buoy #46002 has significant differences compared to the climate observed at the Port Orford #46015 and Umpqua Offshore #46229 buoys.

To transform the NDBC buoy #46002 waves to the shelf edge, wave period bins were created to evaluate if there has been a wave period dependent difference in wave heights observed at NDBC buoy #46002 compared with the Port Orford #46015. For comparison, the time stamps associated with waves measured at NDBC buoy #46002 were adjusted based upon the group celerity (for the appropriate wave period bin) and travel time it takes the wave energy to propagate to Port Orford #46015.

After correcting for the time of wave energy propagation the differences in wave heights between the two buoys, for each wave period bin, were calculated in two ways. First, a best-fit linear regression through the wave height differences was computed for each wave period bin. Second, a constant offset was computed for the wave height differences for each period bin.

Upon examination of the empirical probability density functions (PDF) of both buoys' raw time series (using only approximately last 5 years of NDBC buoy #46002, the time of overlap with the shelf buoys) and after applying both transformation methods, it was determined that the constant offset method did a superior job of matching the PDF, particularly at high wave heights. Therefore, a constant offset adjustment dependent on the wave period was applied to the wave heights of NDBC buoy #46002.

Because the WIS hindcast data used in this study was also located well beyond the boundary of the SWAN model (effectively at the location of NDBC buoy #46002), the same series of steps comparing WIS wave heights to those from Port Orford #46015 were carried out, with a new set of constant offsets having been calculated and applied. Data from the Port Orford #46015 and Umpqua Offshore #46229 were also compared in this same manner and it was determined that their wave height differences in the alongshore extent (e.g. offshore from Coos County) are negligible. Therefore it is assumed that a constant offshore wave height boundary condition is appropriate for the SWAN model.

After applying the wave height offsets to the NDBC buoy #46002, gaps in this time series were filled in respectively with Port Orford #46015 and subsequently the Umpqua Offshore #46229. Where there were still gaps following this procedure the time series was then filled in with the corrected WIS data. Because wave transformations (particularly refraction) computed by SWAN are significantly dependent on wave direction, when this information was missing in the buoy records it was replaced with WIS data for the same date in the time series; the wave height and period data was carried over from buoy observations where applicable. For conditions in the time series that had no estimate of wave direction from either the buoys or the WIS data a value of 270 degrees (e.g. westerly waves) was assumed.

The final synthesized wave time series developed for Coos County extends from late 1979 through to the end of 2008 and consists of approximately 27.5 years of good data (measurements including at least wave height and periods) out of a possible 29.2 years.

The wave climate offshore from the Oregon coast is episodically characterized by large wave events (> 26 ft), with some storms having generated deepwater extreme waves on the order of 49 ft. The average wave height offshore from Coos County is 8.5 ft, while the average peak spectral wave period is 11.1 seconds, although periods of 20-25 seconds are not uncommon.

The Pacific Northwest wave climate is characterized by a distinct seasonal cycle evident in the variability in the wave heights and peak periods between summer and winter. Monthly mean significant wave heights are typically highest in December and January, although large wave events (> 39.4 ft) have occurred in all of the winter months except March. The highest significant wave height observed in the wave climate record is 50.9 ft, substantially exceeding the 1-percent-annual-chance wave height used in the previous Bandon FIS (1996), which was 24.6 ft and was derived from WIS data for the period of 1956 to 1975. In general, the smallest waves occur during late spring and in the summer, with wave heights typically averaging approximately 5 ft during the peak of the summer (July/August). These findings are consistent with other studies that have examined the Pacific Northwest wave climate (Tillotson and Komar, 1997; Allan and Komar, 2006; P. Ruggiero et al., 2010).

A probability density function determined for the complete time series indicates that for 50% of the time waves are typically less than 7.2 ft, and less than 14.8 ft for 90% of the time. Wave heights exceed 24.3 ft for 1% of the time. However, it is these latter events that typically produce the most significant erosion and flooding events along the Oregon coast.

With regard to wave direction along the south Oregon coast, in general, the summer is characterized by waves arriving from the northwest, while winter waves typically arrive from the west or southwest (Komar, 1997). Separate analyses of the summer and winter directional data developed from the synthesized time series, comprised of both WIS data from the shelf edge buoys, agree with this pattern. To better highlight the predominant wave directions for the winter months, wave heights less than 33 ft have been eliminated from the analyses. Summer months are characterized by waves arriving from mainly the west-northwest (~25%) to northwesterly quadrant (~21%), with few waves out of the southwest. The bulk of these reflect waves with amplitudes that are predominantly less than 9.8 ft. In contrast, the winter months are dominated by much larger wave heights out of the west (~25-35%), and to a lesser extent the northwest (~18%).

Figure 15 is a profile for a hypothetical transect showing the effects of energy dissipation on a wave as it moves inland. This figure shows the wave elevations being decreased by obstructions, such as buildings, vegetation, and rising ground elevations and being increased by open, unobstructed wind fetches. Actual wave conditions may not necessarily include all of the situations shown in Figure 15.

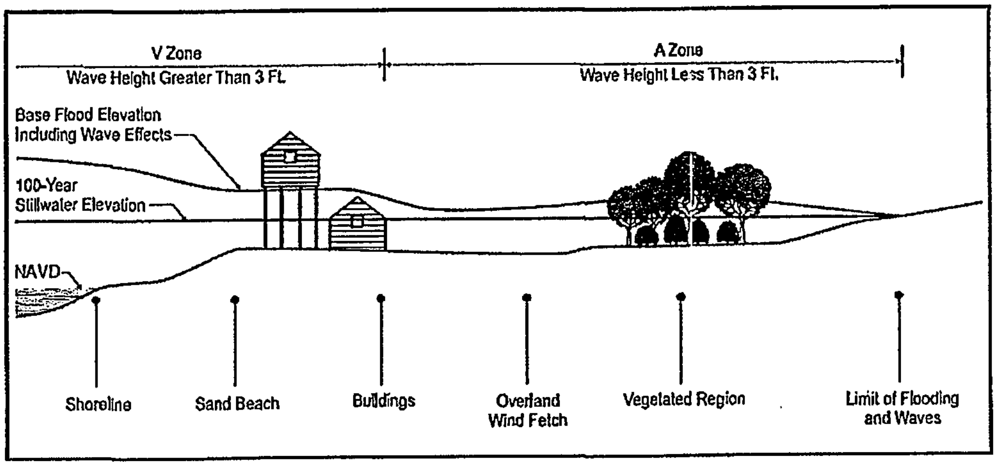


Figure 15 - Schematic of Coastal Profile

3.4 Vertical Datum

All FIS reports and FIRMs are referenced to a specific vertical datum. The vertical datum provides a starting point against which flood, ground, and structure elevations can be referenced and compared. Until recently, the standard vertical datum in use for newly created or revised FIS reports and FIRMs was the National Geodetic Vertical Datum of 1929 (NGVD29). With the finalization of North American Vertical Datum of 1988 (NAVD88), many FIS reports and FIRMs are being prepared using NAVD88 as the referenced vertical datum.

All flood elevations shown in this FIS report and on the FIRM are referenced to NAVD88. Structure and ground elevations in the community must, therefore, be referenced to NAVD88. It is important to note that adjacent communities may be referenced to NGVD29. This may result in differences in Base Flood Elevations (BFEs) across the corporate limits between the communities.

For additional information regarding conversion between NGVD29 and NAVD88, visit the NGS website at www.ngs.noaa.gov, or contact the NGS at the following address:

Vertical Network Branch, N/CG13
National Geodetic Survey, NOAA
Silver Spring Metro Center 3
1315 East-West Highway
Silver Spring, Maryland 20910
(301) 713-3191

The conversion factor from NGVD to NAVD for all streams in this report was +3.62 feet. The conversion was performed during the initial countywide update.

Temporary vertical monuments are often established during the preparation of a flood hazard analysis for the purpose of establishing local vertical control. Although these monuments are not shown on the FIRM, they may be found in the Technical Support Data Notebook associated with the FIS report and FIRM for this community. Interested individuals may contact FEMA to access these data.

To obtain current elevation, description, and/or location information for benchmarks shown on this map, please contact the Information Services Branch of the NGS at (301) 713-3242, or visit their website at www.ngs.noaa.gov.

4.0 FLOODPLAIN MANAGEMENT APPLICATIONS

The NFIP encourages State and local governments to adopt sound floodplain management programs. Therefore, each FIS provides 1-percent-annual-chance (100-year) flood elevations and delineations of the 1- and 0.2-percent-annual-chance (500-year) floodplain boundaries and 1-percent-annual-chance floodway to assist communities in developing floodplain management measures. This information is presented on the FIRM and in many components of the FIS report, including Flood Profiles, Floodway Data Table, and Summary of Elevations Table. Users should reference the data presented in the FIS report as well as additional information that may be available at the local map repository before making flood elevation and/or floodplain boundary determinations.

4.1 Floodplain Boundaries

To provide a national standard without regional discrimination, the 1-percent-annual-chance flood has been adopted by FEMA as the base flood for floodplain management purposes. The 0.2-percent-annual-chance flood is employed to indicate additional areas of flood risk in the community.

For each flooding source studied by detailed methods, the 1- and 0.2-percent-annual-chance floodplain boundaries have been delineated using the flood elevations determined at each cross section. Between cross sections, the boundaries were interpolated using 1 meter resolution bare earth LiDAR DEMs (effective map scale of approximately 1:2,300), with a contour interval of 0.5 feet (Oregon LiDAR Consortium, 2009).

For streams studied by approximate methods, the 1-percent-annual-chance floodplain boundaries have been delineated using flood elevations at every grid cell of 1 meter resolution bare earth LiDAR DEMs (effective map scale of approximately 1:2,300). No interpolation was performed. Note that exceptions exist where LiDAR was not available in the far eastern portion of Coos County. In these areas 1-percent-annual-chance flood boundaries were delineated using Flood Hazard Boundary Maps for Coos County (U.S. Department of Housing and Urban Development, 1977), Geologic Hazard Maps (Beaulieu and Hughes, 1975), and engineering judgment. These exceptions include areas along the upper East Fork Millicoma River, Glenn Creek, upper East Fork Coquille River, West Fork Brummit Creek, and East Fork Brummit Creek.

The 1- and 0.2-percent-annual-chance floodplain boundaries are shown on the FIRM (Exhibit 2). On this map, the 1-percent-annual-chance floodplain boundary corresponds to the boundary of the areas of special flood hazards (Zones A, AE, V, and VE), and the 0.2-percent-annual-chance floodplain boundary corresponds to the boundary of areas of moderate flood hazards. In cases where the 1- and 0.2-percent-annual-chance floodplain boundaries are close together, only the 1-percent-annual-chance floodplain boundary has been shown. Small areas within the floodplain boundaries may lie above the flood elevations but cannot be shown due to limitations of the map scale and/or lack of detailed topographic data.

For the streams studied by approximate methods, only the 1-percent-annual-chance floodplain boundary is shown on the FIRM (Exhibit 2).

4.2 Floodways

Encroachment on floodplains, such as structures and fill, reduces flood-carrying capacity, increases flood heights and velocities, and increases flood hazards in areas beyond the encroachment itself. One aspect of floodplain management involves balancing the economic gain from floodplain development against the resulting increase in flood hazard. For purposes of the NFIP, a floodway is used as a tool to assist local communities in this aspect of floodplain management. Under this concept, the area of the 1-percent-annual-chance floodplain is divided into a floodway and a floodway fringe. The floodway is the channel of a stream, plus any adjacent floodplain areas, that must be kept free of encroachment so that the 1-percent-annual-chance flood can be carried without substantial increases in flood heights. Minimum Federal standards limit such increases to 1 foot, provided that hazardous velocities are not produced. The floodways in this study are presented to local agencies as minimum standards that can be adopted directly or that can be used as a basis for additional floodway studies.

The floodways presented in this FIS report and on the FIRM were computed for certain stream segments on the basis of equal-conveyance reduction from each side of the floodplain. Floodway widths were computed at cross sections. Between cross sections, the floodway boundaries were interpolated. The results of the floodway computations have been tabulated for selected cross sections in Table 13, "Floodway Data". In cases where the floodway and 1-percent-annual-chance floodplain boundaries are either close together or collinear, only the floodway boundary has been shown.

Floodways for the Coquille River and the South Fork Coquille River were computed on the basis of equal-conveyance reduction from each side of the floodplain. Because of the complexity and hydraulic controls on the Calloway

Creek/Cunningham Creek floodplain, a standard floodway based on equal-conveyance reduction is not possible. Instead, the floodways for these two creeks were calculated by trial-and-error based on the flow divisions of the normal depth 1-percent-annual-chance flood.

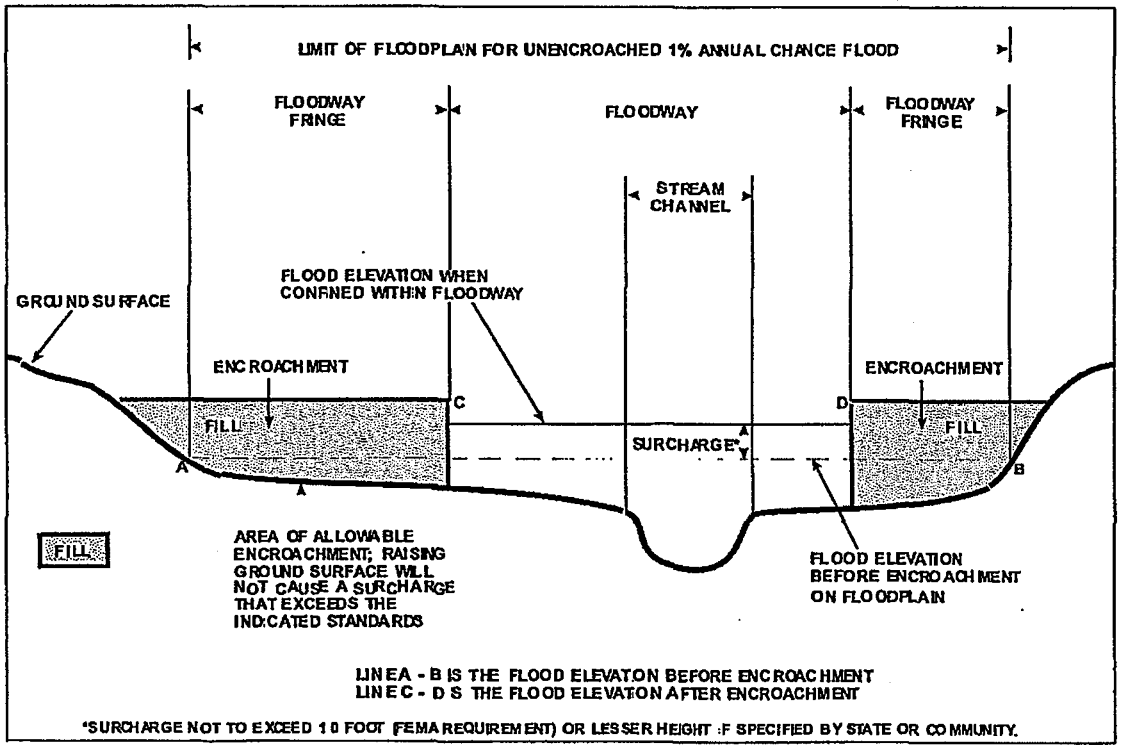
As shown on the Flood Information Rate Maps (FIRM), the floodway widths were determined at cross sections; between cross sections, the boundaries were interpolated. In cases where the boundaries of the floodway and the 1-percent-annual-chance flood are either close together or collinear, only the floodway boundary has been shown.

The floodway for Pony Creek above Newmark Street was computed on the basis of equal conveyance reduction from each side of the floodplain. No floodway was delineated on Pony Creek between Crowell Lane and Newmark Street or downstream of Crowell Lane because the floodway concept is not applicable in areas where flooding is controlled by tidal influences.

No floodway was determined for the Coquille River within the City of Bandon corporate limits and for Ferry Creek because both streams are subject to tidal influence.

The area between the floodway and 1-percent-annual-chance floodplain boundaries is termed the floodway fringe. The floodway fringe encompasses the portion of the floodplain that could be completely obstructed without increasing the water surface elevation of the 1-percent-annual-chance flood more than 1 foot at any point. Typical relationships between the floodway and the floodway fringe and their significance to floodplain development are shown in Figure 16.

Figure 16. Floodway Schematic



FLOODING SOURCE		FLOODWAY				1-PERCENT-ANNUAL-CHANCE FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	DISTANCE	WIDTH (FEET)	PRIOR STUDY WIDTH (FEET)	SECTION AREA (SQUARE FEET)	MEAN VELOCITY (FEET PER SECOND)	REGULATORY (FEET NAVD88)	WITHOUT FLOODWAY (FEET NAVD88)	WITH FLOODWAY (FEET NAVD88)	INCREASE (FEET)
Calloway Creek									
A	60^{1}	37		262	5.8	24.0	20.1	20.2	0.1
B	160^{1}	61		353	4.3	24.8	21.5	22.5	1.0
C	680^{1}	173		1,253	1.2	24.8	22.0	22.9	0.9
Cunningham Creek									
A	920^{2}	56		219	4.4	24.0	14.2^{3}	15.2^{3}	1.0
B	2,560^{2}	47		188	4.6	24.0	18.0^{3}	18.1^{3}	0.1
C	3,560^{2}	47		187	4.7	24.0	20.0^{3}	20.1^{3}	0.1
D	4,280^{2}	51		169	2.5	24.0	20.1^{3}	20.2^{3}	0.1
E	4,390^{2}	N/A^{4}	38	169	2.5	24.5	20.1^{3}	20.2^{3}	0.1
F	4,830^{2}	36		102	4.2	24.6	20.6^{3}	20.7^{3}	0.1
G	5,270^{2}	38		109	3.9	24.6	21.5^{3}	21.7^{3}	0.2
H	5,360^{2}	40		109	3.9	24.6	21.5^{3}	21.7^{3}	0.2
I	5,530^{2}	45		167	2.6	24.8	22.0^{3}	23.0^{3}	1.0
Cunningham Creek Overflow Channel									
A	1,130^{2}	121		452	2.4	24.0	10.9^{3}	11.9^{3}	1.0
B	2,710^{2}	120		660	1.6	24.0	12.4^{3}	13.4^{3}	1.0
C	4,030^{2}	195		194	5.5	24.0	19.5^{3}	19.5^{3}	0.0

[1] Feet above Cunningham Creek [2] Feet above mouth [3] Elevations computed without effects from Coquille River [4] Due to re-delineation floodway is now outside of SFHA at this location

TABLE 13

FEDERAL EMERGENCY MANAGEMENT AGENCY

COOS COUNTY, OREGON
AND INCORPORATED AREAS

FLOODWAY DATA

CALLOWAY CREEK, CUNNINGHAM CREEK, CUNNINGHAM CREEK OVERFLOW CHANNEL

FLOODING SOURCE		FLOODWAY			1-PERCENT-ANNUAL-CHANCE FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQUARE FEET)	MEAN VELOCITY (FEET PER SECOND)	REGULATORY (FEET NAVD88)	WITHOUT FLOODWAY (FEET NAVD88)	WITH FLOODWAY (FEET NAVD88)	INCREASE (FEET)
Coquille River at Riverton								
A	82,440	1,377	23,879	4.9	22.2	22.2	23.2	1.0
B	84,650	2,194	42,275	2.7	22.8	22.8	23.8	1.0
C	86,800	2,511	45,371	2.6	23.1	23.1	24.1	1.0
D	89,600	3,945	72,926	1.6	23.3	23.3	24.3	1.0
Coquille River at Coquille								
E	121,600	5,535	88,146	1.3	24.0	24.0	25.0	1.0
F	123,550	6,949	129,249	0.9	24.0	24.0	25.0	1.0
G	126,250	7,603	138,886	0.8	24.0	24.0	25.0	1.0
H	128,400	6,443	125,613	0.9	24.1	24.1	25.1	1.0
I	130,300	7,178	133,927	0.8	24.1	24.1	25.1	1.0
J	132,250	6,716	128,508	0.9	24.1	24.1	25.1	1.0
K	133,050	7,211	131,137	0.8	24.1	24.1	25.1	1.0
L	135,700	6,110	113,706	1.0	24.1	24.1	25.1	1.0
M	137,800	5,930	103,284	1.1	24.1	24.1	25.1	1.0
N	139,600	6,293	115,736	1.0	24.2	24.2	25.2	1.0
O	141,500	6,376	111,041	1.0	24.2	24.2	25.2	1.0
P	143,150	6,546	101,204	1.1	24.2	24.2	25.2	1.0
Q	145,200	5,996	88,563	1.2	24.3	24.3	25.3	1.0

[1] Feet above mouth

TABLE 13

FEDERAL EMERGENCY MANAGEMENT AGENCY

COOS COUNTY, OREGON
AND INCORPORATED AREAS

FLOODWAY DATA

COQUILLE RIVER

FLOODING SOURCE		FLOODWAY			1-PERCENT-ANNUAL-CHANCE FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQUARE FEET)	MEAN VELOCITY (FEET PER SECOND)	REGULATORY (FEET NAVD88)	WITHOUT FLOODWAY (FEET NAVD88)	WITH FLOODWAY (FEET NAVD88)	INCREASE (FEET)
Coquille River at Arago								
R	168,350	5,605	49,712	2.2	30.4	30.4	31.4	1.0
S	171,350	5,669	47,885	2.3	31.2	31.2	32.2	1.0
T	174,250	7,465	62,370	1.7	31.9	31.9	32.8	0.9
Coquille River at Myrtle Point								
U	191,520	1,106	16,630	6.4	38.0	38.0	39.0	1.0
South Fork Coquille River at Myrtle Point								
V	192,920	1,574	25,610	3.1	39.9	39.9	40.9	1.0
W	194,650	1,506	17,474	4.5	40.5	40.5	41.5	1.0
X	196,300	924	12,254	6.5	41.8	41.8	42.6	0.8
Y	196,950	1,013	15,959	5.0	42.7	42.7	43.6	0.9
Z	197,590	947[2]	16,806	4.7	43.0	43.0	44.0	1.0
AA	197,640	1,486[2]	17,025	4.7	43.1	43.1	44.1	1.0
AB	197,840	1,778	25,829	3.1	43.5	43.5	44.5	1.0
AC	200,260	2,493	32,327	2.5	43.9	43.9	44.8	0.9
AD	202,260	3,048	35,928	2.2	44.2	44.2	45.1	0.9

[1] Feet above mouth [2] Floodway bifurcated due to re-delineation

FEDERAL EMERGENCY MANAGEMENT AGENCY

COOS COUNTY, OREGON
AND UNINCORPORATED AREAS

FLOODWAY DATA

COQUILLE RIVER, SOUTH FORK COQUILLE RIVER

TABLE 13

FLOODING SOURCE		FLOODWAY			1-PERCENT-ANNUAL-CHANCE FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQUARE FEET)	MEAN VELOCITY (FEET PER SECOND)	REGULATORY (FEET NAVD88)	WITHOUT FLOODWAY (FEET NAVD88)	WITH FLOODWAY (FEET NAVD88)	INCREASE (FEET)
Millicoma River								
A	39,950	622	16,224	1.7	36.7	36.7	37.7	1.0
B	43,630	300	7,306	3.7	36.7	36.7	37.7	1.0
C	45,630	291	7,335	3.7	37.0	37.0	38.0	1.0
East Fork Millicoma River								
D	46,590	446	7,137	2.5	37.2	37.2	38.2	1.0
E	48,910	317	6,198	2.9	37.5	37.5	38.5	1.0
F	50,070	451	6,885	2.6	37.7	37.7	38.7	1.0
G	50,670	316	5,233	3.2	37.8	37.8	38.8	1.0
H	50,760	286	5,330	3.2	38.1	38.1	39.1	1.0
I	50,860	289	5,335	3.1	38.2	38.2	39.2	1.0
J	52,260	205	4,812	3.5	38.4	38.4	39.3	0.9
K	53,700	109	4,275	3.9	38.7	38.7	39.6	0.9
L	54,080	121	3,835	4.4	38.8	38.8	39.7	0.9
M	54,130	142	3,835	4.4	38.8	38.8	39.7	0.9
N	54,350	179	3,784	4.4	39.0	39.0	39.8	0.8
O	55,190	191	3,605	4.7	39.2	39.2	40.1	0.9
P	57,150	132	3,352	5.0	39.9	39.9	40.9	1.0

[1] Feet above mouth

FEDERAL EMERGENCY MANAGEMENT AGENCY

COOS COUNTY, OREGON
AND UNINCORPORATED AREAS

FLOODWAY DATA

MILLICOMA RIVER, EAST FORK MILLICOMA RIVER

TABLE 13

FLOODING SOURCE		FLOODWAY				1-PERCENT-ANNUAL-CHANCE FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	DISTANCE	WIDTH (FEET)	PRIOR STUDY WIDTH (FEET)	SECTION AREA (SQUARE FEET)	MEAN VELOCITY (FEET PER SECOND)	REGULATORY (FEET NAVD88)	WITHOUT FLOODWAY (FEET NAVD88)	WITH FLOODWAY (FEET NAVD88)	INCREASE (FEET)
West Fork Millicoma River									
A	500[1]	319		7,466	1.8	37.2	37.2	38.2	1.0
B	620[1]	259		7,221	1.8	37.2	37.2	38.2	1.0
C	1,020[1]	284		7,632	1.8	37.3	37.3	38.3	1.0
D	2,620[1]	286		9,307	1.5	37.4	37.4	38.4	1.0
E	4,580[1]	298		6,278	2.2	37.4	37.4	38.4	1.0
F	7,020[1]	327		6,501	2.1	37.6	37.6	38.6	1.0
G	7,940[1]	234		3,395	4.0	37.6	37.6	38.6	1.0
H	8,140[1]	231		3,346	4.1	37.7	37.7	38.7	1.0
I	8,190[1]	236		3,337	4.1	37.7	37.7	38.7	1.0
J	8,420[1]	219		3,175	4.3	37.8	37.8	38.8	1.0
K	10,700[1]	180		3,745	3.7	38.6	38.6	39.6	1.0
Pony Creek									
A – L[3]									
M	13,165[2]	N/A[4]	25	98	4.5	12.2	12.2	13.2	1.0
N	13,315[2]	66		210	2.1	12.2	12.2	12.9	0.7
O	13,835[2]	81		279	1.6	12.2	12.2	13.0	0.8
P	14,345[2]	42		85	4.7	12.2	12.2	12.5	0.3
Q	14,425[2]	36		95	4.2	12.2	12.2	12.5	0.3
R	14,695[2]	29		91	4.4	12.2	12.2	12.3	0.1

[1] Feet above mouth [2] Feet above Coos Bay [3] Floodway not shown for these cross sections due to tidal influence [4] Due to re-delineation floodway is now outside of SFHA at this location

FEDERAL EMERGENCY MANAGEMENT AGENCY

COOS COUNTY, OREGON
AND INCORPORATED AREAS

FLOODWAY DATA

WEST FORK MILLICOMA RIVER, PONY CREEK

TABLE 13

FLOODING SOURCE		FLOODWAY			1-PERCENT-ANNUAL-CHANCE FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	DISTANCE	WIDTH (FEET)	SECTION AREA (SQUARE FEET)	MEAN VELOCITY (FEET PER SECOND)	REGULATORY (FEET NAVD88)	WITHOUT FLOODWAY (FEET NAVD88)	WITH FLOODWAY (FEET NAVD88)	INCREASE (FEET)
Pony Creek								
S	14,985[1]	93	144	2.8	12.6	12.6	12.7	0.1
T	15,785[1]	31	98	2.2	13.6	13.6	13.8	0.2
U	16,465[1]	40	80	2.7	14.8	14.8	15.7	0.9
V	17,965[1]	27	69	3.2	19.8	19.8	20.3	0.5
Tenmile Creek								
A	17,700[2]	93	1,273	3.1	21.5	21.5	22.5	1.0
B	19,180[2]	350	3,260	1.2	22.3	22.3	23.3	1.0
C	21,380[2]	215	2,389	1.6	22.9	22.9	23.9	1.0
D	22,900[2]	812	7,235	0.5	23.1	23.1	24.1	1.0
E	24,680[2]	964	6,866	0.6	23.2	23.2	24.2	1.0
F	26,200[2]	127	1,577	2.5	23.4	23.4	24.4	1.0
G	26,570[2]	109	1,602	2.4	23.6	23.6	24.6	1.0
H	26,597[2]	112	1,602	2.4	23.7	23.7	24.7	1.0
I	26,807[2]	116	1,680	2.3	23.8	23.8	24.8	1.0

[1] Feet above Coos Bay [2] Feet above mouth

TABLE 13

FEDERAL EMERGENCY MANAGEMENT AGENCY

COOS COUNTY, OREGON
AND UNINCORPORATED AREAS

FLOODWAY DATA

PONY CREEK, TENMILE CREEK

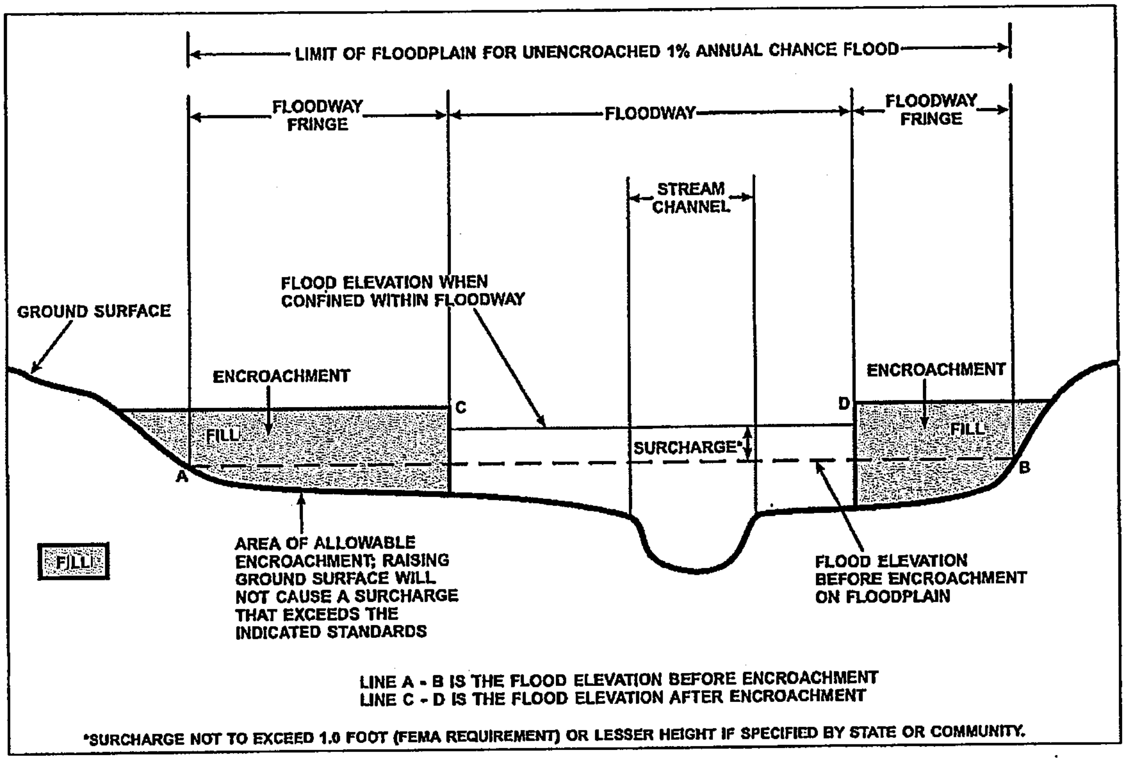


Figure 16 - Floodway Schematic

4.3 Base Flood Elevations

Areas within the community studied by detailed engineering methods have BFEs established in AE and VE Zones. These are the elevations of the 1-percent-annual-chance (base flood) relative to NAVD88. In coastal areas affected by wave action, BFEs are generally maximum at the normal open shoreline. These elevations generally decrease in a landward direction at a rate dependent on the presence of obstructions capable of dissipating the wave energy. Where possible, changes in BFEs have been shown in 1-foot increments on the FIRM. However, where the scale did not permit, 2- or 3-foot increments were sometimes used. BFEs shown in the wave action areas represent the average elevation within the zone. Current program regulations generally require that all new construction be elevated such that the first floor, including basement, is elevated to or above the BFE in AE and VE Zones.

4.4 Velocity Zones

The USACE has established the 3-foot wave height as the criterion for identifying coastal high hazard zones (USACE, 1975). This was based on a study of wave action effects on structures. This criterion has been adopted by FEMA for the determination of VE zones. Because of the additional hazards associated with high-energy waves, the NFIP regulations require much more stringent floodplain management measures in these areas, such as elevating structures on piles or piers. In addition, insurance rates in VE zones are higher than those in AE zones.

The location of the VE zone is determined by the 3-foot wave as discussed previously. The detailed analysis of wave heights performed in this study allowed a much more accurate location of the VE zone to be established. The VE zone generally extends inland to the point where the 1-percent-annual-chance stillwater flood depth is insufficient to support a 3-foot wave.

5.0 INSURANCE APPLICATIONS

For flood insurance rating purposes, flood insurance zone designations are assigned to a community based on the results of the engineering analyses. These zones are as follows:

Zone A

Zone A is the flood insurance risk zone that corresponds to the 1-percent-annual-chance floodplains that are determined in the FIS by approximate methods. Because detailed hydraulic analyses are not performed for such areas, no BFEs or base flood depths are shown within this zone.

Zone AE

Zone AE is the flood insurance risk zone that corresponds to the 1-percent-annual-chance floodplains that are determined in the FIS by detailed methods. In most instances, whole-foot BFEs derived from the detailed hydraulic analyses are shown at selected intervals within this zone.

Zone V

Zone V is the flood insurance risk zone that corresponds to the 1-percent-annual-chance coastal floodplains that have additional hazards associated with storm waves. Because approximate hydraulic analyses are performed for such areas, no BFEs are shown within this zone.

Zone VE

Zone VE is the flood insurance risk zone that corresponds to the 1-percent-annual-chance coastal floodplains that have additional hazards associated with storm waves. Whole-foot BFEs derived from the detailed hydraulic analyses are shown at selected intervals within this zone.

Zone X

Zone X is the flood insurance risk zone that corresponds to areas outside the 0.2-percent-annual-chance floodplain, areas within the 0.2-percent-annual-chance floodplain, areas of 1-percent-annual-chance flooding where average depths are less than 1 foot, areas of 1-percent-annual-chance flooding where the contributing drainage area is less than 1 square mile, and areas protected from the 1-percent-annual-chance flood by levees. No BFEs or base flood depths are shown within this zone.

Table 14 lists the flood insurance zones that each community is responsible for regulating.

Table 14. Flood Insurance Zones within Each Community

Community	Flood Zone(s)
Bandon, City of	A, AE, V, VE, X
Coos Bay, City of	A, AE, X
Coos County, Unincorporated Areas	A, AE, V, VE, X
Coquille, City of	A, AE, X
Lakeside, City of	A, AE, X
Myrtle Point, City of	A, AE, X
North Bend, City of	AE, X
Powers, City of	A, X

6.0 FLOOD INSURANCE RATE MAP

The FIRM is designed for flood insurance and floodplain management applications.

For flood insurance applications, the map designates flood insurance risk zones as described in Section 5.0 and, in the 1-percent-annual-chance floodplains that were studied by detailed methods, shows selected whole-foot BFEs or average depths. Insurance agents use the zones and BFEs in conjunction with information on structures and their contents to assign premium rates for flood insurance policies.

For floodplain management applications, the map shows by tints, screens, and symbols, the 1- and 0.2-percent-annual-chance floodplains, floodways, and the locations of selected cross sections used in the hydraulic analyses and floodway computations.

The countywide FIRM presents flooding information for the entire geographic area of Coos County. Previously, FIRMs were prepared for each incorporated community and the unincorporated areas of the County identified as flood-prone. This countywide FIRM also includes flood-hazard information that was presented separately on Flood Boundary and Floodway Maps, where applicable. Historical data relating to the maps prepared for each community are presented in Table 15, "Community Map History".

7.0 OTHER STUDIES

The Federal Insurance Administration previously published Flood Hazard Boundary Maps for Coos County (U.S. Department of Housing and Urban Development, 1975), City of Bandon (U.S. Department of Housing and Urban Development, 1976), City of Coos Bay (U.S. Department of Housing and Urban Development, 1977), City of Coquille (U.S. Department of Housing and Urban Development, 1975), the City of Myrtle Point (U.S. Department of Housing and Urban Development, 1975), the City of North Bend (U.S. Department of Housing and Urban Development, 1974). The present Flood Insurance Study is more detailed and thus supersedes the earlier maps.

The USACE Tsunami Prediction Study (Garcia and Houston, 1978) was used in the coastal flood analysis.

This report either supersedes or is compatible with all previous studies published on streams studied in this report and should be considered authoritative for the purposes of the NFIP.

8.0 LOCATION OF DATA

Information concerning the pertinent data used in the preparation of this study can be obtained by contacting FEMA, Federal Insurance and Mitigation Division, Federal Regional Center, 130 228th Street Southwest, Bothell, WA 98021-8627.

For previous versions of the FIRM Index, the Map Repository information was included on the FIRM Index itself. The map repositories are listed in Table 16 in the FIS.

COMMUNITY NAME	INITIAL IDENTIFICATION	FLOOD HAZARD BOUNDARY MAP REVISION DATE	FIRM EFFECTIVE DATE	FIRM REVISION DATE
Bandon, City of	December 21, 1973	April 16, 1976	August 15, 1984	February 18, 1998
Coos Bay, City of	August 23, 1974	March 25, 1977	August 1, 1984	
Coos County (Unincorporated Areas)	November 1, 1974	September 6, 1977	November 15, 1984	
Confederated Tribes of the Coos, Lower Umpqua and Siuslaw[1]	November 1, 1974	September 6, 1977	November 15, 1984	
Coquille, City of	November 3, 1973	October 10, 1975	September 28, 1984	
Coquille Indian Tribe[1]	November 1, 1974	September 6, 1977	November 15, 1984	
Lakeside, City of	November 22, 1977	N/A	August 1, 1984	
Myrtle Point, City of	November 23, 1973	December 5, 1975	July 16, 1984	
North Bend, City of	June 28, 1974	July 11, 1975	August 1, 1984	
Powers, City of	November 23, 1973	October 17, 1975	June 30, 1976	

[1] This community does not have map history prior to the first countywide mapping

FEDERAL EMERGENCY MANAGEMENT AGENCY

COOS COUNTY, OREGON
AND INCORPORATED AREAS

COMMUNITY MAP HISTORY

TABLE 15

9.0 BIBLIOGRAPHY AND REFERENCES

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Map	Date	Scale	Contour Interval in Feet
Reedsport	1956	1:62,500	80
Scottsburg	1955	1:62,500	80
Ivers Peak	1955	1:62,500	80
Tyee	1955	1:62,500	80
Bandon	1942	1:62,500	50
Coquille	1942	1:62,500	50
Sitkum	1955	1:62,500	80
Camas Valley	1955	1:62,500	80
Langlois	1954	1:62,500	80
Powers	1954	1:62,500	80
Bone Mountain	1954	1:62,500	80
Dutchmen Butte	1946	1:62,500	50
Agness	1954	1:62,500	80
Marial	1954	1:62,500	80
Empire	1970	1:24,000	20
North Bend	1971	1:24,000	40
Coquille	1971	1:24,000	40
McKinley	1971	1:24,000	40
Bandon	1970	1:24,000	40
Bill Peak	1971	1:24,000	40
Myrtle Point	1971	1:24,000	40
Bridge	1971	1:24,000	40
Allegany	1971	1:24,000	40
Cape Arago	1970	1:24,000	40
Charleston	1970	1:24,000	40
Coos Bay	1971	1:24,000	40
Daniels Creek	1971	1:24,000	40
Bullards	1970	1:24,000	20
Riverton	1971	1:24,000	40

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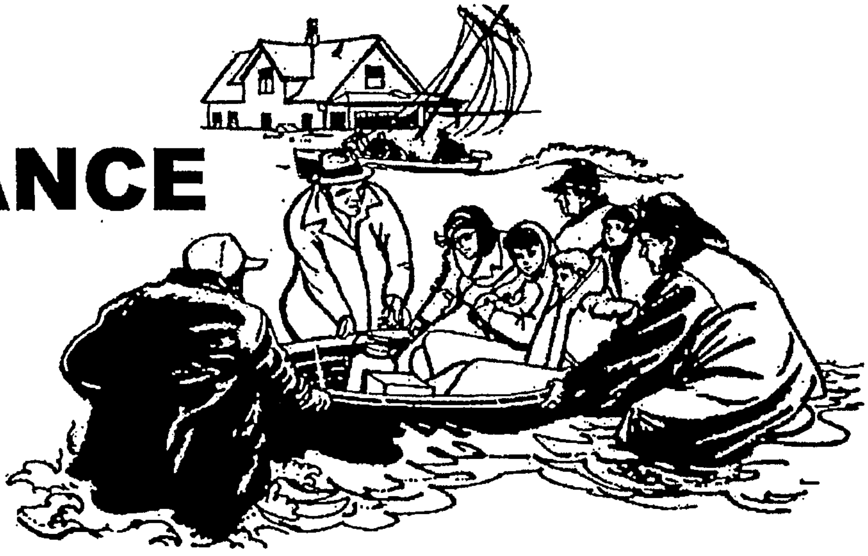
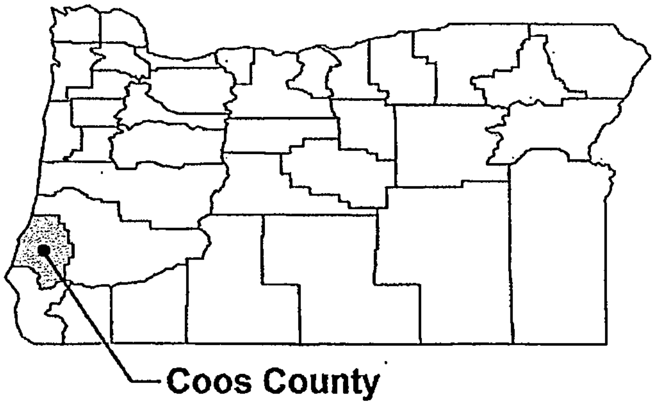
FLOOD INSURANCE STUDY

Volume 2 of 2



COOS COUNTY, OREGON
AND INCORPORATED AREAS

COMMUNITY NAME	COMMUNITY NUMBER
BANDON, CITY OF	410043
CONFEDERATED TRIBES OF COOS, LOWER UMPQUA AND SIUSLAW	410292
COOS BAY, CITY OF	410044
COOS COUNTY (UNINCORPORATED AREAS)	410042
COQUILLE, CITY OF	410045
COQUILLE INDIAN TRIBE	410102
LAKESIDE, CITY OF	410278
MYRTLE POINT, CITY OF	410047
NORTH BEND, CITY OF	410048
POWERS, CITY OF	410049



REVISED:
DECEMBER 7, 2018

U.S. DEPARTMENT OF HOMELAND SECURITY

Federal Emergency Management Agency

FLOOD INSURANCE STUDY NUMBER
41011CV002C

10.0 REVISION DESCRIPTIONS

10.1 First Revision

a. Authority and Acknowledgments

This Physical Map Revision (PMR) was revised to incorporate approximately 515 miles of approximate (Zone A) analyses in Coos County, Oregon, including the Cities of Bandon, Coos Bay, Coquille, Lakeside, Myrtle Point, North Bend, and Powers; the in the Unincorporated Areas of Coos County; the Coquille Indian Tribe; and the Confederated Tribes of Coos, Lower Umpqua, and Siuslaw. The engineering for this project was initiated in 2014 by the Oregon Department of Geology and Mineral Industries (DOGAMI) and was completed by the Strategic Alliance for Risk Reduction (STARR II) in 2016 under contract HSFE60-15-D-0005.

b. Coordination

The results of the Coos County, Oregon PMR were reviewed at a meeting held on December 13, 2016, and attended by representatives of FEMA, OR DLCD, STARR, Coos County, and the Cities of Bandon, Coos Bay, Myrtle Point, and North Bend. All problems raised at that meeting have been addressed.

c. Scope of Study

The effective FIS for Coos County (FEMA, 2014) was performed by DOGAMI for FEMA under Contract No. EMS-2008-GR-0013 in 2008. Following the 2014 Coos County update, concerns were raised regarding the overall modeling approach that had been previously used for the approximate streams in the county. Items of concern included the boundary conditions, the Manning's "n" values, the bank stations, and the ineffective flow areas that had been used. For this revised countywide FIS report, an approximate hydraulic analysis was performed using HEC-RAS hydraulic software which utilized LiDAR data. The update was completed in order to revise areas of concern as well as produce flood maps for previously unstudied areas within Coos County.

d. Important Considerations

Figures 17, 18, and 19 present important considerations for using the information contained in this revised FIS report and the FIRM and is provided in response to changes in format and content.

The jurisdictions that are included in this project area, along with the Community Identification Number (CID) for each community and the USGS 8-digit Hydrologic Unit Code (HUC-8) sub-basins affecting each, are shown in Table 16. The FIRM panel numbers that affect each community are listed. If the flood hazard data for the community is not included in this FIS Report, the location of that data is identified.

Table 17 is a list of the locations where FIRMs for Coos County can be viewed. Please note that the maps at these locations are for reference only and are not for distribution. Also, please note that only the maps for the community listed in the table are available at that particular repository. A user may need to visit another repository to view maps from an adjacent community.

Each FIRM panel may contain specific notes to the user that provide additional information regarding the flood hazard data shown on the map. However, the FIRM panel does not contain enough space to show all notes that may be relevant in helping to better understand the information on the panel. Figure 17 contains the full list of these notes.

Figure 17. FIRM Notes to Users

NOTES TO USERS

For information and questions about this map, available products associated with this FIRM including historic versions of this FIRM, how to order products, or the National Flood Insurance Program in general, please call the FEMA Map Information eXchange at 1-877-FEMA-MAP (1-877-336-2627) or visit the FEMA Map Service Center website at https://msc.fema.gov. Available products may include previously issued Letters of Map Change, a Flood Insurance Study Report, and/or digital versions of this map. Many of these products can be ordered or obtained directly from the website. Users may determine the current map date for each FIRM panel by visiting the FEMA Map Service Center website or by calling the FEMA Map Information eXchange.

Communities annexing land on adjacent FIRM panels must obtain a current copy of the adjacent panel as well as the current FIRM Index. These may be ordered directly from the Map Service Center at the number listed above.

To determine if flood insurance is available in the community, contact your insurance agent or call the National Flood Insurance Program at 1-800-638-6620.

For community and countywide map dates, refer to Table 15 in this FIS Report.

BASE FLOOD ELEVATIONS: For more detailed information in areas where Base Flood Elevations (BFEs) and/or floodways have been determined, consult the Flood Profiles and Floodway Data and/or Summary of Stillwater Elevations tables within this FIS Report. Use the flood elevation data within the FIS Report in conjunction with the FIRM for construction and/or floodplain management.

FLOODWAY INFORMATION: Boundaries of the floodways were computed at cross sections and interpolated between cross sections. The floodways were based on hydraulic considerations with regard to requirements of the National Flood Insurance Program. Floodway widths and other pertinent floodway data are provided in the FIS Report for this jurisdiction.

Figure 17. FIRM Notes to Users *(continued)*

FLOOD CONTROL STRUCTURE INFORMATION: Certain areas not in Special Flood Hazard Areas may be protected by flood control structures. Refer to Section 4.3 "Non-Levee Flood Protection Measures" of this FIS Report for information on flood control structures for this jurisdiction.

PROJECTION INFORMATION: The projection used in the preparation of the map was Universal Transverse Mercator (UTM Zone 18). The horizontal datum was North American Datum 1983. Differences in datum, spheroid, projection or State Plane zones used in the production of FIRMs for adjacent jurisdictions may result in slight positional differences in map features across jurisdiction boundaries. These differences do not affect the accuracy of the FIRM.

ELEVATION DATUM: Flood elevations on the FIRM are referenced to North American Vertical Datum of 1988. These flood elevations must be compared to structure and ground elevations referenced to the same vertical datum. For information regarding conversion between the National Geodetic Vertical Datum of 1929 and North American Vertical Datum of 1988, visit the National Geodetic Survey website at http://www.ngs.noaa.gov/

Local vertical monuments may have been used to create the map. To obtain current monument information, please contact the appropriate local community listed in Table 16 of this FIS Report.

BASE MAP INFORMATION: Base map information shown on the FIRM was provided by various sources. For information about base maps, refer to Section 6.2 "Base Map" in this FIS Report.

The map reflects more detailed and up-to-date stream channel configurations than those shown on the previous FIRM for this jurisdiction. The floodplains and floodways that were transferred from the previous FIRM may have been adjusted to conform to these new stream channel configurations. As a result, the Flood Profiles and Floodway Data tables may reflect stream channel distances that differ from what is shown on the map.

Corporate limits shown on the map are based on the best data available at the time of publication. Because changes due to annexations or de-annexations may have occurred after the map was published, map users should contact appropriate community officials to verify current corporate limit locations.

NOTES FOR FIRM INDEX

REVISIONS TO INDEX: As new studies are performed and FIRM panels are updated within Coos County, Oregon and Incorporated Areas, corresponding revisions to the FIRM Index will be incorporated within the FIS Report to reflect the effective dates of those panels. Please refer to Table 15 of this FIS Report to determine the most recent FIRM revision date for each community. The most recent FIRM panel effective date will correspond to the most recent index date.

SPECIAL NOTES FOR SPECIFIC FIRM PANELS

This Notes to Users section was created specifically for Coos County, Oregon and Incorporated Areas, effective date December 7, 2018.

Figure 17. FIRM Notes to Users *(continued)*

FLOOD RISK REPORT: A Flood Risk Report (FRR) may be available for many of the flooding sources and communities referenced in this FIS Report. The FRR is provided to increase public awareness of flood risk by helping communities identify the areas within their jurisdictions that have the greatest risks. Although non-regulatory, the information provided within the FRR can assist communities in assessing and evaluating mitigation opportunities to reduce these risks. It can also be used by communities developing or updating flood risk mitigation plans. These plans allow communities to identify and evaluate opportunities to reduce potential loss of life and property. However, the FRR is not intended to be the final authoritative source of all flood risk data for a project area; rather, it should be used with other data sources to paint a comprehensive picture of flood risk.

Each FIRM panel contains an abbreviated legend for features shown on the maps. However, the FIRM panel does not contain enough space to show the legend for all map features. Figure 18 shows the full legend of all map features. Note that not all of these features may appear on the FIRM panels in Coos County.

Figure 18. Map Legend for FIRM

SPECIAL FLOOD HAZARD AREAS: *The 1% annual chance flood, also known as the base flood or 100-year flood, has a 1% chance of happening or being exceeded each year. Special Flood Hazard Areas are subject to flooding by the 1% annual chance flood. The Base Flood Elevation is the water-surface elevation of the 1% annual chance flood. The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights. See note for specific types. If the floodway is too narrow to be shown, a note is shown.*

🟦	Special Flood Hazard Areas subject to inundation by the 1% annual chance flood (Zones A, AE, AH, AO, AR, A99, V and VE)
Zone A	The flood insurance rate zone that corresponds to the 1% annual chance floodplains. No base (1% annual chance) flood elevations (BFEs) or depths are shown within this zone.
Zone AE	The flood insurance rate zone that corresponds to the 1% annual chance floodplains. Base flood elevations derived from the hydraulic analyses are shown within this zone, either at cross section locations or as static whole-foot elevations that apply throughout the zone.
Zone AH	The flood insurance rate zone that corresponds to the areas of 1% annual chance shallow flooding (usually areas of ponding) where average depths are between 1 and 3 feet. Whole-foot BFEs derived from the hydraulic analyses are shown at selected intervals within this zone.
Zone AO	The flood insurance rate zone that corresponds to the areas of 1% annual chance shallow flooding (usually sheet flow on sloping terrain) where average depths are between 1 and 3 feet. Average whole-foot depths derived from the hydraulic analyses are shown within this zone.
Zone AR	The flood insurance rate zone that corresponds to areas that were formerly protected from the 1% annual chance flood by a flood control system that was subsequently decertified. Zone AR indicates that the former flood control system is being restored to provide protection from the 1% annual chance or greater flood.

Figure 18. Map Legend for FIRM *(continued)*

Zone A99	The flood insurance rate zone that corresponds to areas of the 1% annual chance floodplain that will be protected by a Federal flood protection system where construction has reached specified statutory milestones. No base flood elevations or flood depths are shown within this zone.
Zone V	The flood insurance rate zone that corresponds to the 1% annual chance coastal floodplains that have additional hazards associated with storm waves. Base flood elevations are not shown within this zone.
Zone VE	Zone VE is the flood insurance rate zone that corresponds to the 1% annual chance coastal floodplains that have additional hazards associated with storm waves. Base flood elevations derived from the coastal analyses are shown within this zone as static whole-foot elevations that apply throughout the zone.
▨	Regulatory Floodway determined in Zone AE.
OTHER AREAS OF FLOOD HAZARD	
	Shaded Zone X: Areas of 0.2% annual chance flood hazards and areas of 1% annual chance flood hazards with average depths of less than 1 foot or with drainage areas less than 1 square mile.
▨	Future Conditions 1% Annual Chance Flood Hazard – Zone X: The flood insurance rate zone that corresponds to the 1% annual chance floodplains that are determined based on future-conditions hydrology. No base flood elevations or flood depths are shown within this zone.
▨	Zone X Protected by Accredited Levee: Areas protected by an accredited levee, dike or other flood control structures. See Notes to Users for important information.
OTHER AREAS	
	Zone D (Areas of Undetermined Flood Hazard): The flood insurance rate zone that corresponds to unstudied areas where flood hazards are undetermined, but possible
NO SCREEN	Unshaded Zone X: Areas determined to be outside the 0.2% annual chance floodplain
FLOOD HAZARD AND OTHER BOUNDARY LINES	
▬	Flood Zone Boundary (white line)
═	Limit of Study
—	Jurisdiction Boundary
━	Limit of Moderate Wave Action (LiMWA): Indicates the inland limit of the area affected by waves greater than 1.5 feet

Figure 18. Map Legend for FIRM *(continued)*

GENERAL STRUCTURES

Aqueduct *Channel* *Culvert* *Storm Sewer*	Channel, Culvert, Aqueduct, or Storm Sewer
Dam *Jetty* *Weir*	Dam, Jetty, Weir
ǀǀǀǀǀǀǀǀǀǀǀǀǀǀǀǀǀǀ	Levee, Dike or Floodwall
>—< *Bridge*	Bridge

COASTAL BARRIER RESOURCES SYSTEM (CBRS) AND OTHERWISE PROTECTED AREAS (OPA): *CBRS areas and OPAs are normally located within or adjacent to Special Flood Hazard Areas. See Notes to Users for important information.*

▨ **CBRS AREA** **09/30/2009**	Coastal Barrier Resources System Area: Labels are shown to clarify where this area shares a boundary with an incorporated area or overlaps with the floodway.
▨ **OTHERWISE PROTECTED AREA** **09/30/2009**	Otherwise Protected Area

REFERENCE MARKERS

● 22.0	River mile Markers

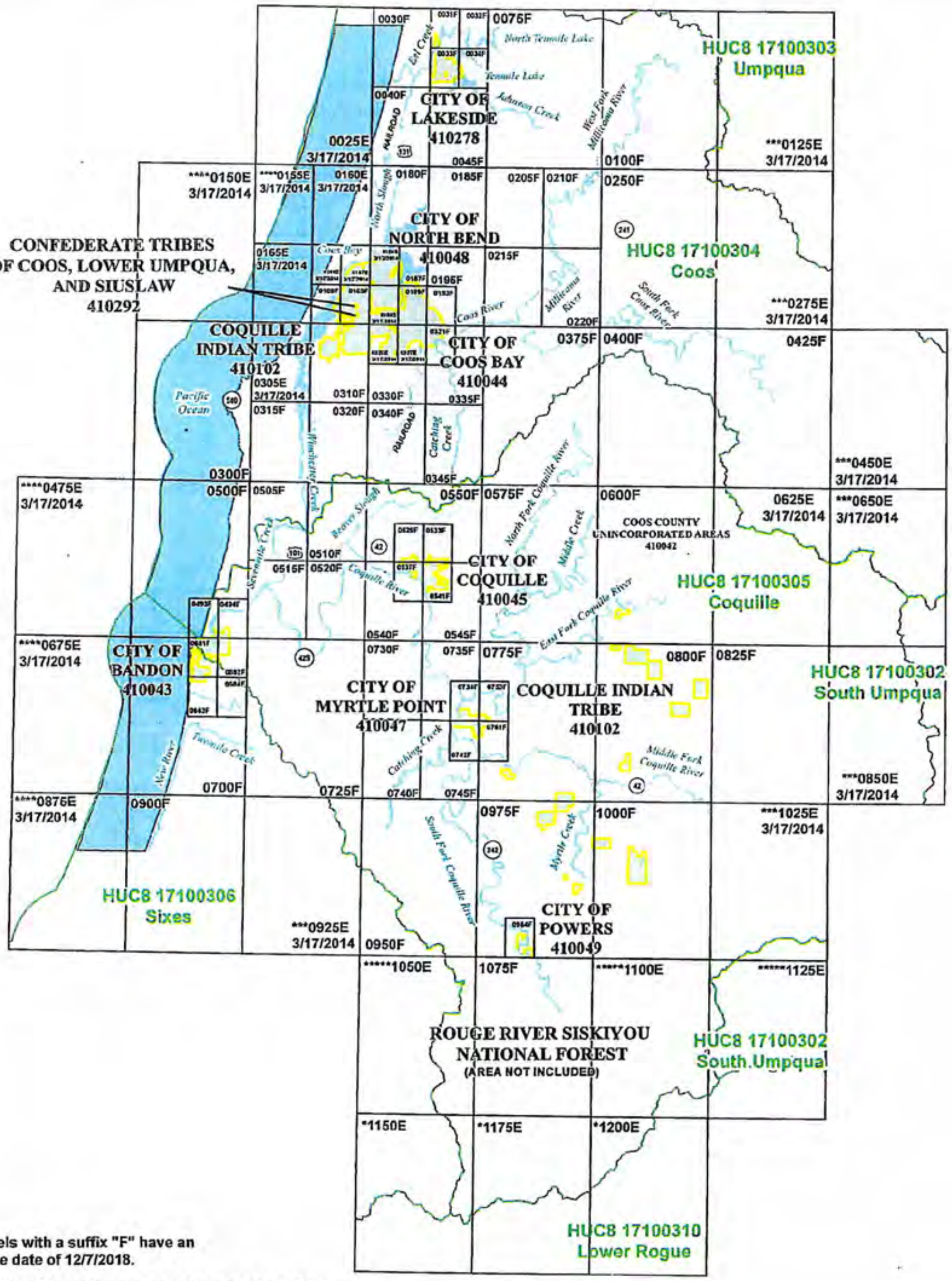
CROSS SECTION & TRANSECT INFORMATION

⬡B —— 20.2	Lettered Cross Section with Regulatory Water Surface Elevation (BFE)
⬡5280 —— 21.1	Numbered Cross Section with Regulatory Water Surface Elevation (BFE)
—— 17.5	Unlettered Cross Section with Regulatory Water Surface Elevation (BFE)
⑧ - - - - - - -	Coastal Transect

Figure 18. Map Legend for FIRM *(continued)*

—— - ——— -	Profile Baseline: Indicates the modeled flow path of a stream and is shown on FIRM panels for all valid studies with profiles or otherwise established base flood elevation.
—— - - ——— - -	Coastal Transect Baseline: Used in the coastal flood hazard model to represent the 0.0-foot elevation contour and the starting point for the transect and the measuring point for the coastal mapping.
~~ 513 ~~~~	Base Flood Elevation Line (shown for flooding sources for which no cross sections or profile are available)
ZONE AE **(EL 16)**	Static Base Flood Elevation value (shown under zone label)
ZONE AO **(DEPTH 2)**	Zone designation with Depth
ZONE AO **(DEPTH 2)** **(VEL 15 FPS)**	Zone designation with Depth and Velocity
BASE MAP FEATURES	
Missouri Creek	River, Stream or Other Hydrographic Feature
234	Interstate Highway
234	U.S. Highway
234	State Highway
234	County Highway
MAPLE LANE	Street, Road, Avenue Name, or Private Drive if shown on Flood Profile
—+— *RAILROAD*	Railroad
————	Horizontal Reference Grid Line
—	Horizontal Reference Grid Ticks
+	Secondary Grid Crosshairs
Land Grant	Name of Land Grant
7	Section Number
R. 43 W. T. 22 N.	Range, Township Number
$^{42}76^{000\text{m}}$E	Horizontal Reference Grid Coordinates (UTM)
365000 FT	Horizontal Reference Grid Coordinates (State Plane)
80° 16' 52.5"	Corner Coordinates (Latitude, Longitude)

Figure 19. FIRM Index



All panels with a suffix "F" have an effective date of 12/7/2018.

ATTENTION: The corporate limits shown on this FIRM Index are based on the best information available at the time of publication. As such, they may be more current than those shown on FIRM panels Issued before 12/7/2018.

1 inch = 30,000 feet

0 16,000 32,000 64,000 Feet

Map Projection:
Universal Transverse Mercator Zone 10 North;
North American Datum of 1983

THE INFORMATION DEPICTED ON THIS MAP AND SUPPORTING DOCUMENTATION ARE ALSO AVAILABLE IN DIGITAL FORMAT AT

HTTP://MSC.FEMA.GOV

SEE FLOOD INSURANCE STUDY FOR ADDITIONAL INFORMATION

COUNTY LOCATOR

NATIONAL FLOOD INSURANCE PROGRAM

FLOOD INSURANCE RATE MAP INDEX

COOS COUNTY, OR AND INCORPORATED AREAS

PANELS PRINTED:

0025, 0030, 0031, 0032, 0033, 0034, 0040, 0045, 0075, 0100, 0160, 0165, 0166, 0167, 0168, 0169, 0180, 0185, 0186, 0187, 0188, 0189, 0193, 0195, 0205, 0210, 0215, 0220, 0250, 0300, 0305, 0310, 0315, 0320, 0326, 0327, 0330, 0331, 0335, 0340, 0345, 0375, 0400, 0425, 0493, 0494, 0500, 0505, 0510, 0515, 0520, 0529, 0533, 0537, 0540, 0541, 0545, 0550, 0575, 0600, 0625, 0681, 0682, 0683, 0684, 0700, 0725, 0730, 0734, 0735, 0740, 0742, 0745, 0753, 0781, 0775, 0800, 0825, 0900, 0950, 0964, 0975, 1000, 1075

MAP NUMBER
41011CINDOC

MAP REVISED
DECEMBER 7, 2018

* PANEL NOT PRINTED - AREA NOT INCLUDED
** PANEL NOT PRINTED - AREA NOT INCLUDED/NO SPECIAL FLOOD HAZARD AREAS
*** PANEL NOT PRINTED - NO SPECIAL FLOOD HAZARD AREAS
**** PANEL NOT PRINTED - OPEN WATER AREA
***** PANEL NOT PRINTED - NO SFHA EXCEPT NATIONAL FOREST WHICH IS AREA NOT INCLUDED

Table 16. Listing of NFIP Jurisdictions

Community	CID	HUC-8 Sub-Basin(s)	Located on FIRM Panel(s)	If Not Included, Location of Flood Hazard Data
Bandon, City of	410043	17100305 17100306	41011C0493F, 41011C0494F, 41011C0681F, 41011C0682F, 41011C0683F	
Confederated Tribes of Coos, Lower Umpqua and Siuslaw	410292	17100304	41011C0169F, 41011C0195F, 41011C0186E, 41011C0188E, 41011C0310F	
Coos Bay, City of	410044	17100304	41011C0167E, 41011C0168F, 41011C0169F, 41011C0187F, 41011C0188E, 41011C0189F, 41011C0193F, 41011C0310F, 41011C0326E, 41011C0327E, 41011C0331F	
Coos County (Unincorporated Areas)	410042	17100302 17100303 17100304 17100305 17100306 17100310	41011C0025E, 41011C0030F, 41011C0031F, 41011C0032F, 41011C0033F, 41011C0034F, 41011C0040F, 41011C0045F, 41011C0075F, 41011C0100F, 41011C0125E*, 41011C0150E*, 41011C0155E*, 41011C0160E, 41011C0165E, 41011C0166E, 41011C0167E, 41011C0168F, 41011C0169F, 41011C0180F, 41011C0185F, 41011C0186E, 41011C0187F, 41011C0188E, 41011C0189F, 41011C0193F, 41011C0195F, 41011C0205F, 41011C0210F, 41011C0215F, 41011C0220F, 41011C0250F, 41011C0275E*, 41011C0300F, 41011C0305E, 41011C0310F, 41011C0315F, 41011C0320F, 41011C0326E, 41011C0327E, 41011C0330F, 41011C0331F, 41011C0335F, 41011C0340F, 41011C0345F, 41011C0375F, 41011C0400F, 41011C0425F, 41011C0450E*, 41011C0475E*, 41011C0493F, 41011C0494F, 41011C0500F, 41011C0505F, 41011C0510F, 41011C0515F, 41011C0520F, 41011C0529F, 41011C0533F, 41011C0537F, 41011C0540F, 41011C0541F, 41011C0545F, 41011C0550F,	

Table 16. Listing of NFIP Jurisdictions *(continued)*

Coos County (Unincorporated Areas) *(continued)*			41011C0575F, 41011C0600F, 41011C0625E, 41011C0650E*, 41011C0675E*, 41011C0681F, 41011C0682F, 41011C0683F, 41011C0684F, 41011C0700F, 41011C0725F, 41011C0730F, 41011C0734F, 41011C0735F, 41011C0740F, 41011C0742F, 41011C0745F, 41011C0753F, 41011C0761F, 41011C0775F, 41011C0800F, 41011C0825F, 41011C0850E*, 41011C0875E*, 41011C0900F, 41011C0925E*, 41011C0950F, 41011C0964F, 41011C0975F, 41011C1000F, 41011C1025E*, 41011C1050E*, 41011C1075F, 41011C1100E*, 41011C1125E*, 41011C1150E*, 41011C1175E*, 41011C1200E*	
Coquille, City of	410045	17100305	41011C0529F, 41011C0533F, 41011C0537F, 41011C0541F	
Coquille Indian Tribe	410102	17100304 17100305	41011C0168F, 41011C0169F, 41011C0188E, 41011C0189F, 41011C0310F, 41011C0600F, 41011C0681F, 41011C0775F, 41011C0800F, 41011C0975F, 41011C1000F	
Lakeside, City of	410278	17100304	41011C0030F, 41011C0031F, 41011C0033F, 41011C0034F	
Myrtle Point, City of	410047	17100305	41011C0734F, 41011C0742F, 41011C0753F, 41011C0761F	
North Bend, City of	410048	17100304	41011C0167E, 41011C0169F, 41011C0186E, 41011C0187F, 41011C0188E, 41011C0189F	
Powers, City of	410049	17100305	41011C0964F	

*Panel not printed

Table 17. Map Repositories

Community	Address	City	State	Zip Code
Bandon, City of	City Hall, 555 Highway 101	Bandon	OR	97411
Confederated Tribes of Coos, Lower Umpqua and Siuslaw	Tribal Headquarters, 1245 Fulton Avenue	Coos Bay	OR	97420
Coos Bay, City of	City Hall, 500 Central Avenue	Coos Bay	OR	97420
Coos County (Unincorporated Areas)	Coos County Courthouse, 250 North Baxter Street	Coquille	OR	97423
Coquille, City of	City Hall, 851 North Central Boulevard	Coquille	OR	97423
Coquille Indian Tribe	Administration Building, 3050 Tremont Avenue	North Bend	OR	97459
Lakeside, City of	City Hall, 915 North Lake Road	Lakeside	OR	97449
Myrtle Point, City of	City Hall, 424 5th Street	Myrtle Point	OR	97458
North Bend, City of	City Hall, 835 California Street	North Bend	OR	97459
Powers, City of	City Hall, 275 Fir Street	Powers	OR	97466

e. Flood Protection Measures

According to the National Levee Database, there are no levees in Coos County that have been demonstrated by the community or levee owner(s) to meet the requirements of 44 CFR Part 65.10 of the NFIP regulations, as it relates to the levee's capacity to provide 1% annual chance flood protection. Please refer to the Notice to Flood Insurance Study Users page at the front of this FIS report for more information.

f. Hydrology

DOGAMI estimated the discharges that were used for the model, except for the Coquille River between the cities of Riverton and Myrtle Point, where effective discharges were available for a detailed portion of study located within the area of approximate study.

Portions of the Coquille River were previously mapped as Zone A, and detailed (Zone AE) study on the effective FIRM, with considerable differences in the discharges for the Zone A and Zone AE reaches. Because of these differences, water surface elevations did not match at the tie-in areas between these reaches. In order to resolve the discrepancies, the Set Water Surface Elevation option was used in the HEC-RAS models in order to match the water surface elevations.

g. Hydraulics

The hydraulic model used for this flood study was the USACE Hydraulic Engineering Center River Analysis System (HEC-RAS), version 4.1.0 (USACE, 2010). Steady flow HEC-RAS models were developed for the 50-, 20-, 10-, 4-, 2-, 1-, and 0.2-percent-annual-chance-flood events.

Topographic data for the floodplain models was developed using LiDAR data from Oregon Department of Geology and Mineral Industries (Oregon LiDAR Consortium, 2009). Topographic data was converted into 1-meter and 3-meter digital elevation models (DEM). The data is in UTM Zone 10 coordinates system, (units feet), horizontal datum NAD83, vertical datum NAVD 88, (units feet). No field survey data was used in this analysis.

The downstream starting water-surface elevations in the HEC-RAS models were estimated assuming normal depth.

Stream and valley cross sections were placed at representative locations along the stream centerline perpendicular to the flow direction. Cross section spacing varied for all streams. Cross section geometries were obtained from the DEM topography.

Use of ineffective flow areas were limited for this analysis. Ineffective flow areas were used only for areas of extreme expansion and contraction, and for areas of divided flow.

For this analysis, Manning's "n" values of 0.03-0.04 were used for channel areas, and 0.05-0.12 were used on overbank areas.

Expansion and contraction values of 0.1 and 0.03 were used at all cross sections in this analysis.

h. Letters of Map Revision

There were no Letters of Map Change (LOMCs) incorporated during this processing of this PMR.

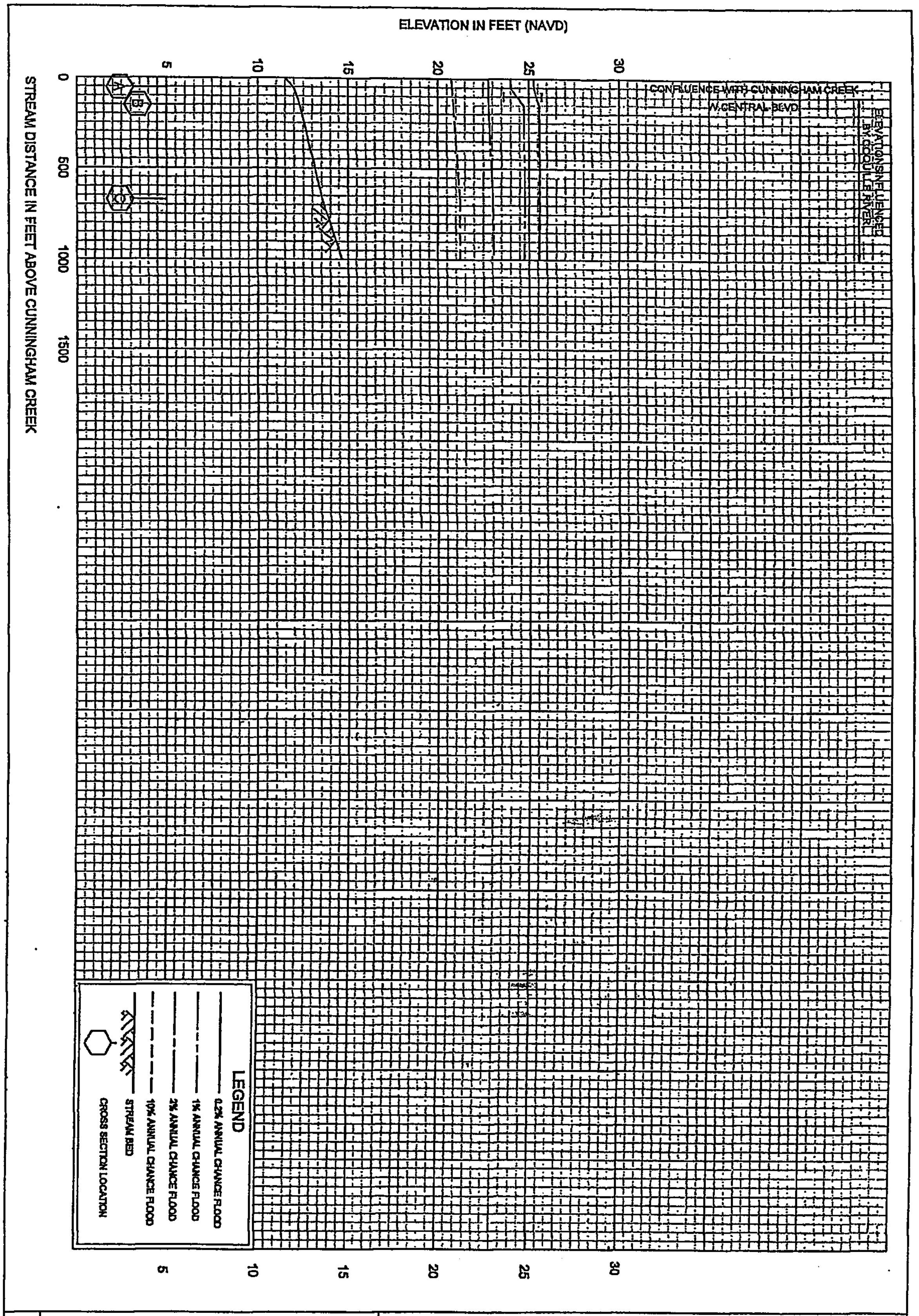
i. Bibliography for the First Revision

Federal Emergency Management Agency, Flood Insurance Study, Coos County, OR and Incorporated Areas, March 17, 2014.

Federal Emergency Management Agency, Guidelines and Specifications for Flood Hazard Mapping Partners, U.S. Department of Homeland Security, November, 2009.

Hydrologic Engineering Center, HEC-RAS River Analysis System, Version 4.1, U.S. Army Corps of Engineers, Davis, California, Jan 2010.

Oregon LiDAR Consortium, 1-Meter Resolution Bare Earth LiDAR Digital Elevation Models for Coos County, Oregon South Coast Project, Acquired June-August 2008, May 2009.



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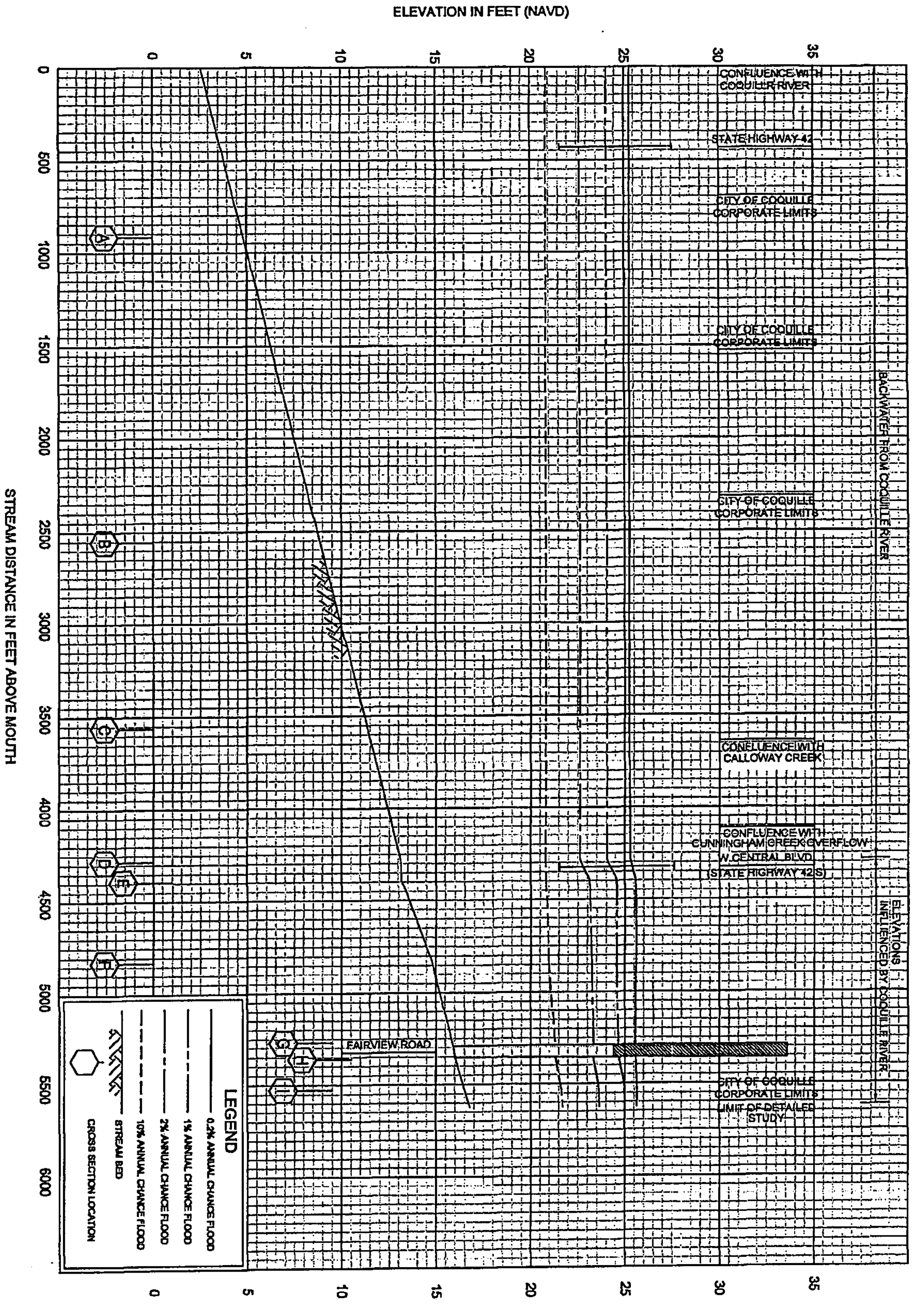
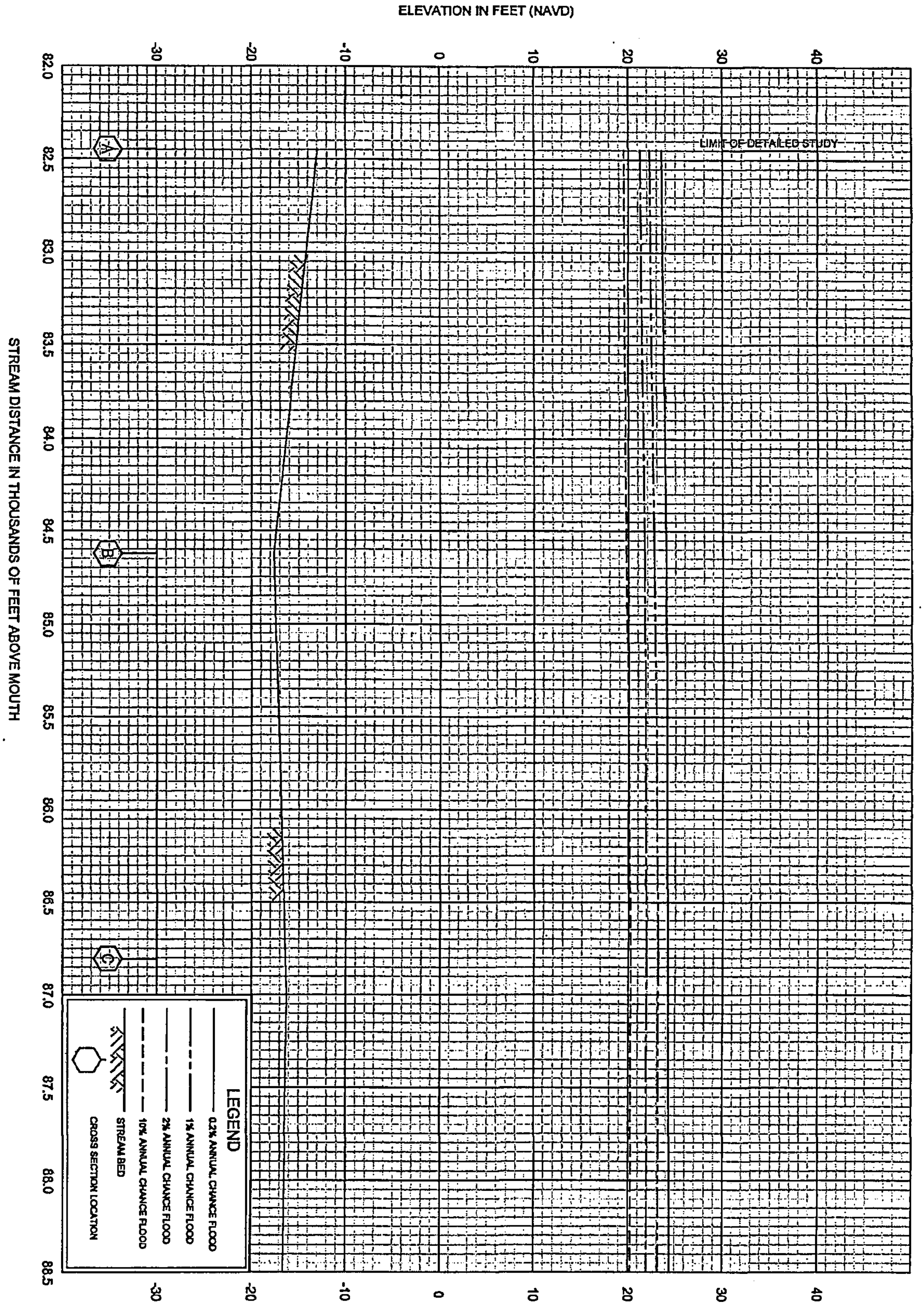


FEDERAL EMERGENCY MANAGEMENT AGENCY COOS COUNTY, OR AND INCORPORATED AREAS	FLOOD PROFILES CUNNINGHAM CREEK

02P



03P

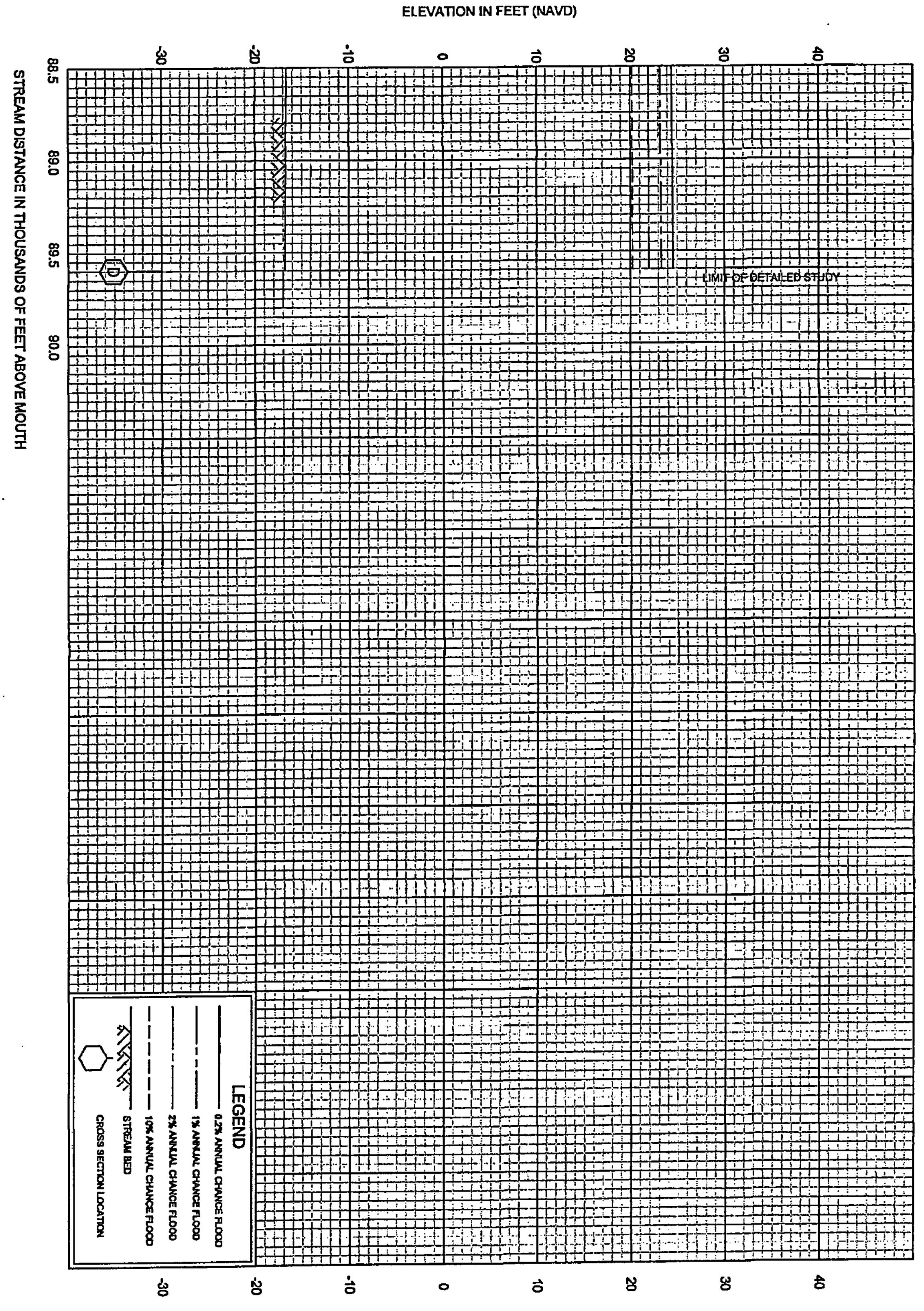
FEDERAL EMERGENCY MANAGEMENT AGENCY

COOS COUNTY, OR

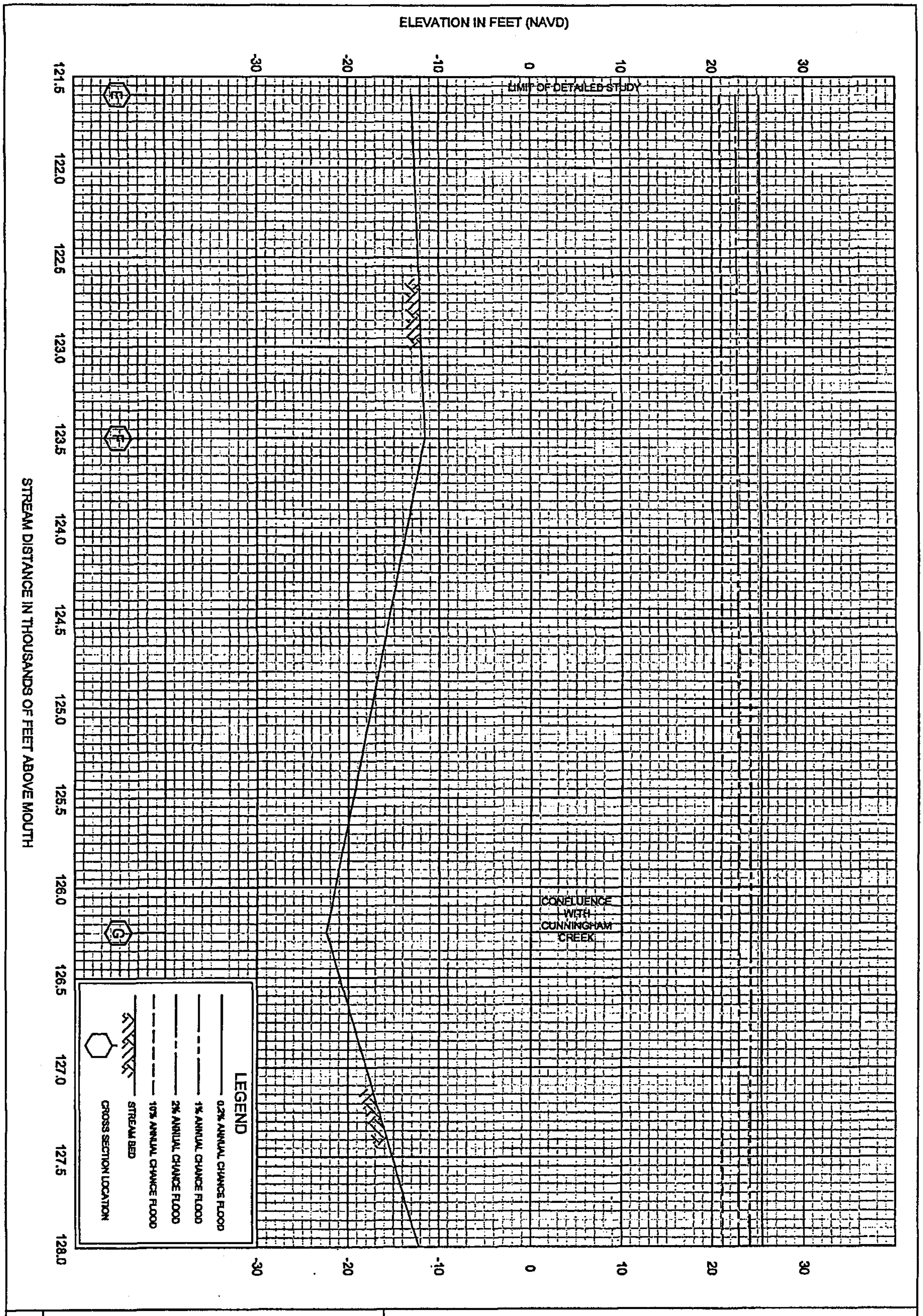
AND INCORPORATED AREAS

FLOOD PROFILES

COQUILLE RIVER AT RIVERTON



04P	FEDERAL EMERGENCY MANAGEMENT AGENCY COOS COUNTY, OR AND INCORPORATED AREAS	FLOOD PROFILES COQUILLE RIVER AT RIVERTON

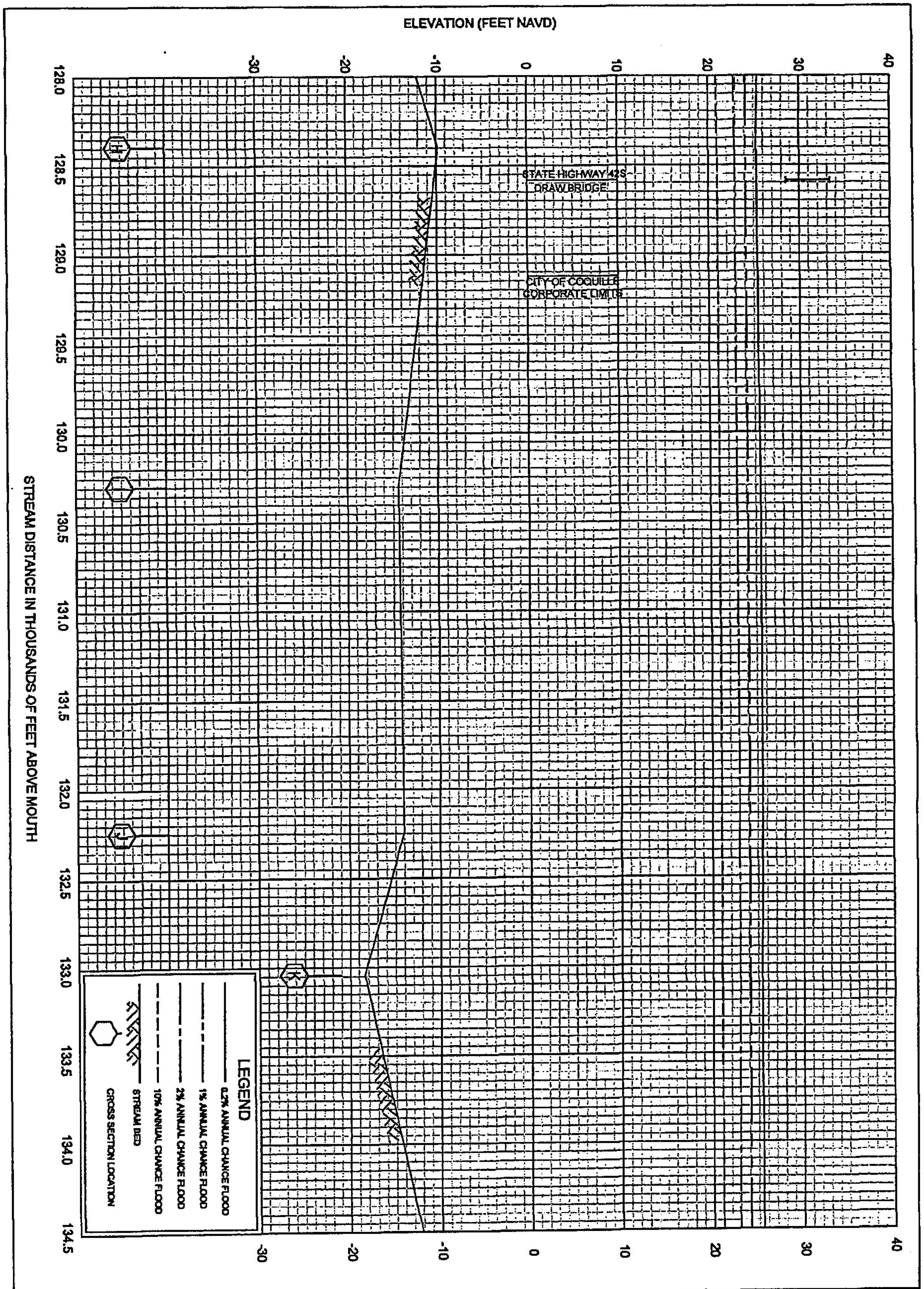


05P

FEDERAL EMERGENCY MANAGEMENT AGENCY
COOS COUNTY, OR
AND INCORPORATED AREAS

FLOOD PROFILES

COQUILLE RIVER AT COQUILLE



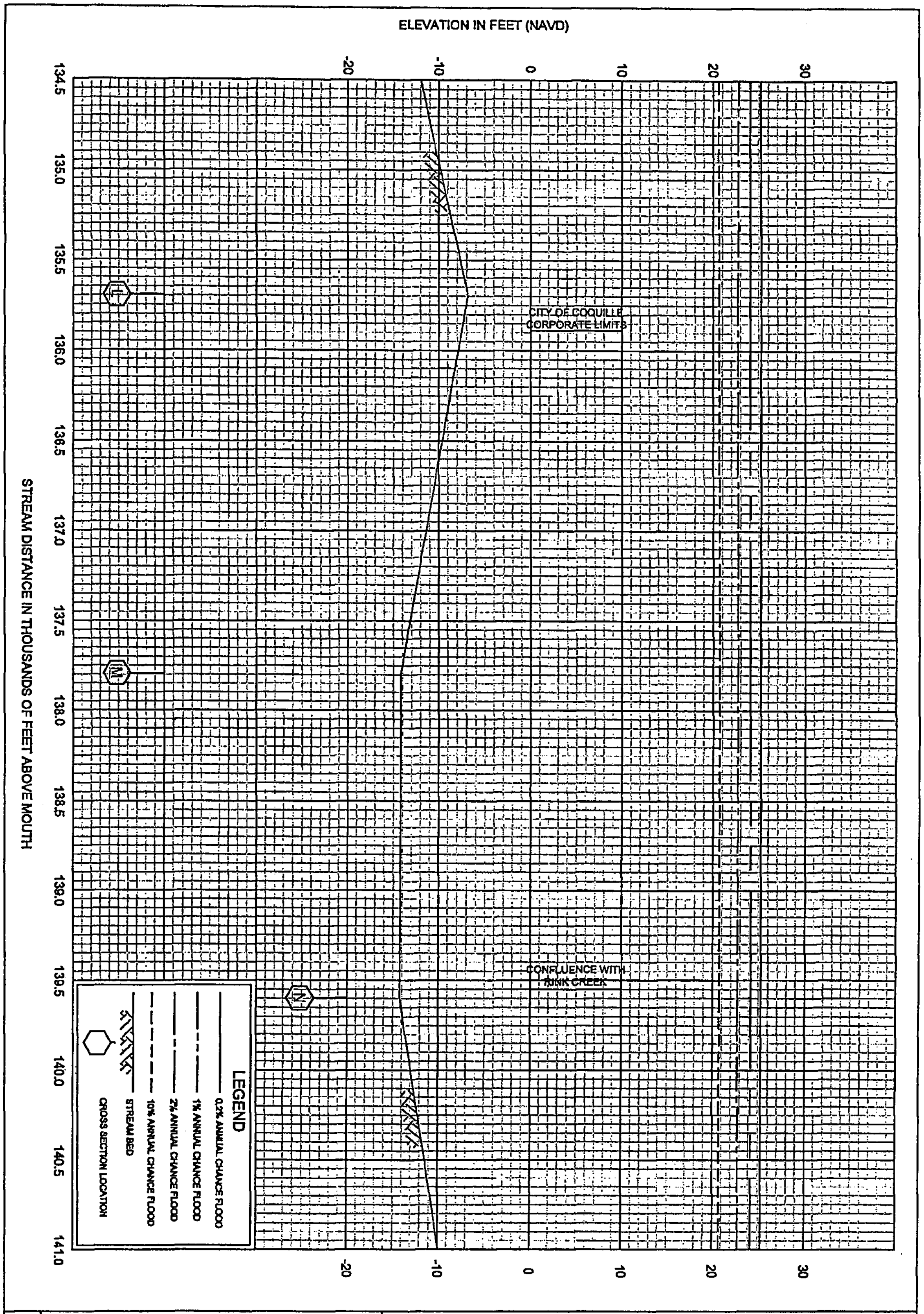
06P

FEDERAL EMERGENCY MANAGEMENT AGENCY

COOS COUNTY, OR
AND INCORPORATED AREAS

FLOOD PROFILES

COQUILLE RIVER AT COQUILLE



07P

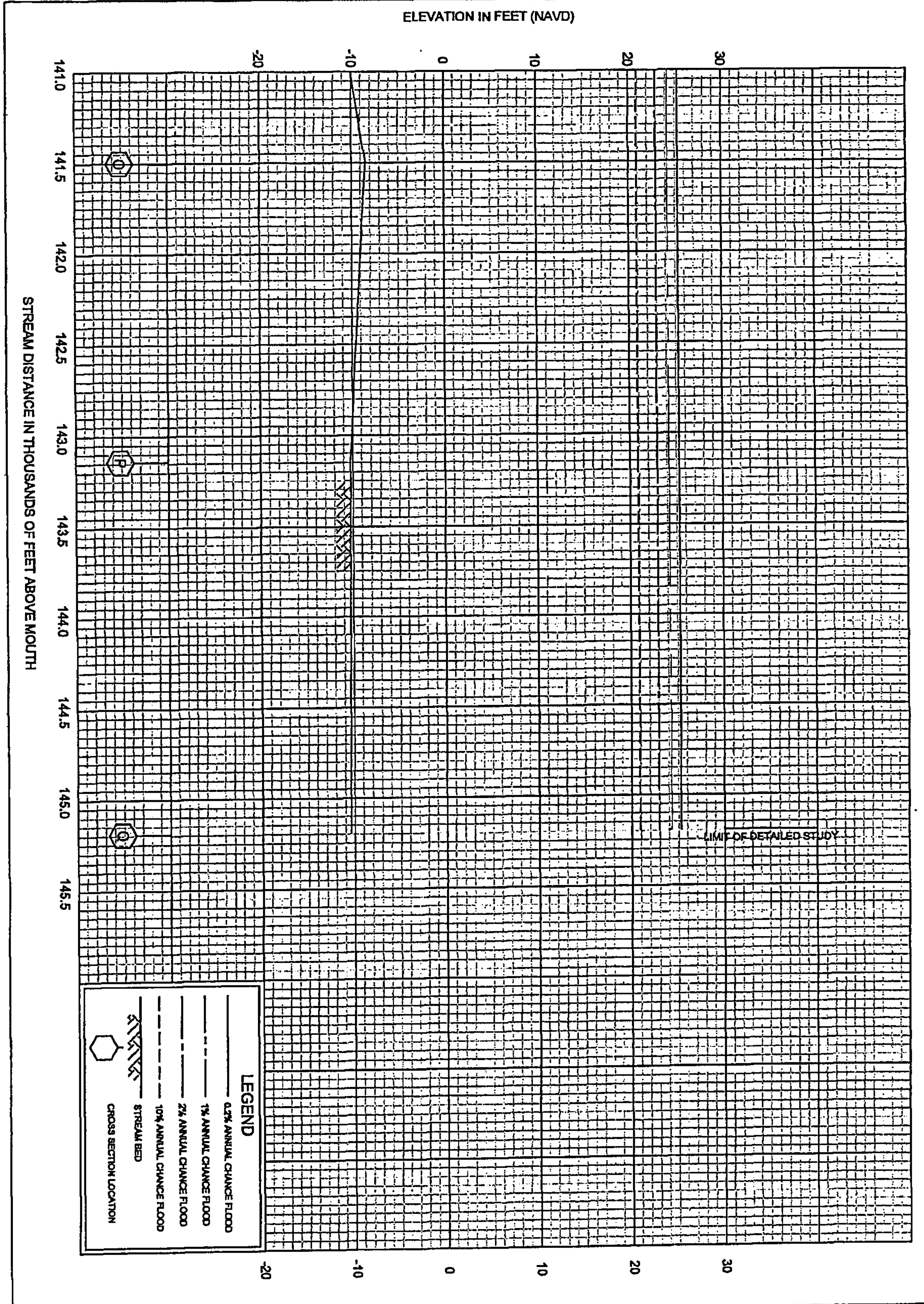
FEDERAL EMERGENCY MANAGEMENT AGENCY

COOS COUNTY, OR

AND INCORPORATED AREAS

FLOOD PROFILES

COQUILLE RIVER AT COQUILLE



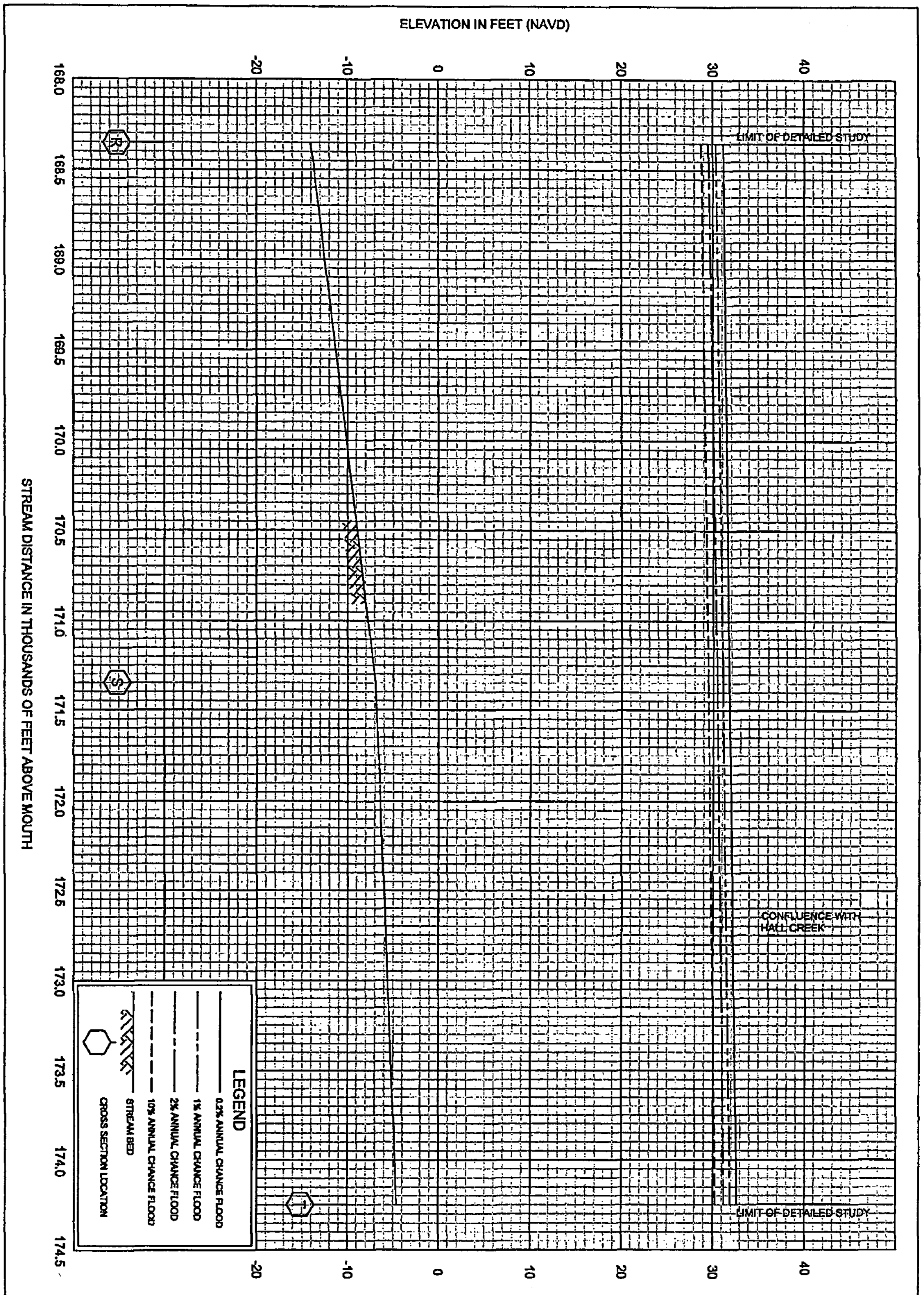
08P

FEDERAL EMERGENCY MANAGEMENT AGENCY

COOS COUNTY, OR
AND INCORPORATED AREAS

FLOOD PROFILES

COQUILLE RIVER AT COQUILLE



FEDERAL EMERGENCY MANAGEMENT AGENCY

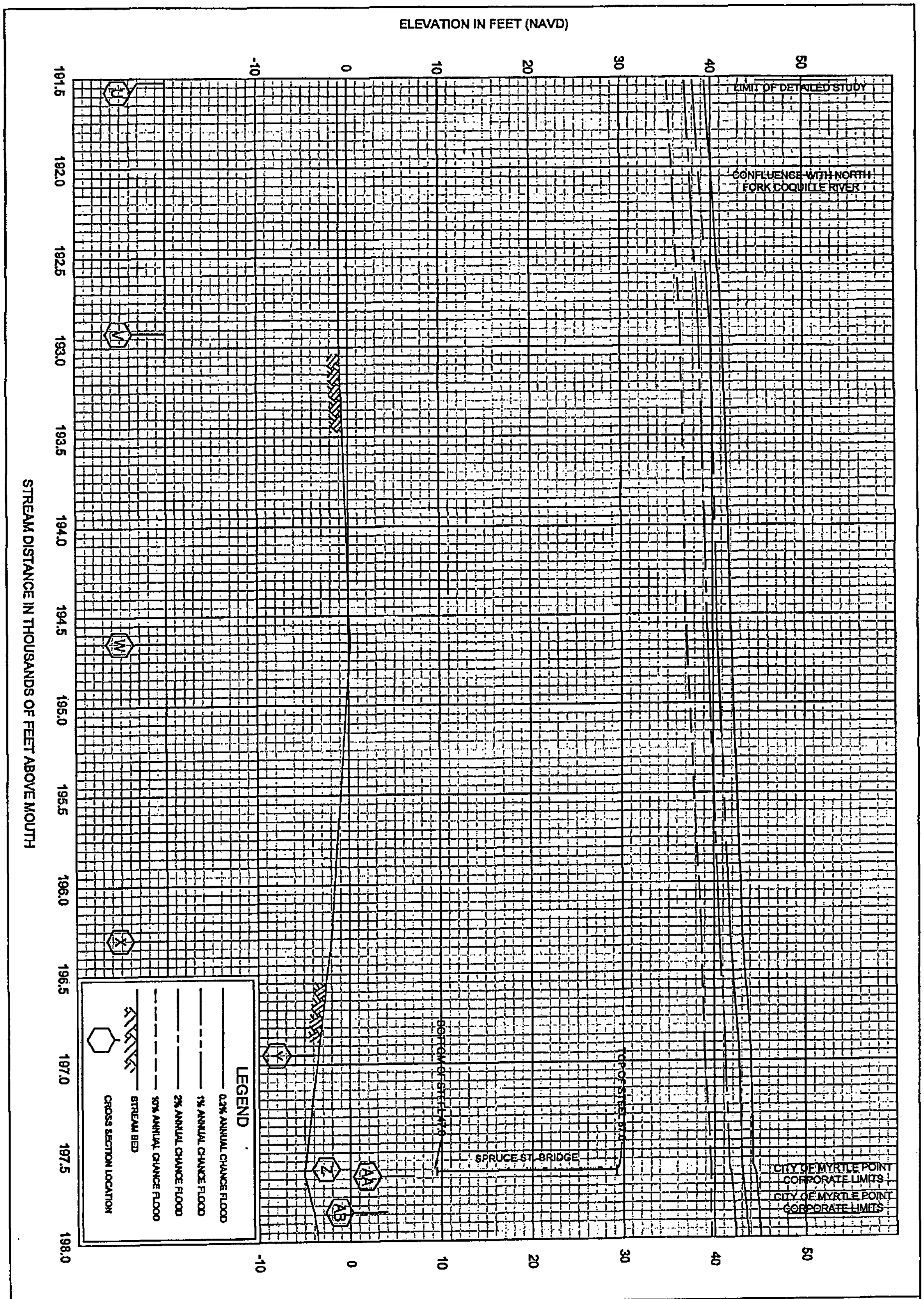
COOS COUNTY, OR

AND INCORPORATED AREAS

FLOOD PROFILES

COQUILLE RIVER AT ARAGO

09P



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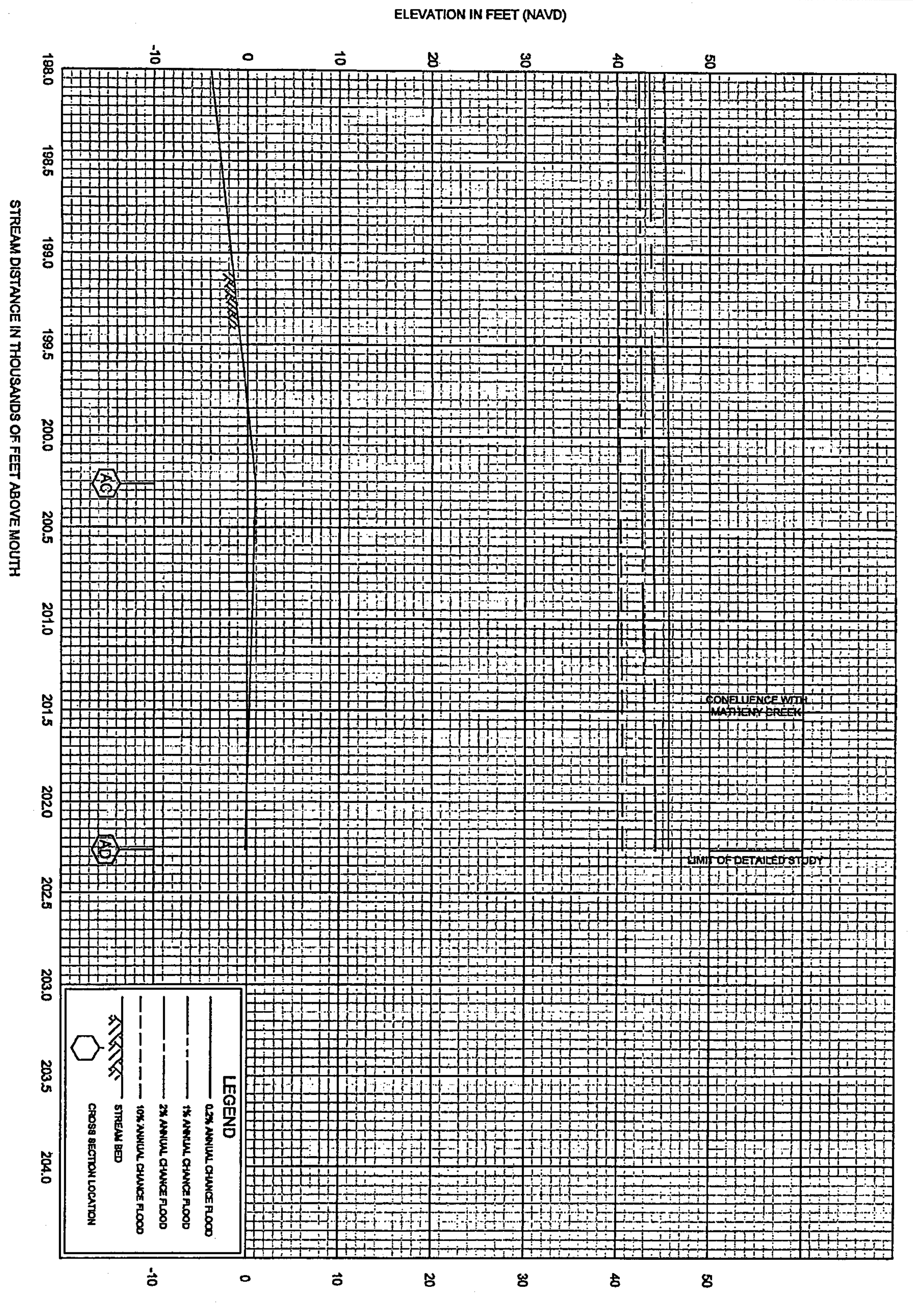


11P

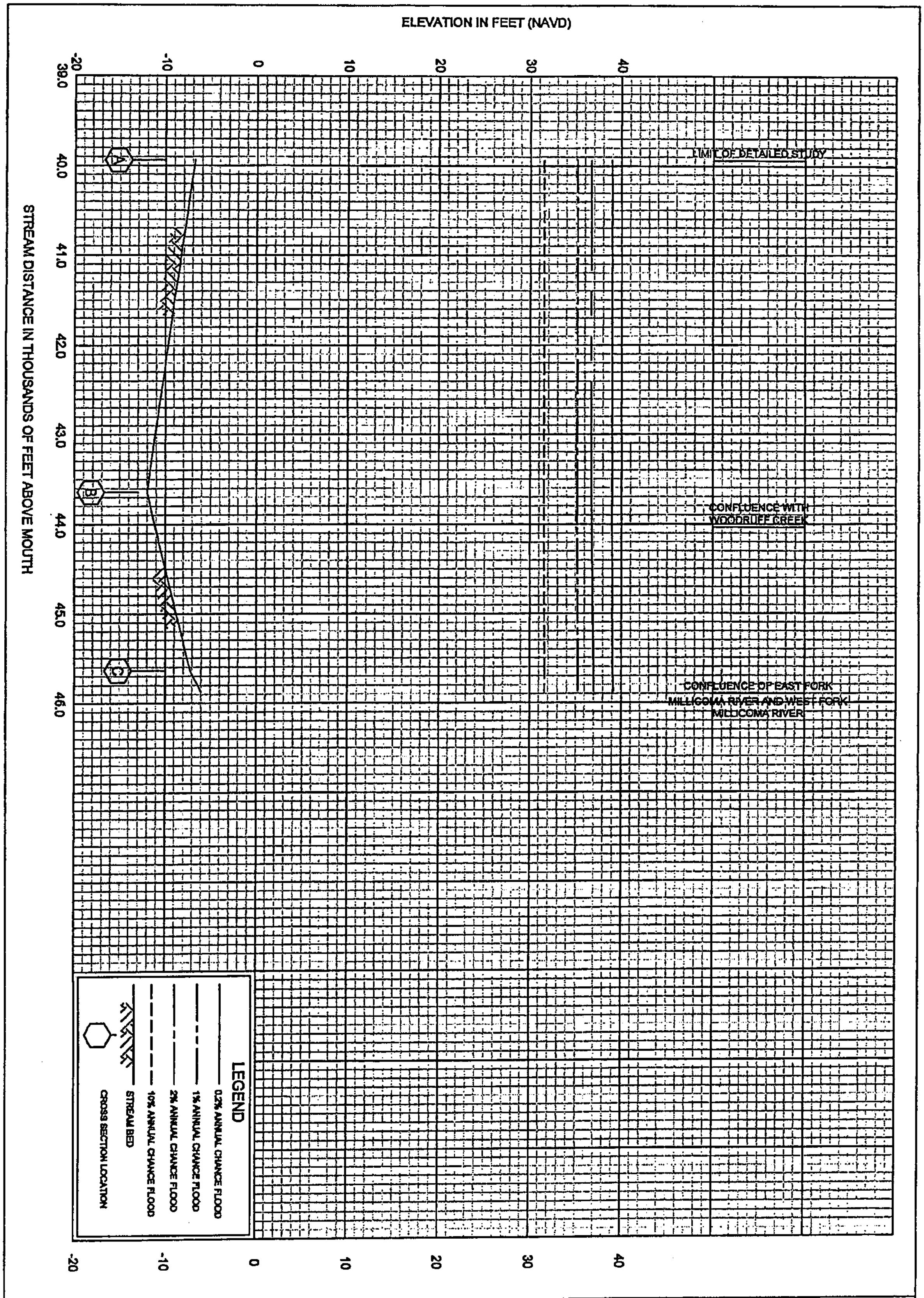
FEDERAL EMERGENCY MANAGEMENT AGENCY

COOS COUNTY, OR

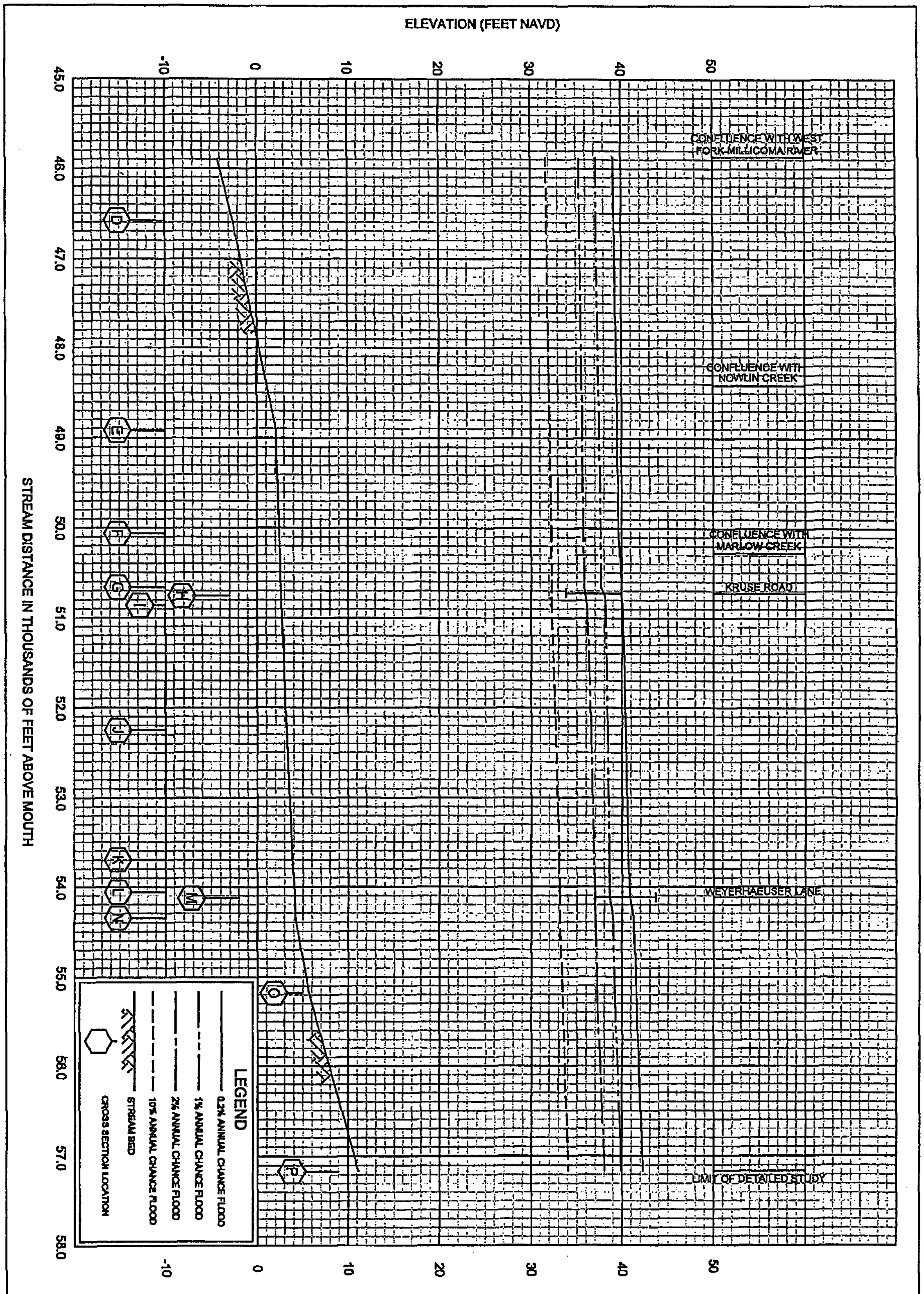
AND INCORPORATED AREAS

FLOOD PROFILES

SOUTH FORK COQUILLE RIVER AT MYRTLE POINT



12P	FEDERAL EMERGENCY MANAGEMENT AGENCY COOS COUNTY, OR AND INCORPORATED AREAS	FLOOD PROFILES MILLICOMA RIVER



13P

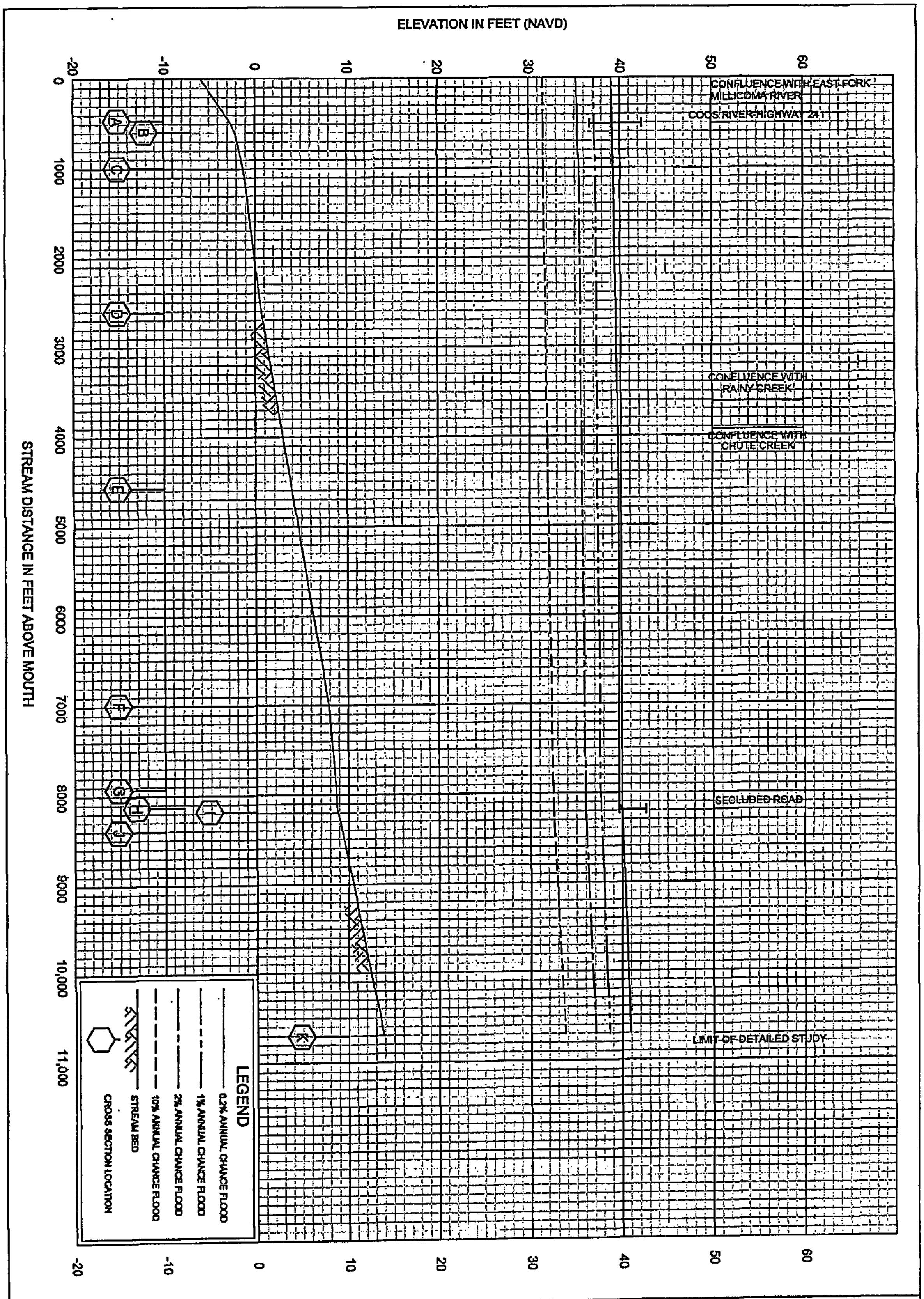
FEDERAL EMERGENCY MANAGEMENT AGENCY

COOS COUNTY, OR

AND INCORPORATED AREAS

FLOOD PROFILES

EAST FORK MILLICOMA RIVER



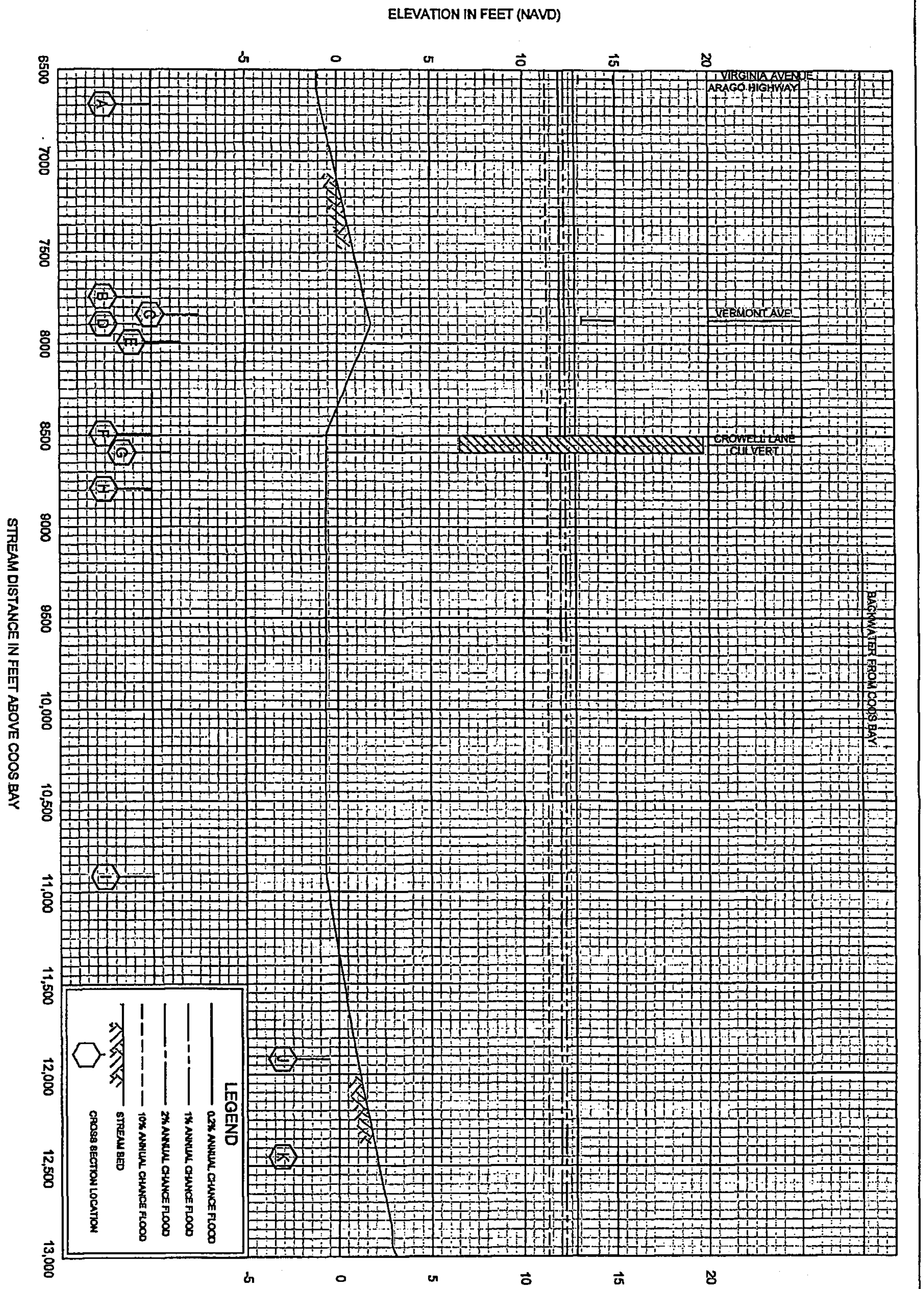
14P

FEDERAL EMERGENCY MANAGEMENT AGENCY

COOS COUNTY, OR
AND INCORPORATED AREAS

FLOOD PROFILES

WEST FORK MILLICOMA RIVER



15P

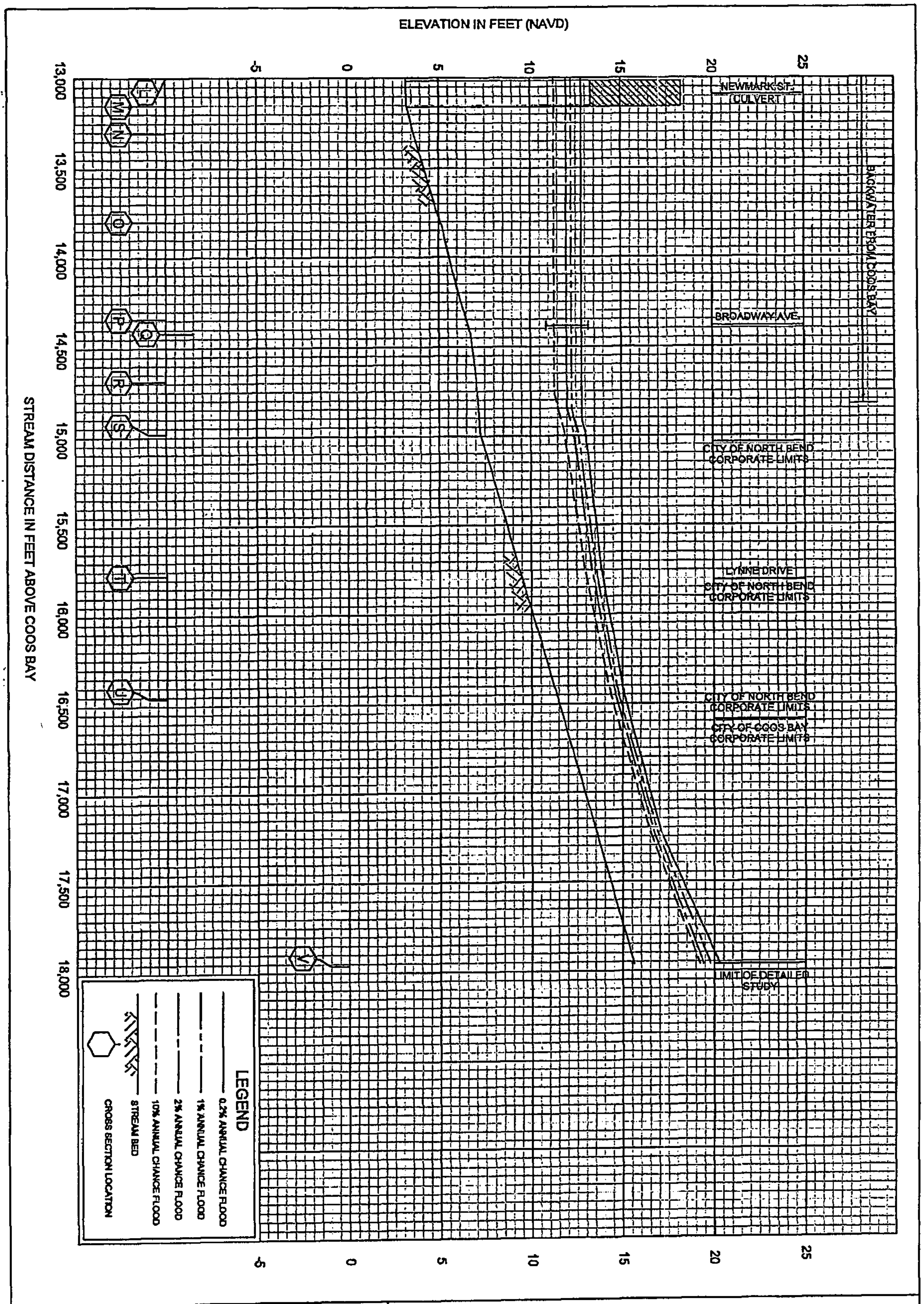
FEDERAL EMERGENCY MANAGEMENT AGENCY

COOS COUNTY, OR

AND INCORPORATED AREAS

FLOOD PROFILES

PONY CREEK



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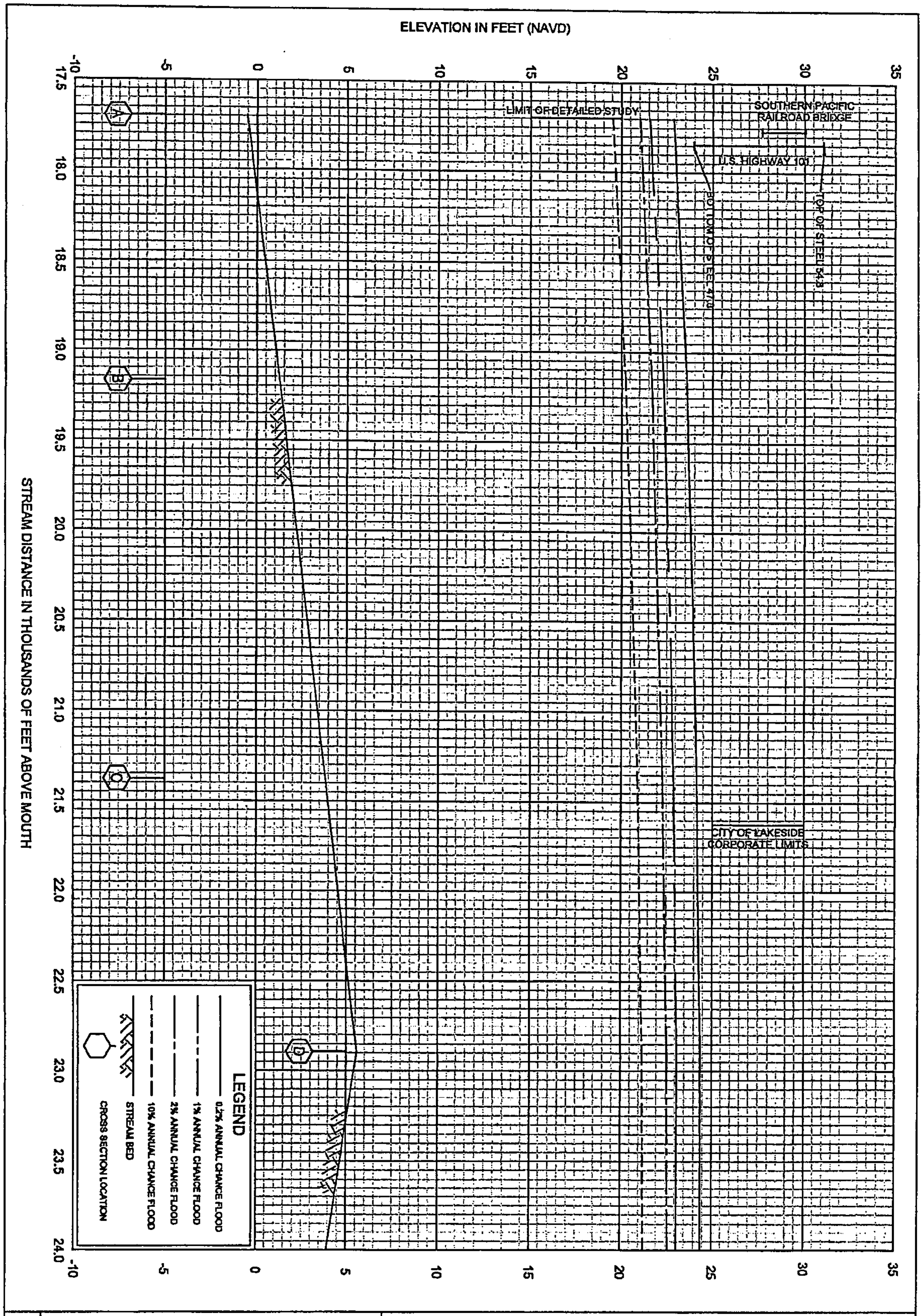


17P

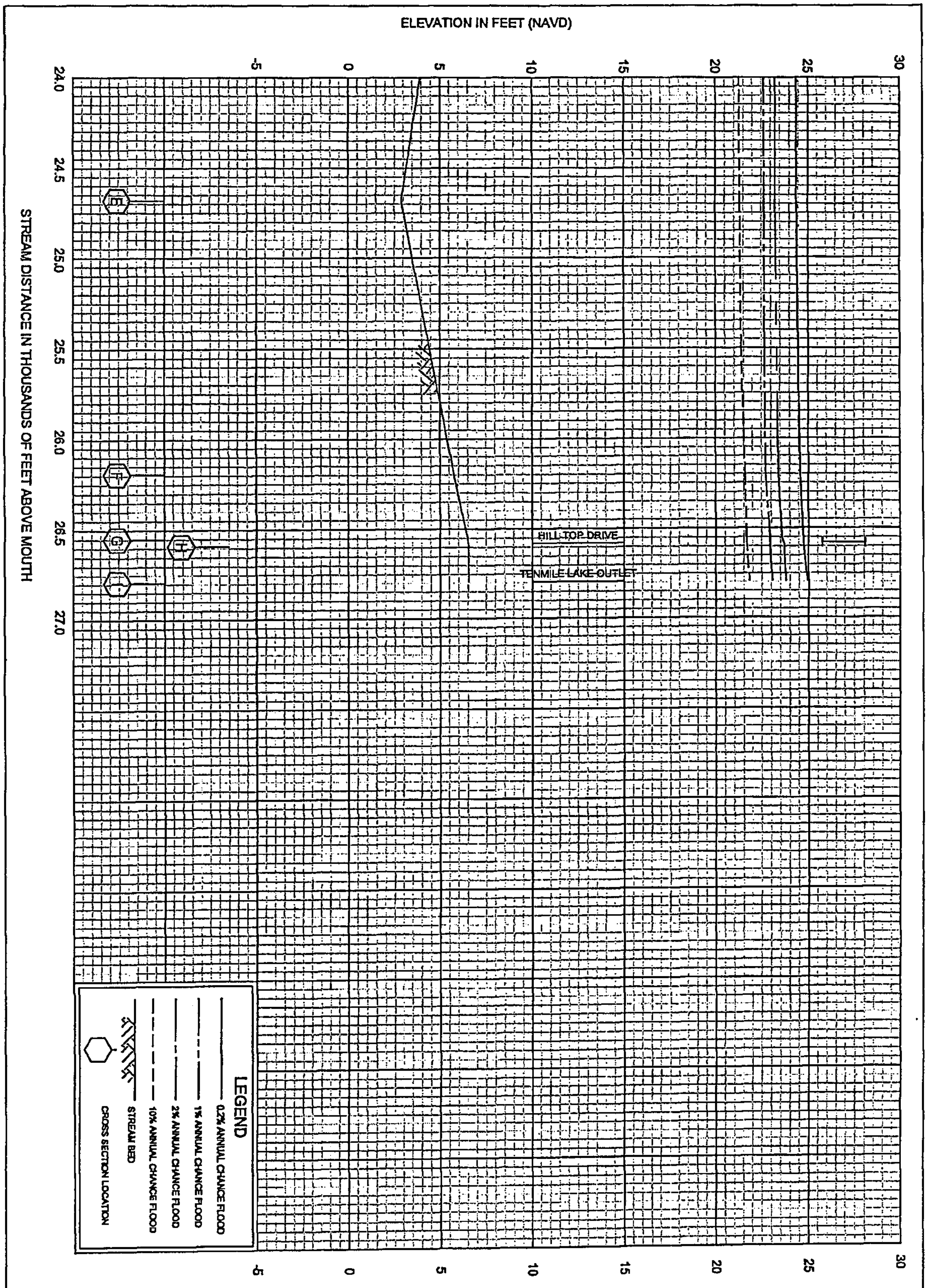
FEDERAL EMERGENCY MANAGEMENT AGENCY

COOS COUNTY, OR

AND INCORPORATED AREAS

FLOOD PROFILES

TENMILE CREEK



18P

FEDERAL EMERGENCY MANAGEMENT AGENCY

COOS COUNTY, OR

AND INCORPORATED AREAS

FLOOD PROFILES

TENMILE CREEK

SECTION 3.9.200 LANDSLIDES AND EARTHQUAKES

Landslides: New development or substantial improvements proposed in such areas shall be subject to geologic assessment review in accordance with this section. Potential landslide areas subject to geologic assessment review shall include all lands partially or completely within "very high" landslide susceptibility areas as mapped in DOGAMI Open File Report O-16-02, "Landslide susceptibility map of Oregon."

Earthquakes: New development or substantial improvements in mapped areas identified as potentially subject to earthquake induced liquefaction shall be subject to a geologic assessment review as set out in this section. Such areas shall include lands subject to "very high" and "high" liquefaction identified in DOGAMI Open File Report O-13-06, "Ground motion, ground deformation, tsunami inundation, co-seismic subsidence, and damage potential maps for the 2012 Oregon Resilience Plan for Cascadia Subduction Zone Earthquakes."

In the past earthquakes have not been addressed in the mapping as most of those experienced in the county originate on the Mendocino Fault off the northern Californian coast. Earthquakes originating there in 1922, 1923, and 1954 caused no damage here, though buildings swayed and sleepers were awakened in 1922 and shaking was observed in 1954. The potential for damage from earthquakes is greater in the Coos Bay area and southern part of the county, and damage is more likely to be a result of liquefaction and landslides than of faulting. Structural design incorporating seismic considerations is a good response to earthquake potential in all parts of the county. This is especially critical in the Coos Bay/North Bend area because of the greater instability of the older stabilized dunes, former marshes, and fills material that much of the development occurs on. High occupancy and critical use facilities such as schools and hospitals should be located in areas of solid ground conditions.

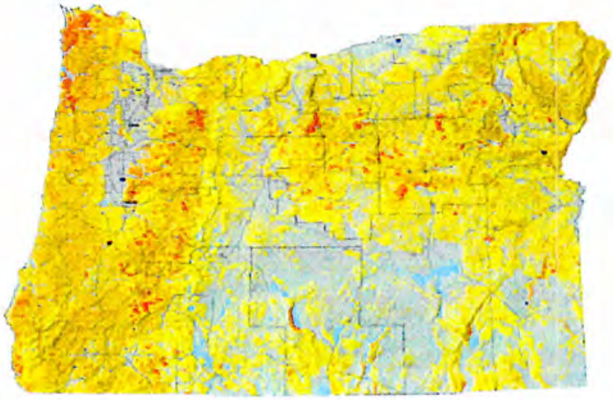
LANDSLIDE REPORT

State of Oregon
Oregon Department of Geology and Mineral Industries
Brad Avy, State Geologist

OPEN-FILE REPORT O-16-02

LANDSLIDE SUSCEPTIBILITY OVERVIEW MAP OF OREGON

By
William J. Burns[1], Katherine A. Mickelson[1], and Ian P. Madin[1]



2016

[1] Oregon Department of Geology and Mineral Industries, 800 NE Oregon Street, Suite 965, Portland, Oregon 97232

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Oregon Department of Geology and Mineral Industries Open-File Report O-16-02
Published in conformance with ORS 516.030

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http://www.oregongeology.org
http://www.oregon.gov/DOGAMI/

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1.0 REPORT SUMMARY

This project provides a generalized (1:500,000 data scale; ~32 ft^2 grid) landslide susceptibility overview map of the entire state. The intended use of this overview map is to help identify regions (cities, counties, communities, portions of lifelines, watersheds, etc.) that may be at risk for future landslides. The map is designed to provide landslide hazard information for regional planning and specifically to identify areas where more detailed landslide mapping is needed.

The landslide susceptibility overview map of Oregon uses three statewide data sets: 1) geologic map (a pre-release version of the Oregon Geologic Data Compilation, release 6), 2) landslide inventory (Statewide Landslide Information Layer for Oregon [SLIDO], release 3.2), and 3) slope map (lidar-derived data and U.S. Geological Survey national elevation data). We combined generalized geology and landslide inventory to determine landslide area per geologic unit area and to establish classes of low, moderate, and high landslide density. Then we calculated spatial statistics of the slope map to determine classes of low, moderate, and high slopes prone to landsliding within each geologic unit. Using a hazard matrix, we combined these two data sets, landslide density and slopes prone to landsliding, with the original landslide inventory to establish final landslide susceptibility overview map zones.

The statewide overview map zones classify Oregon into the following susceptibility zones: 37% low, 28% moderate, 30% high, and 5% very high (the very high zone by definition consists of mapped landslides). Most areas classified as moderate or higher landslide susceptibility are located in the Cascade Mountains, the Coast Range, and the Klamath Mountains and portions of central and northeastern Oregon.

We used the SLIDO-3.2 historic landslide point data set (9,997 points) to test the landslide susceptibility overview map. We found approximately 80% of the landslide points in the high and very high classes. We examined correspondence between landslide susceptibility and the 242 cities, 36 counties, and 536 watersheds (average watershed size of 170 mi^2) in Oregon (Appendix C). In the counties, high and very high susceptibility percentages range from less than 10% in Deschutes County to greater than 80% in Tillamook County. Note, however, that a high percentage of landslide susceptibility for county, city, or watershed does not mean there is an equivalent high risk, because risk is the intersection of hazard *and assets.* For example, Tillamook County has greater than 80% high and very high landslide susceptibility, but if the majority of assets (people, buildings, infrastructure, etc.) are located in the other 20%, which is ranked moderate to low susceptibility, this indicates a relatively high overall *susceptibility* for the county, but a relative low *risk* for the county.

2.0 INTRODUCTION

Climate, geology, and topography combine to make portions of Oregon landslide-prone. Precipitation, earthquakes, and human activity are the main triggers of landslides. The growing Oregon population has pushed development into landslide-prone areas, putting people and infrastructure at risk. Detailed (large scale, e.g., 1:8,000 or better) landslide hazards maps provide the public and local officials one of the tools to reduce this risk. However, there is as yet neither the data nor the capacity to create detailed landslide hazards maps across the entire state of Oregon.

The purpose of this project is to create a generalized data (coarse grid: ~32 ft^2; small scale: 1:500,000) landslide susceptibility overview map of the entire state. The intended use of this overview map is to help identify regions (cities, counties, communities, portions of lifelines) that maybe more or less at risk for future landslides. This information facilitates regional planning by providing an understanding of relative vulnerability to slides and identifying areas where more detailed mapping is needed. The Oregon Department of Administrative Services, Geospatial Enterprise Office, partially funded this study (Interagency Agreement No. 55019).

3.0 SOURCE DATA, METHODS, AND RESULTS

Several other state geological surveys have completed similar statewide landslide susceptibility maps: California (Willis and others, 2011), Utah (Giraud and Shaw, 2007), and Alabama (Ebersole and others, 2011). The method described in this paper was developed on the basis of these existing methods and is described in detail in the sections below.

3.1 Overview

We used these statewide data sets to produce the landslide susceptibility overview map of Oregon:

- Generalized geologic map (148 generalized geologic unit polygons) created from a pre-release version of the Oregon Geologic Data Compilation [OGDC], release 6 (statewide) provided by I. P. Madin, 2014
- Landslide inventory (54,758 landslide polygons) from the Statewide Landslide Information Database for Oregon [SLIDO], release 3.2 (Burns, 2014)
- Slope map, in degrees, based on a 32.8 ft^2 grid derived from lidar-derived elevation data and U.S. Geological Survey National Elevation Data (NED) [Gesch, 2007]

The general steps to produce the overview map are:

1. Create a geology-landslide intersect map by combining the generalized geology (described in more detail in section 3.2.1) and landslide inventory (described in detail in section 3.2.2) to determine landslide area per geologic unit area. We then used the percent of landslide areas in each of 148 generalized geologic units to establish classes of low, moderate, and high **Landslide Density** (i.e., landslide area/geologic unit area).
2. Calculate spatial statistics between the geology-landslide intersect map and the slope map to determine the mean and standard deviation of slope angles within the landslides per geologic unit. We used the mean and standard deviation to establish classes of low, moderate, and high **Slopes Prone to Landsliding** within each geologic unit.
3. Use a hazard matrix to combine these two data sets, Landslide Density and Slopes Prone to Landsliding, along with the original landslide inventory to establish zones in the final landslide susceptibility overview map.

Each of these steps is described below and in more detail in Appendix A and on Plate 1.

3.2 Source data

Geological and geomorphic information from the Oregon Department of Geology and Mineral Industries (DOGAMI) and the U.S. Geological Survey (USGS) are the best available statewide data at the time of this publication.

3.2.1 Generalized geologic map

We created the generalized geologic map by starting with the same pre-release version of OGDC-6. The compilation has over 120,000 geologic unit polygons. This is too much detail for a statewide overview map. We generalized the geology polygons on the geology general unit (GEO_GENL_U; general rock type) and geologic rock type (G_ROCK_TYP; characteristic lithology type) fields, which resulted in 190 unique generalized geologic units.

This pre-release version of OGDC-6 contained landslides as a "unit." We needed to remove these so that landslide inventory polygons (see section 3.2.2) would correlate not to landslides in the geology but to geologic units. We removed the 11,373 landslide polygons from our pre-release version of OGDC-6 and stored these in a separate file. We tested several GIS tools and found that the Esri® Eliminate tool worked best at merging these separated landslides into the 190 generalized geologic units. The tool allowed us to determine which units had the most coincident boundaries with landslides (or in other words, correlated best) and then merge the landslides with those units. After we performed this process, several hundred landslide polygons remained. We manually merged these with adjacent and appropriate geology units.

We then examined the 190 generalized geology units for size and lack of attributes. If the generalized geologic unit had a small extent (for example 1,000 ft^2) and/or if the unit did not have information that distinguished it from other similar units, we merged these units with other similar units. The final generalized geology data set has 148 units.

See Appendix A.1 for GIS process details and Appendix B for a list of geologic units.

3.2.2 Landslide inventory

This project required two landslide inventory files. The first inventory was of landslide polygons (mapped deposits in SLIDO), which we used as a model input. The second inventory was of historic landslide points, which we used as a quality assurance test of the landslide susceptibility model output. We created both inventory data sets from the Statewide Landslide Information Database for Oregon (SLIDO) release 3.2 (Burns, 2014).

Landslide polygon inventory

We began by removing the debris fans and talus-colluvium polygons from the landslide polygon data set. We did this because the end product is a generalized overview landslide susceptibility map and is not intended to identify debris flows or similar generally long-runout landslide hazard areas or rock fall/topple hazard areas. We divided the remaining landslides into two sets: those mapped following general procedures of Special Paper 42 (SP-42; Burns and Madin, 2009), which is a method using light detection and ranging (lidar) data and a base map; and those mapped without a lidar base or mapped using a lidar base but that did not follow the SP-42 method completely. We then cleaned these two data sets to remove overlapping polygons and very small polygons (<35,000 ft^2) (see Appendix A). We did this because the end product is not intended to identify future very small shallow landslides that in any case would be inappropriate for the ~32-ft^2 grid. Finally, we intersected the landslide polygons with the 148 generalized geological units by running the Esri Intersect tool, because the statistics calculated later in this method must be for each generalized geologic unit. This resulted in 6,629 SP-42 landslides and 48,129 non-SP-42 landslide and portions of landslide polygons (Plate 1). Each landslide area was unique to each generalized geology unit.

See Appendix A.2 for GIS processing details.

Historic landslide point inventory

The second landslide data set is the historic landslide points. Like the other landslide data set, we first removed the debris flow fan and rock fall by determining where the points intersected debris fans and talus-colluvium polygons. We then removed points attributed as shallow debris flow runout deposits and points with areas or volumes too small for the grid resolution. This resulted in 9,997 historic landslide points.

See Appendix A.2 for GIS processing details.

3.2.3 Digital elevation models (DEMs)

We started with two DEMs. The first is from the USGS National Elevation Data set (NED, http://ned.usgs.gov/), which has a 10-m^2 grid resolution. The second is a compilation of available lidar derived bare-earth DEMs, which have a 3-ft^2 grid resolution (see Appendix A.3 for GIS process details).

We projected the NED data set into the NAD1983HARN Oregon Statewide Lambert projection, which is in feet and has a grid cell size of 32.8 ft^2 and elevation in feet. We resampled the lidar-derived DEM to a 32.8-ft^2 grid. We then merged these two data sets to create a statewide DEM by using lidar-derived data where available. We converted the DEM into a statewide slope map in degrees.

3.3 Analysis

We used the three generalized data sets—the geologic map, landslide inventory, and slope map—to create two susceptibility data sets: one focused on identification of slopes more or less prone to landslides called **Slopes Prone to Landsliding**, and one focused on the density of existing mapped landslide areas called **Landslide Density**.

We combined the generalized geologic map and landslide inventory to establish zones of low, moderate, and high **Landslide Density**, which is the ratio of landslide area to geologic unit area. We also combined the generalized geologic map with the landslide inventory and the slope map to establish zones of low, moderate, and high classes of **Slopes Prone to Landsliding** within each geologic unit. We combined these two sub data sets with the landslide inventory to establish the final landslide susceptibility overview map zones. Details of this process are described in the following sections.

3.3.1 Landslide density

We intersected the 148 generalized geologic units with the landslide inventory polygons; 119 units contained landslides. Next, we calculated landslide area per area of each generalized geologic unit, referred to as the **Landslide Density** (Appendix B). The **Landslide Density** ranged from 0% to just over 45% across the state of Oregon.

We calculated the mean and standard deviation of the data set. We found a mean of 7.35 and a standard deviation of 8.92. The mean plus one standard deviation is 16.27. We plotted the generalized geologic units and the corresponding Landslide Density in percent as a histogram for visual examination of primary changes in frequency (Figure 1).

We examined several recent studies in Oregon and the generalized (overall) relative hazard classification concluded in those reports. Although these studies concluded that relative hazard classifications are largely subjective, the studies are still valuable for comparison. The percent of land covered by landslides and the concluded generally (overall) relative hazard are presented in Table 1.

Finally, we examined the thresholds used at the national scale established by the U.S. Geologic Survey in the Landslide Overview Map of the Conterminous United States (Radbruch-Hall and others, 1982). Radbruch-Hall and others selected >15% as high, 1.5–15% as medium, and <1.5% as low for landslide susceptibility and incidence across the entire United States. If we apply these relative hazard classes in Oregon, most of the state is classified as moderate or high with very little low (<1.5%; see Figure 1). This means Oregon is generally rated as having moderate

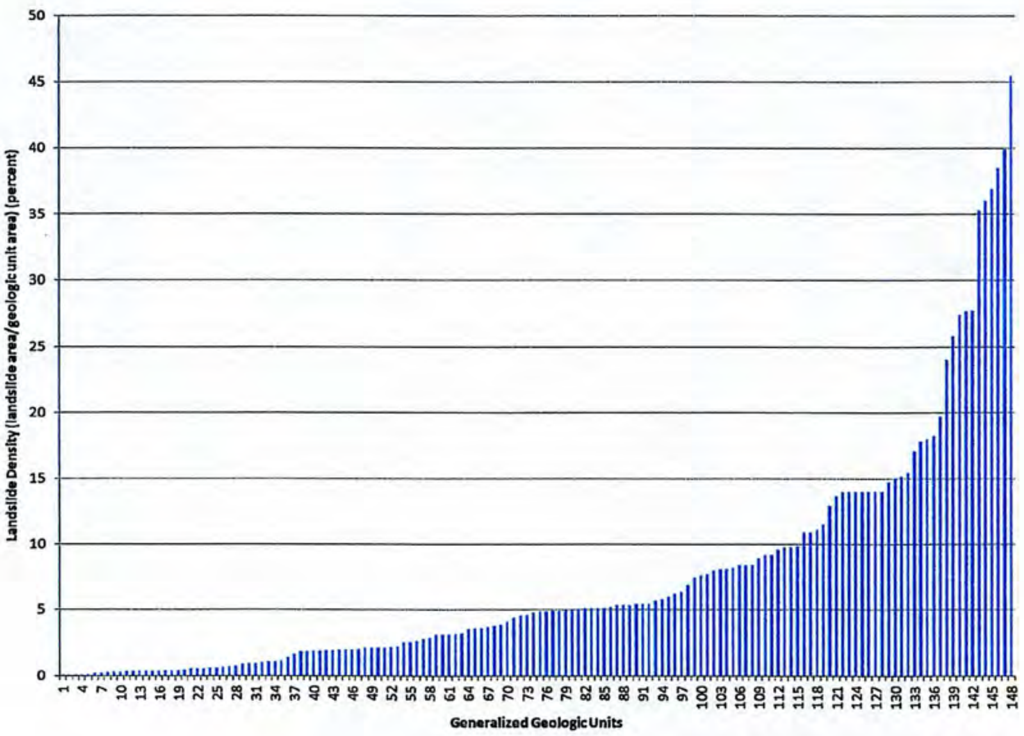


Figure 1. Histogram of landslide density per generalized geologic unit.

to high landslide susceptibility when compared to other states/areas across the United States.

While it is good to know where Oregon landslide hazards rank compared to other states, our goal with this study is to classify areas in Oregon relative to other areas in Oregon. We selected the following ranges to define generalized (overall) relative landslide classes:

Table 1. Other Oregon landslide inventory studies, percent coverage of the mapped area, and relative landslide hazard.

Study	Percent Landslide Inventory Deposit Coverage	Relative Overall Hazard Classification Concluded in Report
Astoria (Burns and Mickelson, 2013)	27%	High
North Fork Siuslaw Watershed (Burns and others, 2012a)	37%	High
Coastal Curry County (Burns and others, 2014)	25%	High
Bull Run Watershed (Burns and others, 2015)	15%	Moderate to High

Low Landslide Density	< 7%
Moderate Landslide Density	7% to 17%
High Landslide Density	> 17%

These ranges are consistent a) with the mean (~7%) and the mean plus one standard deviation (~16%) of our data set (Figure 1), b) with the classifications from recent studies in Oregon (Table 1), and c) generally with national thresholds (1.5% and 15%). The thresholds are displayed on the histogram (Figure 1) with the relative landslide classes (low, moderate, high) (Figure 2).

We then converted the generalized geologic map to a raster file with 32.8-ft^2 grid cell size to match the DEM resolution. We attributed each grid cell with a value of low, moderate, or high depending on the final landslide density percent (landslide area/geologic unit area; see Appendix B).

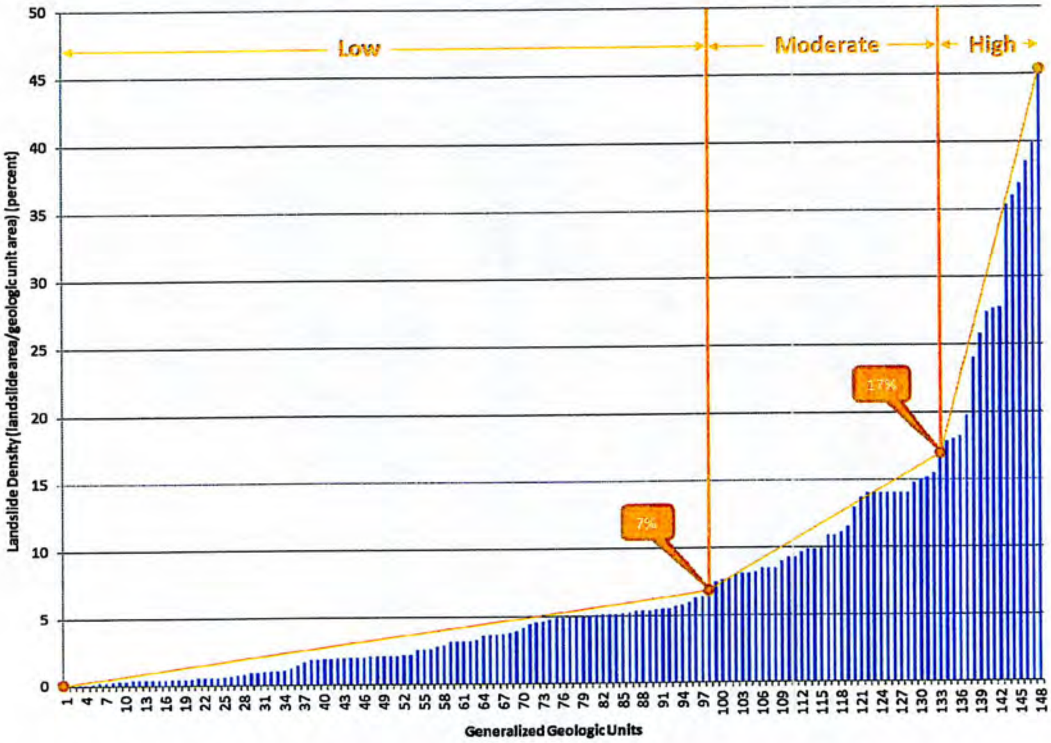


Figure 2. Histogram of landslide density with thresholds and relative landslide density classes.

3.3.2 *Slopes prone to landsliding*

To establish **Slopes Prone to Landsliding**, we used two data sets: a slope map and a map of generalized geologic units intersected with landslide polygons. We started by converting the statewide DEM into a slope map in degrees. We used the slope map grid and landslide polygons (attributed with associated generalized geology) to establish spatial statistics or slope statistics within the landslide polygons in each of the 148 generalized geologic units (Appendix B). The spatial statistics examine the slope grid cells within the landslide polygons attributed with the same generalized geologic unit. The output includes the mean and standard deviation of the slope within those landslide polygons (i.e., post-failure slope) per generalized geologic unit (Appendix B).

Following the Burns and Madin (2009) landslide inventory method results in an estimated overall pre-failure slope angle at each individual landslide. This slope angle is estimated through measurement, directly adjacent to each landslide, on the native 3 ft^2 cell size lidar-derived bare-earth slope map and is therefore considered to be as close to the pre-landslide slope angle as possible. We compared the results of the analysis done on the statewide best available DEM (post-failure) to the results of the landslides with the lidar data estimated slopes (pre-failure). There were 6,629 landslides with both measurements. We subtracted the mean from the estimated slope at each landslide and then examined statistics on the entire 6,629. We found that the mean slope of the pre-failure measurements was approximately 9 degrees higher than the post-failure. This makes sense, as we expect the slope to be steeper before failure and less steep on the landslide body after failure. On the basis of this analysis, we used the more conservative (less steep and thus more "safe"), post-failure slope angle to establish the **Slopes Prone to Landsliding** used in the final landslide susceptibility matrix. This also helps justify using the mean slope as a threshold for the high and moderate **Slopes Prone to Landsliding** classes, instead of the likely overly conservative one standard deviation less than the mean, which would capture the majority of slopes identified as associated with existing landslides.

Similarly to other statewide or regional landslide susceptibility methods (used in other U.S. state surveys), we used the following relative hazard thresholds to establish classes of slopes prone to landsliding:

- Highly Prone Slopes: slopes equal or greater than the mean slope found within the landslides per geologic unit.
- Moderately Prone Slopes: slopes less than the mean and greater than the mean minus one standard deviation slope found within the landslides per geologic unit.
- Least Prone Slopes: slopes less than the mean minus one standard deviation slope found within the landslides per geologic unit.

We then saved the Slopes Prone to Landsliding map as raster file with 32.8-ft^2 grid cell size to match the resolution of the landslide density map. We attributed each grid cell with a value of Low, Moderate, or High.

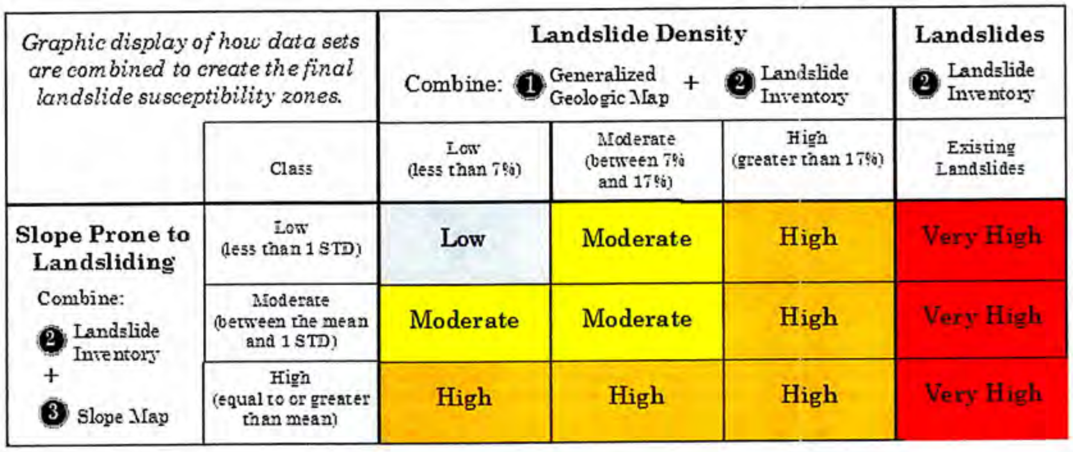
3.4 Landslide susceptibility categories

We combined the two final data sets, Landslide Density and Slopes Prone to Landsliding, with the existing landslides as shown graphically in Figure 3 and on Plate 1. We defined each susceptibility class on Plate 1 as:

- **Low: Landsliding unlikely.** Areas classified as Landslide Density = Low (less than 7%) and areas classified as Slopes Prone to Landsliding = Low. Note that landslide density and slopes prone to landsliding data were not considered in this category because existing slides are inherently prone to instability. Note also that the inventory quality of existing landslides varies highly across the state.
- **Moderate: Landsliding possible.** Areas classified as Landslide Density = Low to Moderate (less than 17%) and areas classified as Slopes Prone to Landsliding = Moderate OR areas classified as Landslide Density = Moderate (7%-17%) and areas classified as Slopes Prone to Landsliding = Low.
- **High: Landsliding likely.** Areas classified as Landslide Density = High (greater than 17%) and areas classified as Slopes Prone to Landsliding = Low and Moderate OR areas classified as Landslide Density = Low and Moderate (less than 17%) and areas classified as Slopes Prone to Landsliding = High.
- **Very High: Existing landslides.** Landslide Density and Slopes Prone to Landsliding data were not considered in this category. Note: the quality of landslide inventory (existing landslides) mapping varies across the state.

The statewide results for the classes are:

- 37% low
- 28% moderate
- 30% high
- 5% very high (mapped landslides)



Graphic display of how data sets are combined to create the final landslide susceptibility zones.		**Landslide Density** Combine: ❶ Generalized Geologic Map + ❷ Landslide Inventory			**Landslides** ❷ Landslide Inventory
	Class	Low (less than 7%)	Moderate (between 7% and 17%)	High (greater than 17%)	Existing Landslides
Slope Prone to Landsliding Combine: ❷ Landslide Inventory + ❸ Slope Map	Low (less than 1 STD)	Low	Moderate	High	Very High
	Moderate (between the mean and 1 STD)	Moderate	Moderate	High	Very High
	High (equal to or greater than mean)	High	High	High	Very High

Figure 3. Matrix to combine data sets into final landslide susceptibility classes.

3.5 Testing and comparison

To test the ability of the landslide susceptibility method described above to predict locations of future landslides, we compared the map to a landslide inventory (historic landslide points) not used as one of the input data sets. The historic landslide point data set had 9,997 points after processing as described in section 3.2.2 and Appendix A2. Some points (161) likely had spatial error issues indicated by location in water bodies or outside the state boundary and therefore were not compared to the landslide susceptibility map.

We found 508 historic landslide points in the Low landslide susceptibility category; 1,587 in Moderate; 6,373 in High; and 1,368 in Very High (Figure 4); approximately 80% of the landslide points are in the high and very high classes.

We visually compared the new landslide susceptibility overview map to recent, detailed (1:8,000 scale) mapping (compiled by Burns and others, 2013) completed for a small portion of Clackamas County (~15 mi², approximately one quarter of the county). The landslide inventory maps for Clackamas County were made by following the method of Burns and Madin (2009) (Figure 5). while the deep and shallow landslide susceptibility maps for the county were made by following the method of Burns and others (2012b, 2013).

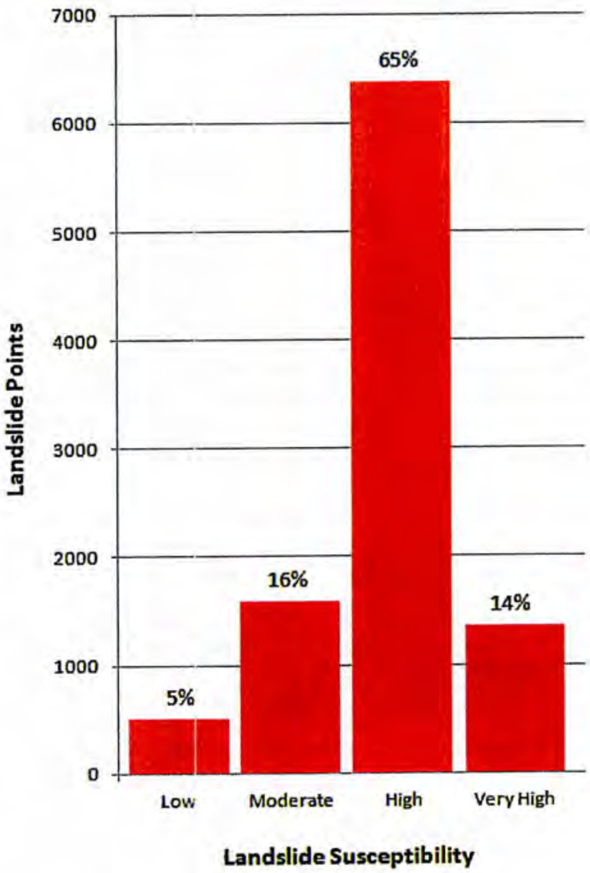


Figure 4. Number and percent of total landslides captured in each landslide susceptibility class.

On the basis of visual comparison, the new statewide landslide susceptibility overview map appears to reasonably capture the landslide inventory and the detailed moderate to high susceptibility for deep and shallow slides from previous studies performed for Clackamas County (Figure 5; Burns and others, 2013).

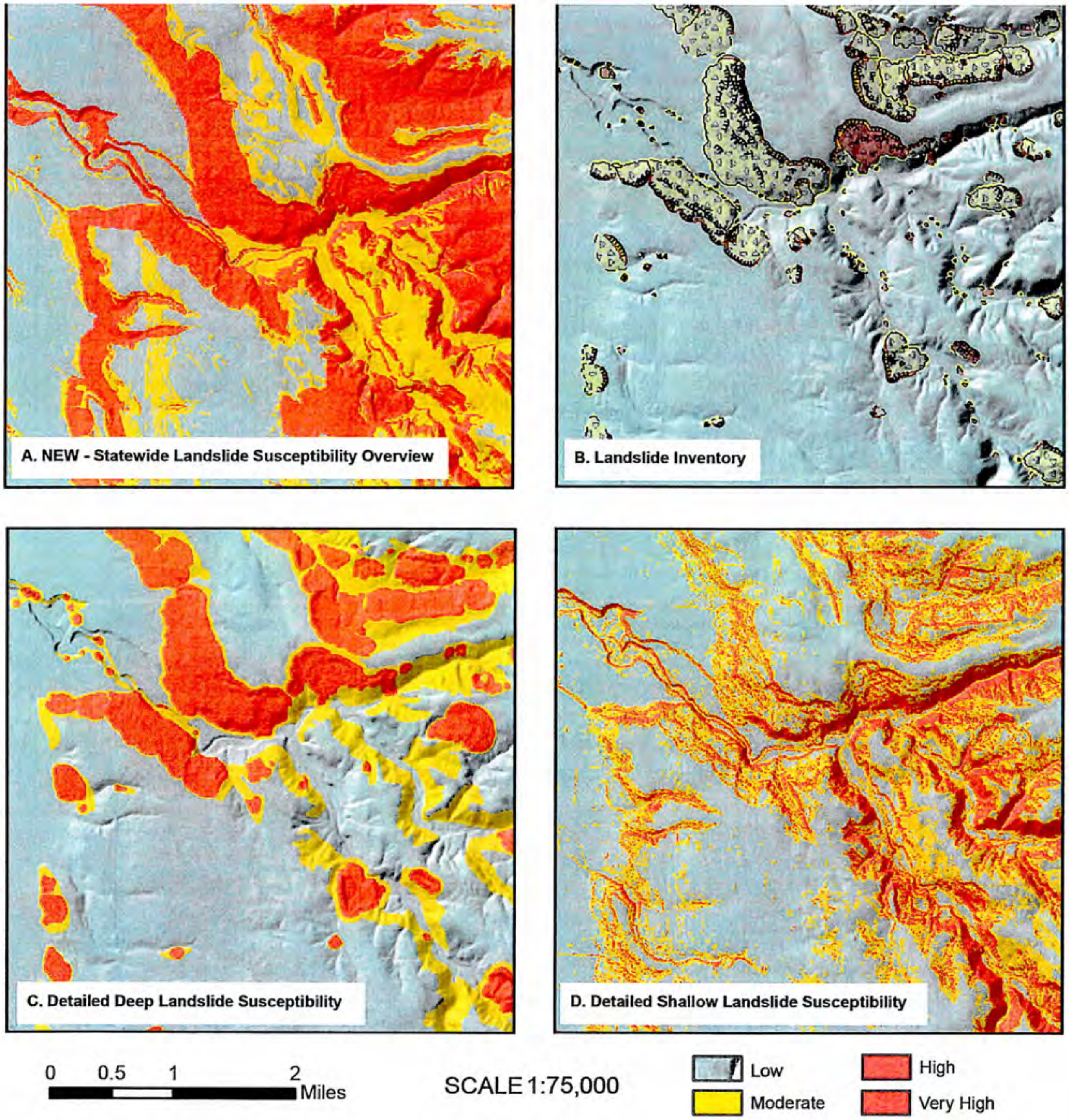


Figure 5. Comparison of (A) new statewide landslide susceptibility overview map to (B) landslide inventory and detailed (C) deep and (D) shallow landslide susceptibility maps (compiled by Burns and others, 2013).

However, the statewide map also appears to over predict in some areas; for example, in the southwest portion of the map (Figure 5A) there is almost entirely moderate and high/very high susceptibility, but far fewer landslides in the inventory and less deep landslide susceptibility in the detailed maps (Figure 5).This is likely caused by several factors. Lumping the geologic units into the generalized units can result in over and under classification of units. The **Landslide Density** portion of the susceptibility matrix (Figure 3) can override low slope angles in the density is high enough, which results in a likely over prediction, by classifying that entire unit as moderate or high. This is very likely what happened in the southeast corner (extensive moderate zone covering sloped and flat areas) of the new stateside landslide susceptibility overview map in Figure 5. Areas with little or no landslide inventory could have completely erroneous results.

3.6 Exposure analysis

We calculated landslide susceptibility for the 242 incorporated cities and the 36 counties in Oregon (Appendix C). High and very high susceptibility percentages range from less than 10% in Deschutes County to greater than 80% in Tillamook County (Figure 6).

Most cities have very low percentages of high and very high susceptibility. Only 14 of the 242 cities had more than 17% of the city area in high and very high landslide susceptibility zones. Note that even if a county or city has a high percentage of area in a high or very high hazard zone, this does not mean there is a high risk, because *risk* is the intersection of hazard and assets. For example, in Tillamook County more than 80% of the area is classes as having high and very high landslide susceptibility, but if most assets (people, buildings, infrastructure, etc.) are in the remaining 20% (moderate to low susceptibility), there is a relatively low risk of losses to landslides. Landslide risk analysis is beyond the scope of this study.

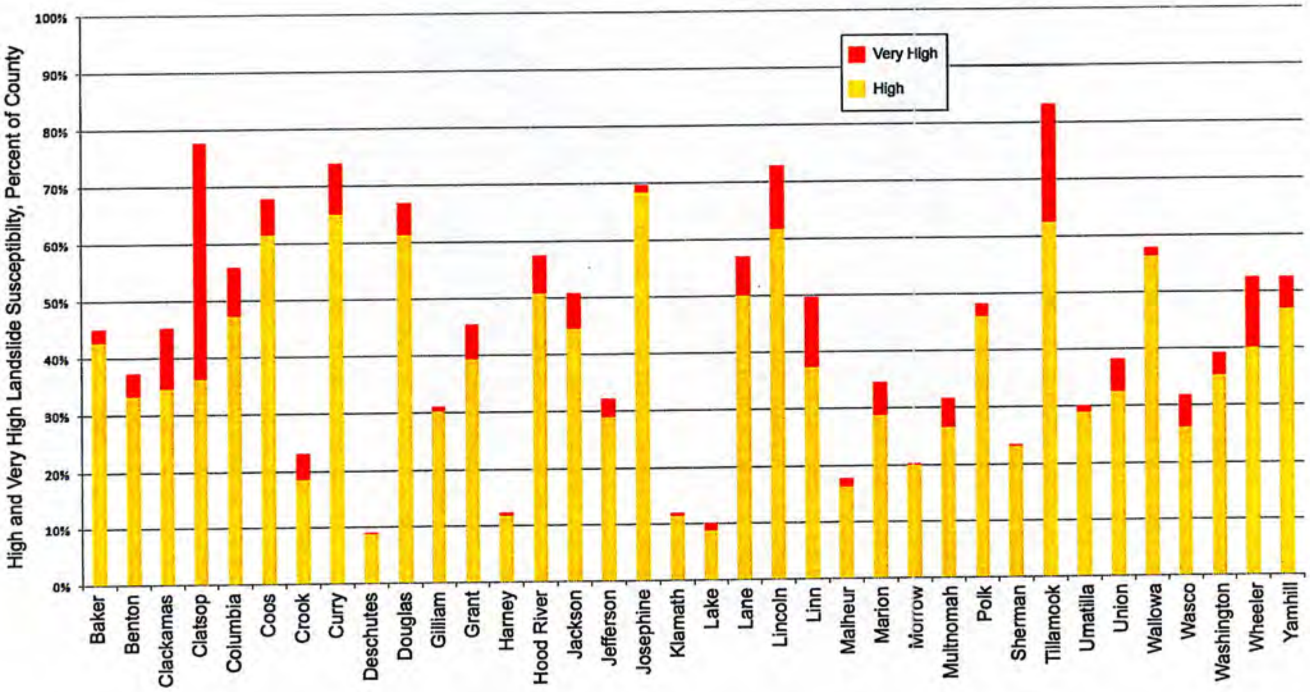


Figure 6. Percentages of Oregon county areas in high (yellow) and very high (red) landslide susceptibility zones as shown on the overview map (Plate 1).

Finally, we examined Oregon watersheds. It is beneficial to look at susceptibility by watershed because environmental issues are commonly confined within watersheds and because many communities get their drinking water from surface water within watersheds. We chose to examine HUC 10 watersheds, which range in size from 40 to 250,000 acres (62 to 390 mi^2) and are sometimes called fifth level watersheds (USGS, 2012). There are 536 HUC 10 watersheds within or mostly within the Oregon state boundary. We performed zonal statistics between the watershed boundaries and the statewide landslide susceptibility overview map zones (low, moderate, high, and very high) (Figure 7). This type of statistic results in a mean value for each watershed, where the input values were low = 1.0, moderate = 2.0, high = 3.0, and very high = 4.0.

We found that the mean per HUC 10 watershed ranged from 1.02, which is effectively all low, to 3.41, which is roughly 50% high and 50% very high (existing landslides) (Figure 8). There are very few watersheds with values between 3 and 4, which is mostly likely because of the lack of detailed mapping of existing landslides in those watersheds. Appendix C3 is a table listing watershed statistics.

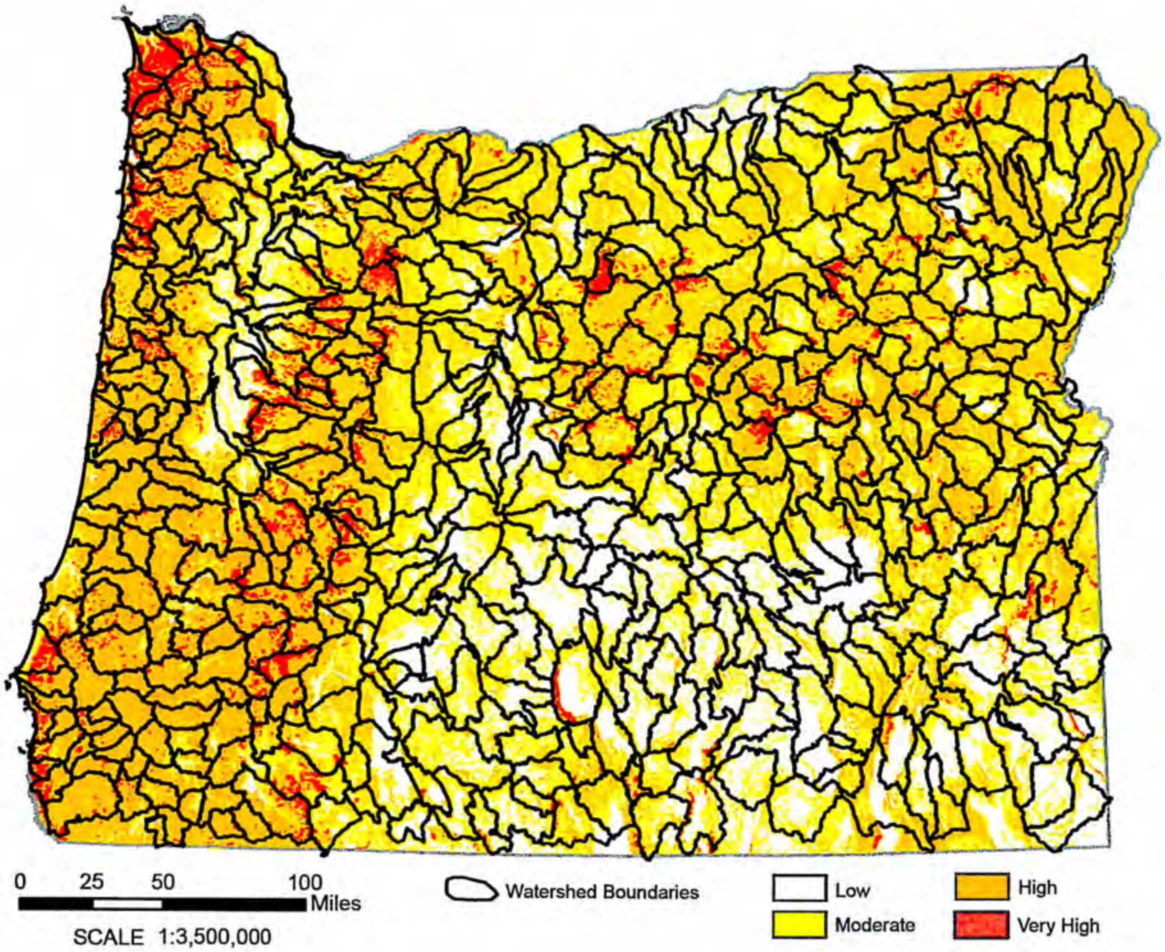


Figure 7. Map of HUC 10 watershed boundaries in Oregon overlain on the statewide landslide susceptibility overview map (white = Low, yellow = Moderate, orange = High, red = Very High landslide susceptibility).

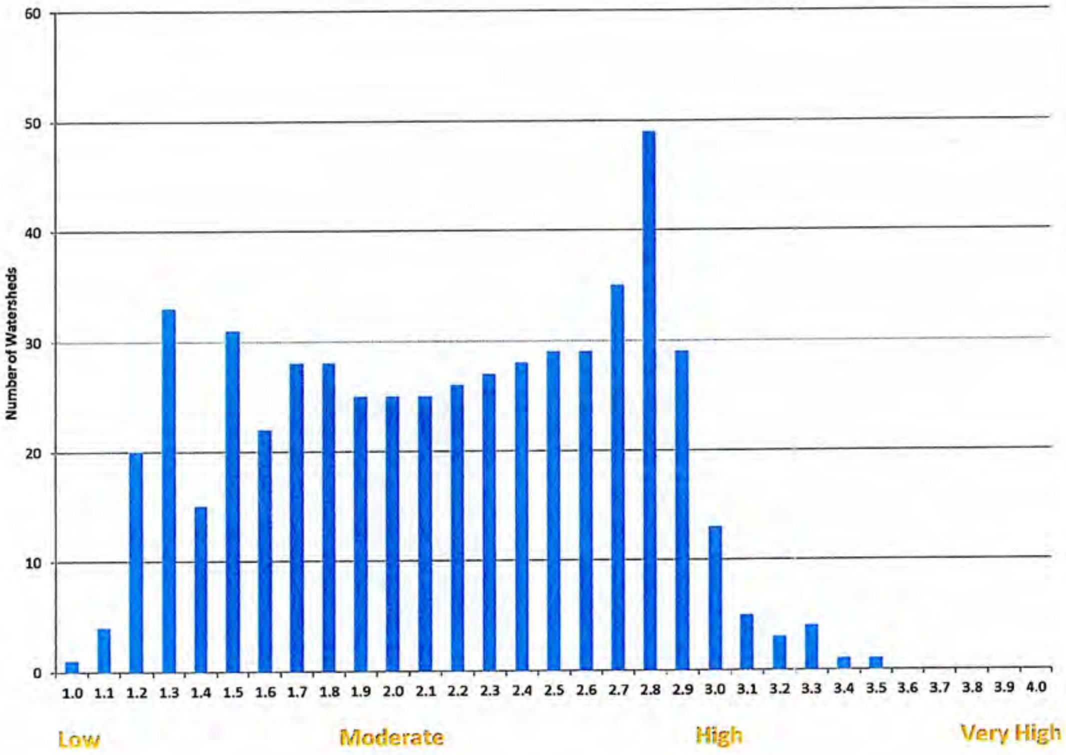


Figure 8. Histogram of mean landslide susceptibility overview score per Oregon HUC 10 watershed.

4.0 MAP USE AND LIMITATIONS

The new statewide overview map displays areas of low to very high landslide susceptibility throughout Oregon. The intended use of this overview map is to help identify the relative susceptibility to landsliding of each region of the state. This map is not intended for use at scales other than the published map data scale (1:500,000). The map is designed to provide a basis for regional planning and localities where more detailed landslide mapping is warranted.

Limitations of the input data and modeling methods we used to make the map are such that the map is not suitable to answer site-specific questions. The map should be used only for regional or community-scale purposes. The following is a list of specific limitations:

- Every effort has been made to ensure the accuracy of the GIS database, but it is not feasible to completely verify all of the original input data.
- The map is based on three primary sources: a) landslide inventory, b) generalized geology, and c) slope. Factors that can affect the level of detail and accuracy of the final susceptibility map include: 1) lack of detailed landslide inventory statewide, 2) too much or too little generalization of the geology, and 3) highly variable DEM resolution resulting in variable accuracy of the slope model.
- Future geologic, topographic, and landslide mapping may render this map locally inaccurate.
- The intent of landslide susceptibility overview map is to help identify regions (cities, counties, communities, portions of lifelines, etc.) that may be more or less at risk for future landslides. We did not consider runout areas from channelized debris flows or other types of landslides with runout deposits. We did not consider talus slopes from rock fall/topple areas and relatively small shallow landslides in this analysis.
- Some landslides areas on the map may have been mitigated, reducing their level of susceptibility. Because it is not feasible to collect detailed site-specific information on every landslide, existing mitigation has been ignored.

5.0 ACKNOWLEDGMENTS

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7.0 APPENDICES

Appendix A: GIS processing details for input data sets

A.1 Geology

We used the following procedure to determine the final set of generalized geologic units.

1. Working with our pre-release copy of the OGDC-6 geodatabase provided by I. P. Madin, DOGAMI, 2014), in Esri ArcGIS v. 10.2 we determined the attributes that would be used during the merge in step #3: GEO_GENL_U (Geology Generalized Unit) and G_ROCK_TYP (Generalized Rock Type) fields.
2. Next, we removed landslide polygons from the data set. In our pre-release OGDC-6 data set, landslide polygons are attributed with GEO_GENL_U = Sediments and G_ROCK_TYP = mixed grained sediments. To remove the landslide polygons, we extracted the polygons from a copy our pre-release version of OGDC-6 to a single shapefile. We removed the landslide polygons by examining the MAP_UNIT_N field and extracting polygons with the following attributes:
   - Bedrock landslides
   - Bedrock landslides, Pleistocene
   - Debris avalanche deposits
   - Dutch Canyon Landslide Complex
   - Landslide
   - Landslide-Columbia River
   - Landslide-John Day
   - Landslide area
   - Landslide areas
   - Landslide debris
   - Landslide Debris
   - Landslide debris
   - Landslide deposit
   - Landslide deposits
   - Landslide Deposits
   - Landslide deposits (grades into Qg)
   - Landslide deposits and colluviums
   - Landslide material
   - landslides
   - Landslides
   - Landslides-blocky surfaces of andesite fragments and debris, some are older than last glaciation
   - Landslides and landslide deposits

The landslides were selected by the following attributes: "MAP_UNIT_N" = 'Bedrock landslides' OR "MAP_UNIT_N" = 'Bedrock landslides, Pleistocene' OR "MAP_UNIT_N" = 'Debris avalanche deposits' OR "MAP_UNIT_N" = 'Dutch Canyon Landslide Complex' OR "MAP_UNIT_N" = 'Landslide' OR "MAP_UNIT_N" = 'Landslide-Columbia River' OR "MAP_UNIT_N" = 'Landslide-John Day' OR "MAP_UNIT_N" = 'Landslide area' OR "MAP_UNIT_N" = 'Landslide areas' OR "MAP_UNIT_N" = 'Landslide debris' OR "MAP_UNIT_N" = 'Landslide Debris' OR "MAP_UNIT_N" = 'Landslide deposit' OR "MAP_UNIT_N" = 'Landslide deposits' OR "MAP_UNIT_N" = 'Landslide Deposits' OR "MAP_UNIT_N" = 'Landslide deposits (grades into Qg)' OR "MAP_UNIT_N" = 'Landslide deposits and colluvium' OR "MAP_UNIT_N" = 'Landslide material' OR "MAP_UNIT_N" = 'landslides' OR "MAP_UNIT_N" = 'Landslides' OR "MAP_UNIT_N" = 'Landslides-blocky surfaces of andesite fragments and debris, some are older than the last glaciation' OR "MAP_UNIT_N" = 'Landslides and landslide deposits'

This extraction resulted in 11,373 landslide polygons.

3. In parallel, we used the Esri Dissolve tool to join the 11,373 landslide polygons into a single multipart landslide polygon. Then we used the Esri Erase tool to remove these areas of landslide out of the generalized geology file. With the landslides temporarily out of the database, we merged the geology units into 190 unique generalized geologic units (determined in step 1). Finally, we used the Esri Merge tool to merge the individual landslide polygons back into the generalized geology dataset.
4. The next challenge was to merge the landslide polygons into the geology. We tested several methods including using the Esri tool Polygon Neighbors, which creates a table with statistics based on polygon contiguity (overlaps, coincident edges, or nodes). If the edges of a landslide touched only one geologic unit, the landslide was merged with that unit. However, this left thousands of landslides. After extensive testing, we determined that the Esri Eliminate tool selected and combined landslides with surrounding geology with the fewest capture errors.

   We then used the Eliminate tool to merge landslide polygons into geologic unit polygons. First we removed alluvium, so that none of the landslide polygons would merge into alluvium. In order to remove the alluvium, we examined the G_ROCK_TYP field and included the polygons with the following attributes, where the first term is the GEO_GENL_U and the second term is the G_ROCK_TYP:

- Sediments-turbidite (two polygons on the bottom of Crater Lake)
- Sediments-tufa (a single polygon that appears to be fine grained Quaternary alluvium [Qal])
- Sediments-sinter deposit (a single polygon surrounded by volcaniclastic deposits)
- Sediments-no data (a single polygon surrounded by coarse grained sediment Qal)
- Sediments-mudflow breccias (a handful of polygons which make up one half of the Sandy River delta)
- Sediments-mixed lithologies (landslides from Wiley and others, 2014)
- Sediments-mixed grained sediments (landslides and alluvium)
- Sediments-metamorphic rocks
- Sediments-ice (glacial ice on the High Cascade Mountains)
- Sediments-fine grained sediments (Qal fine)
- Sediments-coarse grained sediments (Qal coarse)
- Sediments-ash (a single polygon)
- No data-nodata (recent Qal)
- No data-fine grained sediments (two polygons in northeast Oregon adjacent to Sediments-fine grained sediments)

We temporarily removed these 14 units. Then we selected the landslides and ran the Eliminate tool again. The result left 397 landslide polygons. We then merged the alluvium back into the geology. We visually examined the 397 landslides and merged them with the appropriate geology units.

5. Next, we examined the 190 generalized geologic units from step 1 for polygon size. Some units had very small total areas. For example, we established a minimal landslide size of 35,000 ft^2 (see Section 3.2). We found only one geology polygon that matched his criterion. We merged it into the appropriate adjacent geology polygon, giving the database 189 units.
6. Next, we looked at units with "no data" in the attribute fields GEO_GENL_U and/or G_ROCK_TYP. These included:
   - GEO_GENL_U=no data, G_ROCK_TYP=fine grained sediments. We merged this single polygon with adjacent unit sediments, fine grained sediments.
   - GEO_GENL_U=no data, G_ROCK_TYP=no data. This unit looked like the "water" polygon. We merged it with unit sediments, mixed grained sediments because that unit made up most of the surrounding polygons.
   - GEO_GENL_U=sediments, G_ROCK_TYP=no data. We merged this single polygon with adjacent unit sediments, coarse grained sediments.
   - GEO_GENL_U=volcaniclastic rocks, G_ROCK_TYP=no data. We merged several polygons with adjacent unit volcaniclastic rocks, mixed lithologies.
   - GEO_GENL_U=volcanic rocks, G_ROCK_TYP=no data (six polygons). We merged six polygons with adjacent unit volcanic rocks, basalt.
   - GEO_GENL_U=vent and pyroclastic rocks, G_ROCK_TYP=no data (one polygon). We merged one polygon with surrounding unit volcanic rocks, basaltic andesitic.
   - GEO_GENL_U=intrusive rocks, G_ROCK_TYP=no data (one polygon) (four polygons). We merged four polygons with adjacent unit intrusive rocks, intermediate composition lithologies.

   After this process, the database had 182 units.

7. Next, we merged those gelogic units covering only small areas and that had only 1–10 polygons into units on the basis of the following: 1) same GEO_GENL_U, 2) similar G_ROCK_TYP, and 3) spatial correlation; in other words, if individual small polygons were surrounded by like polygons, we merged them. These consisted of:
   - GEO_GENL_U=mélange rocks, G_ROCK_TYP=conglomerate. We merged two very small polygons with surrounding unit mélange rocks, mixed grained sediments.
   - GEO_GENL_U=mélange rocks, G_ROCK_TYP=dacite. We merged six very small polygons with the closest unit, mélange rocks, mixed lithologies.
   - GEO_GENL_U=mélange rocks, G_ROCK_TYP=limestone. We merged six very small polygons with the closest unit, mélange rocks, mudstone.
   - GEO_GENL_U=mélange rocks, G_ROCK_TYP=breccia. There was one very small polygon near Mount Hood where there are no other mélange rocks. This polygon was surrounded by mudflow breccias. The GEO_GENL_U was likely mislabeled, so we merged it with the closest unit, volcaniclasic, mudflow breccia.
   - GEO_GENL_U=mélange rocks, G_ROCK_TYP=ultramafic. We merged five very small polygons with surrounding unit mélange, serpentinite.
   - GEO_GENL_U=mélange rocks, G_ROCK_TYP=schist. We merged five very small polygons with surrounding unit mélange, serpentinite.
   - GEO_GENL_U=batholiths rocks, G_ROCK_TYP=lamprophyre. We merged one very small

polygon with surrounding unit batholiths rocks, intermediate composition lithologies.

- GEO_GENL_U=batholiths rocks, G_ROCK_TYP=mafic composition lithologies. We merged ~six very small polygons with surrounding unit batholiths rocks, intermediate composition lithologies.
- GEO_GENL_U=intrusive rocks, G_ROCK_TYP=trachydacite. We merged one very small polygon with surrounding unit intrusive rocks, intermediate composition lithologies.
- GEO_GENL_U=intrusive rocks, G_ROCK_TYP=marble. We merged one very small polygon with surrounding unit intrusvie rocks, mafic composition lithologies.
- GEO_GENL_U=marine sedimentary rocks, G_ROCK_TYP=marble. We merged one very small polygon with surrounding unit marine sedimentary rocks, quartzite.
- GEO_GENL_U=marine sedimentary rocks, G_ROCK_TYP=marine sedimentary rocks. We merged one very small polygon with nearby unit marine sedimentary rocks, sedimentary rocks.
- GEO_GENL_U=marine sedimentary rocks, G_ROCK_TYP=dolomite. We merged two small polygons with adjacent unit marine sedimentary rocks, fine grained sediments.
- GEO_GENL_U=metamorphic rocks, G_ROCK_TYP=limestone. We merged ~5 small polygons with adjacent unit metamorphic rocks, marine sedimentary rocks.
- GEO_GENL_U=metamorphic rocks, G_ROCK_TYP=gneiss. We merged one very small polygon with nearby unit metamorphic rocks, ultramafic composition lithologies
- GEO_GENL_U=terrestrial sedimentary rocks, G_ROCK_TYP=limestone. We merged three very small polygons with adjacent unit terrestrial sedimentary rocks, fine grained sediments.
- GEO_GENL_U=terrestrial sedimentary rocks, G_ROCK_TYP=basaltic sandstone. We merged one small polygon with the similar unit terrestrial sedimentary rocks, sandstone
- GEO_GENL_U=terrestrial sedimentary rocks, G_ROCK_TYP=mixed lithologies. We merged tens of small polygons with similar unit sediments, mixed grained sediments.
- GEO_GENL_U=sediments, G_ROCK_TYP=tufa. We merged three small polygons with the similar unit sediments, mixed grained sediments.
- GEO_GENL_U=sediments, G_ROCK_TYP=ash. We merged one small polygon with the adjacent unit sediments, mixed grained sediments.
- GEO_GENL_U=sediments, G_ROCK_TYP=sinter deposit. We merged one small polygon with the nearby unit sediments, mixed grained sediments.
- GEO_GENL_U=vent and pyroclastic rocks, G_ROCK_TYP=trachyandesite. We merged one small polygon with unit vent and pyroclastic rocks, andesite unit.
- GEO_GENL_U=vent and pyroclastic rocks, G_ROCK_TYP=dacite. We merged one small polygon with unit vent and pyroclastic rocks, basaltic andesite unit.
- GEO_GENL_U=vent and pyroclastic rocks, G_ROCK_TYP=brecciated rock. We merged one small polygon with surrounding unit vent and pyroclastic rocks, basaltic andesite.
- GEO_GENL_U=vent and pyroclastic rocks, G_ROCK_TYP=vitrophyre. We merged one small polygon with surrounding unit vent and pyroclastic rocks, mixed lithologies.
- GEO_GENL_U=volcaniclastic rocks, G_ROCK_TYP=pumice. We merged five small polygons with unit volcaniclastic rocks, mixed grained sediments.
- GEO_GENL_U=volcaniclastic rocks, G_ROCK_TYP=rhyolite. We merged two small polygons with unit volcaniclastic rocks, rhyodacite.
- GEO_GENL_U=volcaniclastic rocks, G_ROCK_TYP=breccia. We merged about a dozen small polygons with unit volcaniclastic rocks, mixed lithologies.
- GEO_GENL_U=volcaniclastic rocks, G_ROCK_TYP=tuffaceous sedimentary rocks. We merged one small polygon with unit volcaniclastic rocks, mixed lithologies.
- GEO_GENL_U=volcaniclastic rocks, G_ROCK_TYP=basaltic andesite. We merged about five small polygons with unit volcaniclastic rocks, andesite.
- GEO_GENL_U=volcaniclastic rocks, G_ROCK_TYP=rhyodacite. We merged about five small polygons with unit volcaniclastic rocks, dacite.

Performing these merges resulted in 150 units.

8. We combined marine sedimentary rocks_slope channel sandstone and marine sedimentary rocks_tuff with like marine sedimentary rocks.
9. This process resulted in 148 final generalized geologic units. See Table B.1

A.2 Landslide inventory

We used the following procedures to determine the final sets of landslide polygons and landslide points.

Landslide Polygons (Deposits)

1. We started with and landslide polygons from the SLIDO 3.2 database (Burns, 2014): 41,029 landslide polygons.
2. We deleted Fans and Talus-Colluvium (9,869 polygons).
3. We removed all landslides attributed as shallow (4,143 polygons) and saved the removed ploygons as a separate data set for use later in step #5.
4. We split the remaining landslide polygons into two files: lidar landslides (8,504 polygons) and non-lidar landslides (18,513 polygons)
5. From both data sets, we deleted all landslide polygons that had areas less than 35,000 ft². We chose 35,000 ft² as the cutoff because:
    1. 35,000 ft² is less than a 6 × 6 cell area, which means the polygon size is getting close to the resolution of the grid cell size used for the map.
    2. The intended use of the map is to predict future locations of relatively large landslides. Therefore we ran statistics on the areas of the shallow landslide polygons saved in step #3 and found the mean plus 2 standard deviations, or 95% of the shallow slides, was less than 32,000 ft².
6. This resulted in 6,738 lidar landslide polygons and 16,868 non-lidar landslides polygons.
7. For non-lidar landslides:
    a. We merged into one polygon.
    b. We clipped the polygon by geology.
    c. We deleted landslides that had areas less than 35,000 ft².

The final number of non-lidar landslide polygons was 41,500.

8. For lidar landslides:
    a. We ran the Feature to Point tool on polygons.
    b. We ran the Feature to Line tool on polygons.
    c. We ran the Delete Identical on the Line file (step b result).
    d. We ran the Feature to Polygon tool with the Line file (step c result), using the Point file (step a result) in the Label Features option (see Figure A.2.1).
    e. We deleted all polygons with areas less than 9,000 ft².
    f. We hand merged the remaining polygons (see Figure A.2.2).
9. From the lidar landslide set, we removed landslide polygons situated in Washington:
    a. Vancouver quadrangle: 24 polygons
    b. Washougal quadrangle: 45 polygons
    c. Camas quadrangle: 13 polygons

The final number of landslide polygons was 6,629.

Historic Points

1. We started with the Historic Landslide points data set from SLIDO 3.2 (Burns, 2014): 12,095 points.
2. We deleted all Movement class (MOVE_CLASS) points classed as:
    - Debris Flow (255 points)
    - Rockfall; all of these were from ODOT and along roads. (1,051 points).
    - Rock Fall, rock fall, and Rock fall (11 points).
    - debris/rock fall (1 point).
    - Fall (57 points).
    - fall/topple (14 points).
3. We deleted "Type_MTRL" = debris and "MOVE_CLASS" = flow (521 points).
4. We selected by location: point intersects fan polys, then deleted points where the comments field indicated a debris flow or location of point on a fan (37/65 points deleted).
5. We selected by location: point intersects talus/colluvium polys, then deleted points where the comments field indicated a debris flow or location of point on a fan (13/23 deleted).
6. We deleted points with attribute shallow (109 points).
7. We deleted points with areas less than 35,000 ft² (28 points).

The final total of landslide points was 9,997.

Input Features

Z:\GEO_FIT_Statewide_Landslide_Susceptibility\Landslides\GeoFit_landslides.gdb\polyline

Output Feature Class

C:\Users\kate mickelson.PORTLAND\Documents\ArcGIS\Default.gdb\polyline_FeatureToPolygon5

XY Tolerance (optional)

Feet

☑ Preserve attributes (optional)

Label Features (optional)

Z:\GEO_FIT_Statewide_Landslide_Susceptibility\Landslides\GeoFit_landslides.gdb\points

Figure A.2.1. The Esri Feature to Polygon tool is an automated way to remove overlaps in landslide polygons.

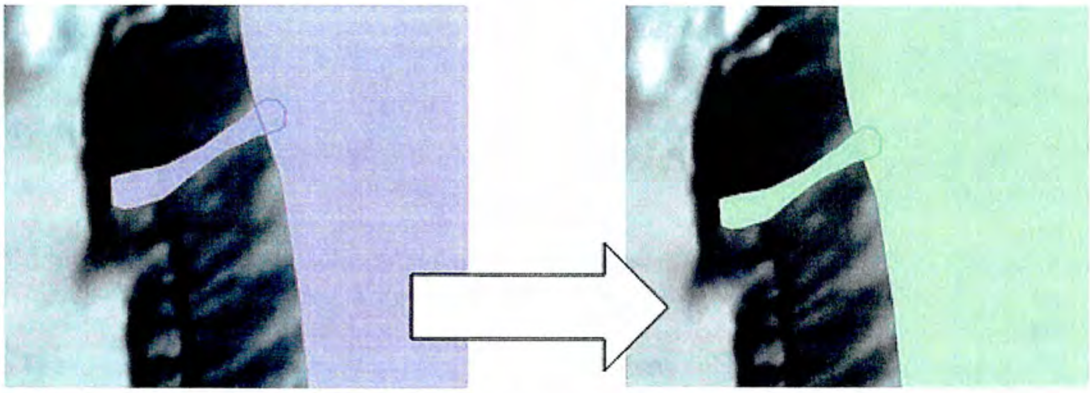

Figure A.2.2. Removing overlaps in landslide polygons.

A.3 Construction of 10-m² digital elevation model (DEM)

1. We gathered all existing lidar-derived bare-earth DEMs for the state of Oregon. The native resolution of most of these lidar data sets was 3-ft² cell size in the NAD1983 HARN Oregon Statewide Lambert projection.
2. We resampled the lidar data to a cell size of 32.8 ft² (10 m²) to match the data resolution available for the rest of the state. In the Environmental Settings, we set the Resample type to Bilinear, which gave us the best reprojection result.
3. We mosaicked the lidar data to a new raster file.
4. Some of the lidar data sets were in a different projection. We mosaicked these raster files with output at a 10-m² cell size, using the same methods as above.
5. We re-projected the raster files into the NAD1983 HARN Oregon Statewide Lambert projection, and we recalculated the elevation values from meters to feet by using the Times tool in Spatial Analyst.
6. We mosaicked data sets from #5 with the ones from #3 above to create a data set of all existing lidar-derived bare-earth DEMs for the state.
7. We acquired the statewide USGS 10-m DEM (NED) from DAS GEO and re-projected it into NAD1983 HARN Oregon Statewide Lambert, again converting elevation values from meters to feet.
8. We mosaicked the NED and lidar-derived DEM together with lidar grids on top of the mosaic.

The result is a 32.8 ft² (10 m²) statewide elevation grid.

Appendix B. Generalized geologic unit details

These data are also available in Excel spreadsheet format (Appendix B_Generalized Geologic Unit Details.xlsx) in the digital appendix folder.

Table B.1. Generalized Geologic Unit Details. STD is standard deviation.

	Generalized Geology	Unit Area, ft^2	Landslide Frequency	Landslide Area/ Geologic Unit Area	Landslide Density Class	Slope Mean, deg	Slope STD, deg	Substitution Unit if No Landslides	Slope High => Mean, deg	Slope Moderate (Upper Bound) < Mean, deg	Slope Moderate (Lower Bound) => (Mean-STD), deg	Slope Low < (Mean-STD), deg
1	batholith rocks_felsic composition lithologies	180,794,000	0	0.1	Low	17.40	5.65	batholith rocks_intermediate composition litholog	17.40	17.40	11.75	11.75
2	batholith rocks_intermediate composition litholog	10,548,599,808	3	0.1	Low	17.40	5.65		17.40	17.40	11.75	11.75
3	batholith rocks_mafic composition lithologies	83,264,800	0	8.4	Moderate	17.40	5.65	batholith rocks_intermediate composition litholog	17.40	17.40	11.75	11.75
4	intrusive rocks_alkali basalt	4,157,400	0	8.4	Moderate	15.45	9.52	intrusive rocks_basalt	15.45	15.45	5.93	5.93
5	intrusive rocks_andesite	465,027,008	6	4.1	Low	22.58	12.76		22.58	22.58	9.81	9.81
6	intrusive rocks_basalt	10,563,900,416	286	8.4	Moderate	15.45	9.52		15.45	15.45	5.93	5.93
7	intrusive rocks_basaltic andesite	77,009,000	0	0.7	Low	12.52	3.49		12.52	12.52	9.03	9.03
8	intrusive rocks_basanite	111,681,000	1	2.6	Low	17.74	10.63		17.74	17.74	7.11	7.11
9	intrusive rocks_breccia	2,604,820	0	5.1	Low	15.21	9.44	intrusive rocks_mixed lithologies	15.21	15.21	5.77	5.77
10	intrusive rocks_brecciated rock	13,996,400	0	5.1	Low	15.21	9.44	intrusive rocks_mixed lithologies	15.21	15.21	5.77	5.77
11	intrusive rocks_dacite	276,081,984	2	1.9	Low	15.65	8.42		15.65	15.65	7.22	7.22
12	intrusive rocks_felsic composition lithologies	3,510,180,096	101	2.2	Low	18.63	7.82		18.63	18.63	10.81	10.81
13	intrusive rocks_gabbro	1,704,649,984	2	1.8	Low	19.10	9.86		19.10	19.10	9.24	9.24

(table continued on next page)

Table B.1. Generalized Geologic Unit Details *(continued)*

	Generalized Geology	Unit Area, ft^2	Landslide Frequency	Landslide Area/ Geologic Unit Area	Landslide Density Class	Slope Mean, deg	Slope STD, deg	Substitution Unit if No Landslides	Slope High => Mean, deg	Slope Moderate (Upper Bound) < Mean, deg	Slope Moderate (Lower Bound) => (Mean-STD), deg	Slope Low < (Mean-STD), deg
14	intrusive rocks_intermediate composition lithology	15,081,799,680	242	3.6	Low	16.23	8.08		16.23	16.23	8.15	8.15
15	intrusive rocks_mafic composition lithologies	14,896,900,096	142	3.6	Low	15.78	8.33		15.78	15.78	7.46	7.46
16	intrusive rocks_mixed lithologies	3,582,259,968	47	5.1	Low	15.21	9.44		15.21	15.21	5.77	5.77
17	intrusive rocks_nepheline syenite	34,438,700	0	0.9	Low	12.55	6.32		12.55	12.55	6.23	6.23
18	intrusive rocks_rhyodacite	20,913,100	1	0.4	Low	10.89	4.21		10.89	10.89	6.67	6.67
19	intrusive rocks_rhyolite	758,097,024	18	6.9	Low	15.18	9.11		15.18	15.18	6.07	6.07
20	intrusive rocks_ultramafic composition lithologies	2,818,860,032	21	3.6	Low	19.98	8.51		19.98	19.98	11.48	11.48
21	invasive extrusive rocks_basalt	2,027,820,032	30	36.0	High	16.46	9.51		16.46	16.46	6.95	6.95
22	marine sedimentary rocks_basalt	179,880,992	0	8.1	Moderate	19.18	7.68		19.18	19.18	11.50	11.50
23	marine sedimentary rocks_basaltic sandstone	1,417,430,016	61	11.5	Moderate	17.88	9.70		17.88	17.88	8.17	8.17
24	marine sedimentary rocks_basin plain mudstone	2,666,289,920	51	3.9	Low	10.30	5.11		10.30	10.30	5.19	5.19
25	marine sedimentary rocks_chert	69,545,200	1	1.0	Low	20.62	5.32		20.62	20.62	15.30	15.30
26	marine sedimentary rocks_coarse grained sediments	5,656,909,824	225	4.6	Low	17.99	9.07		17.99	17.99	8.92	8.92
27	marine sedimentary rocks_conglomerate	2,446,579,968	108	3.2	Low	18.12	9.33		18.12	18.12	8.79	8.79

(table continued on next page)

Table B.1. Generalized Geologic Unit Details *(continued)*

	Generalized Geology	Unit Area, ft^2	Landslide Frequency	Landslide Area/ Geologic Unit Area	Landslide Density Class	Slope Mean, deg	Slope STD, deg	Substitution Unit if No Landslides	Slope High => Mean, deg	Slope Moderate (Upper Bound) < Mean, deg	Slope Moderate (Lower Bound) => (Mean-STD), deg	Slope Low < (Mean-STD), deg
28	marine sedimentary rocks_deltaic sandstone	25,663,799,296	664	5.1	Low	16.69	9.39		16.69	16.69	7.30	7.30
29	marine sedimentary rocks_fine grained sediments	40,649,699,328	585	4.9	Low	15.24	7.74		15.24	15.24	7.50	7.50
30	marine sedimentary rocks_limestone	1,473,469,952	3	2.6	Low	17.76	9.71		17.76	17.76	8.05	8.05
31	marine sedimentary rocks_mixed grained sediments	39,723,798,528	760	9.3	Moderate	16.32	8.07		16.32	16.32	8.25	8.25
32	marine sedimentary rocks_mixed lithologies	1,980,429,952	48	15.5	Moderate	10.70	6.93		10.70	10.70	3.77	3.77
33	marine sedimentary rocks_mudstone	981,353,024	201	18.0	High	14.80	7.73		14.80	14.80	7.06	7.06
34	marine sedimentary rocks_quartzite	788,094,016	6	0.3	Low	21.07	9.31		21.07	21.07	11.76	11.76
35	marine sedimentary rocks_sandstone	14,473,600,000	648	8.1	Moderate	14.02	7.89		14.02	14.02	6.13	6.13
36	marine sedimentary rocks_sedimentary rocks	136,055,008	0	9.3	Moderate	16.32	8.07	marine sedimentary rocks_mixed grained sediments	16.32	16.32	8.25	8.25
37	marine sedimentary rocks_shelf sandstone	8,189,259,776	469	24.0	High	13.86	8.59		13.86	13.86	5.27	5.27
38	marine sedimentary rocks_siltstone	567,308,032	18	5.0	Low	17.80	8.66		17.80	17.80	9.13	9.13
39	marine sedimentary rocks_slope mudstone	34,879,901,696	1148	17.1	High	14.48	8.36		14.48	14.48	6.12	6.12

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Table B.1. Generalized Geologic Unit Details *(continued)*

	Generalized Geology	Unit Area, ft²	Landslide Frequency	Landslide Area/ Geologic Unit Area	Landslide Density Class	Slope Mean, deg	Slope STD, deg	Substitution Unit if No Landslides	Slope High => Mean, deg	Slope Moderate (Upper Bound) < Mean, deg	Slope Moderate (Lower Bound) => (Mean-STD), deg	Slope Low < (Mean-STD), deg
40	marine sedimentary rocks_tuffaceous sedimentary r	11,790,699,520	409	35.3	High	13.07	7.74		13.07	13.07	5.32	5.32
41	marine sedimentary rocks_turbidite	95,471,099,904	3696	7.6	Moderate	15.79	8.80		15.79	15.79	7.00	7.00
42	marine volcanic rocks_basalt	5,132,789,760	166	17.8	High	19.43	10.03		19.43	19.43	9.40	9.40
43	marine volcanic rocks_pillow lavas	2,096,269,952	386	9.0	Moderate	14.77	7.07		14.77	14.77	7.71	7.71
44	melange rocks_basalt	47,127,000	0	0.5	Low	25.19	5.95	melange rocks_volcanic rocks	25.19	25.19	19.25	19.25
45	melange rocks_blueschist	23,567,400	1	27.4	High	16.28	7.69		16.28	16.28	8.59	8.59
46	melange rocks_chert	10,110,600	0	19.7	High	15.69	6.11		15.69	15.69	9.58	9.58
47	melange rocks_gneiss	93,498,800	0	14.0	Moderate	14.04	6.93	melange rocks_mixed lithologies	14.04	14.04	7.11	7.11
48	melange rocks_greenstone	61,177,100	1	0.6	Low	23.41	11.56		23.41	23.41	11.84	11.84
49	melange rocks_hornfels	14,815,300	0	14.0	Moderate	14.04	6.93	melange rocks_mixed lithologies	14.04	14.04	7.11	7.11
50	melange rocks_intermediate composition lithologies	32,433,700	0	14.0	Moderate	14.04	6.93	melange rocks_mixed lithologies	14.04	14.04	7.11	7.11
51	melange rocks_mafic composition lithologies	309,947,008	1	0.5	Low	17.90	6.34		17.90	17.90	11.56	11.56
52	melange rocks_marine sedimentary rocks	16,558,600	0	0.0	Low	21.63	4.68	melange rocks_sedimentary rocks	21.63	21.63	16.95	16.95
53	melange rocks_metamorphic rocks	316,150,016	0	14.0	Moderate	14.04	6.93	melange rocks_mixed lithologies	14.04	14.04	7.11	7.11
54	melange rocks_mixed grained sediments	239,838,000	0	14.0	Moderate	14.04	6.93	melange rocks_mixed lithologies	14.04	14.04	7.11	7.11

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Table B.1. Generalized Geologic Unit Details *(continued)*

	Generalized Geology	Unit Area, ft^2	Landslide Frequency	Landslide Area/ Geologic Unit Area	Landslide Density Class	Slope Mean, deg	Slope STD, deg	Substitution Unit If No Landslides	Slope High => Mean, deg	Slope Moderate (Upper Bound) < Mean, deg	Slope Moderate (Lower Bound) => (Mean-STD), deg	Slope Low < (Mean-STD), deg
55	melange rocks_mixed lithologies	3,089,100,032	113	14.0	Moderate	14.04	6.93		14.04	14.04	7.11	7.11
56	melange rocks_mudstone	1,405,059,968	53	6.0	Low	14.50	6.09		14.50	14.50	8.40	8.40
57	melange rocks_sedimentary rocks	170,484,000	2	0.0	Low	21.63	4.68		21.63	21.63	16.95	16.95
58	melange rocks_serpentinite	4,301,579,776	182	9.9	Moderate	15.17	7.14		15.17	15.17	8.03	8.03
59	melange rocks_turbidite	6,029,810,176	625	18.2	High	16.21	7.08		16.21	16.21	9.13	9.13
60	melange rocks_ultramafic composition lithologies	479,552,992	1	2.0	Low	12.93	5.39		12.93	12.93	7.54	7.54
61	melange rocks_volcanic rocks	354,894,016	1	0.5	Low	25.19	5.95		25.19	25.19	19.25	19.25
62	metamorphic rocks_amphibolite	3,817,609,984	40	3.2	Low	15.64	7.92		15.64	15.64	7.73	7.73
63	metamorphic rocks_chert	1,679,410	0	1.9	Low	14.73	6.50	metamorphic rocks_marine sedimentary rocks	14.73	14.73	8.23	8.23
64	metamorphic rocks_felsic composition lithologies	159,252,992	4	25.8	High	21.62	6.84		21.62	21.62	14.77	14.77
65	metamorphic rocks_fine grained sediments	43,611,400	0	5.4	Low	19.23	8.20	metamorphic rocks_mixed lithologies	19.23	19.23	11.03	11.03
66	metamorphic rocks_greenstone	4,737,339,904	10	4.8	Low	14.45	7.23		14.45	14.45	7.22	7.22
67	metamorphic rocks_hornfels	265,698,000	0	5.4	Low	19.23	8.20	metamorphic rocks_mixed lithologies	19.23	19.23	11.03	11.03
68	metamorphic rocks_mafic composition lithologies	4,012,140,032	25	1.0	Low	20.31	8.09		20.31	20.31	12.22	12.22

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Table B.1. Generalized Geologic Unit Details *(continued)*

	Generalized Geology	Unit Area, ft^2	Landslide Frequency	Landslide Area/ Geologic Unit Area	Landslide Density Class	Slope Mean, deg	Slope STD, deg	Substitution Unit if No Landslides	Slope High => Mean, deg	Slope Moderate (Upper Bound) < Mean, deg	Slope Moderate (Lower Bound) => (Mean-STD), deg	Slope Low < (Mean-STD), deg
69	metamorphic rocks_marble	350,920,992	4	0.5	Low	23.93	7.67		23.93	23.93	16.26	16.26
70	metamorphic rocks_marine sedimentary rocks	992,348,992	46	1.9	Low	14.73	6.50		14.73	14.73	8.23	8.23
71	metamorphic rocks_mixed lithologies	4,324,490,240	207	5.4	Low	19.23	8.20		19.23	19.23	11.03	11.03
72	metamorphic rocks_ quartzite	909,939,008	28	0.6	Low	19.91	7.60		19.91	19.91	12.31	12.31
73	metamorphic rocks_schist	9,031,879,680	316	6.4	Low	18.14	7.64		18.14	18.14	10.50	10.50
74	metamorphic rocks_sedimentary rocks	2,051,849,984	24	3.1	Low	18.75	7.89		18.75	18.75	10.86	10.86
75	metamorphic rocks_serpentinite	1,569,350,016	53	2.9	Low	16.03	8.39		16.03	16.03	7.63	7.63
76	metamorphic rocks_tuff	687,987,968	1	0.7	Low	23.80	6.11		23.80	23.80	17.69	17.69
77	metamorphic rocks_ultramafic composition litholog	6,439,499,776	83	5.7	Low	17.69	8.07		17.69	17.69	9.62	9.62
78	metamorphic rocks_volcanic rocks	14,677,200	1	3.2	Low	25.61	4.98		25.61	25.61	20.62	20.62
79	metamorphic rocks_volcaniclastic rocks	16,943,500	0	3.2	Low	25.61	4.98	metamorphic rocks_volcanic rocks	25.61	25.61	20.62	20.62
80	terrestrial sedimentary rocks_coarse grained sedi	13,842,299,904	62	4.5	Low	12.26	7.24		12.26	12.26	5.03	5.03
81	terrestrial sedimentary rocks_conglomerate	2,789,070,080	39	1.2	Low	10.56	6.81		10.56	10.56	3.75	3.75

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Table B.1. Generalized Geologic Unit Details *(continued)*

	Generalized Geology	Unit Area, ft^2	Landslide Frequency	Landslide Area/ Geologic Unit Area	Landslide Density Class	Slope Mean, deg	Slope STD, deg	Substitution Unit if No Landslides	Slope High => Mean, deg	Slope Moderate (Upper Bound) < Mean, deg	Slope Moderate (Lower Bound) => (Mean-STD), deg	Slope Low < (Mean-STD), deg
82	terrestrial sedimentary rocks_fine grained sedime	33,139,200,000	79	2.0	Low	12.41	7.22		12.41	12.41	5.20	5.20
83	terrestrial sedimentary rocks_mixed grained sedim	55,252,398,080	168	2.0	Low	11.35	7.53		11.35	11.35	3.82	3.82
84	terrestrial sedimentary rocks_mixed lithologies	11,288,500,224	245	2.2	Low	12.05	7.57		12.05	12.05	4.47	4.47
85	terrestrial sedimentary rocks_mudstone	650,190,976	345	27.7	High	13.36	8.24		13.36	13.36	5.12	5.12
86	terrestrial sedimentary rocks_sandstone	3,235,010,048	279	14.8	Moderate	12.18	7.18		12.18	12.18	5.00	5.00
87	terrestrial sedimentary rocks_tuffaceous sediment	67,723,300,864	114	2.5	Low	12.49	8.03		12.49	12.49	4.45	4.45
88	terrestrial sedimentary rocks_turbidite	2,912,360	0	4.9	Low	12.41	7.22	marine sedimentary rocks_fine grained sediments	12.41	12.41	5.20	5.20
89	vent and pyroclastic rocks_andesite	245,724,000	2	0.9	Low	23.93	6.95		23.93	23.93	16.98	16.98
90	vent and pyroclastic rocks_basalt	6,930,509,824	4	0.2	Low	18.44	8.98		18.44	18.44	9.45	9.45
91	vent and pyroclastic rocks_basalt trachyandesite	27,678,500	0	9.8	Moderate	10.32	7.42	volcanic rocks_basalt trachyandesite	10.32	10.32	2.90	2.90
92	vent and pyroclastic rocks_basaltic andesite	656,190,016	3	1.9	Low	12.27	8.10		12.27	12.27	4.17	4.17
93	vent and pyroclastic rocks_felsic composition lit	177,392,992	0	0.4	Low	13.06	7.87	vent and pyroclastic rocks_mixed lithologies	13.06	13.06	5.19	5.19

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Table B.1. Generalized Geologic Unit Details *(continued)*

	Generalized Geology	Unit Area, ft^2	Landslide Frequency	Landslide Area/ Geologic Unit Area	Landslide Density Class	Slope Mean, deg	Slope STD, deg	Substitution Unit if No Landslides	Slope High => Mean, deg	Slope Moderate (Upper Bound) < Mean, deg	Slope Moderate (Lower Bound) => (Mean-STD), deg	Slope Low < (Mean-STD), deg
94	vent and pyroclastic rocks_intermediate compositi	101,398,000	3	9.6	Moderate	11.68	6.18		11.68	11.68	5.50	5.50
95	vent and pyroclastic rocks_mafic composition lith	10,948,800,512	2	0.3	Low	17.25	8.84		17.25	17.25	8.41	8.41
96	vent and pyroclastic rocks_mixed grained sediments	27,434,400	0	0.4	Low	13.06	7.87	vent and pyroclastic rocks_mixed lithologies	13.06	13.06	5.19	5.19
97	vent and pyroclastic rocks_mixed lithologies	4,759,139,840	1	0.4	Low	13.06	7.87		13.06	13.06	5.19	5.19
98	vent and pyroclastic rocks_palagonite tuff	1,173,180,032	0	0.4	Low	13.06	7.87	vent and pyroclastic rocks_mixed lithologies	13.06	13.06	5.19	5.19
99	vent and pyroclastic rocks_rhyodacite	347,207,008	3	15.2	Moderate	18.44	8.67		18.44	18.44	9.77	9.77
100	vent and pyroclastic rocks_rhyolite	2,785,619,968	0	0.4	Low	13.06	7.87	vent and pyroclastic rocks_mixed lithologies	13.06	13.06	5.19	5.19
101	vent and pyroclastic rocks_volcanic rocks	27,373,500	0	0.4	Low	13.06	7.87	vent and pyroclastic rocks_mixed lithologies	13.06	13.06	5.19	5.19
102	volcanic rocks_alkali basalt	161,908,992	2	5.0	Low	9.27	4.10		9.27	9.27	5.18	5.18
103	volcanic rocks_andesite	101,151,997,952	1158	7.7	Moderate	14.68	9.15		14.68	14.68	5.53	5.53
104	volcanic rocks_ash-flow tuff	475,484,992	43	27.7	High	11.30	6.28		11.30	11.30	5.03	5.03
105	volcanic rocks_basalt	799,083,986,944	3392	2.0	Low	14.06	9.36		14.06	14.06	4.70	4.70
106	volcanic rocks_basalt trachyandesite	11,272,800,256	58	9.8	Moderate	10.32	7.42		10.32	10.32	2.90	2.90
107	volcanic rocks_basaltic andesite	76,228,501,504	327	1.9	Low	13.24	8.06		13.24	13.24	5.18	5.18

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Table B.1. Generalized Geologic Unit Details *(continued)*

	Generalized Geology	Unit Area, ft^2	Landslide Frequency	Landslide Area/ Geologic Unit Area	Landslide Density Class	Slope Mean, deg	Slope STD, deg	Substitution Unit if No Landslides	Slope High => Mean, deg	Slope Moderate (Upper Bound) < Mean, deg	Slope Moderate (Lower Bound) => (Mean-STD), deg	Slope Low < (Mean-STD), deg
108	volcanic rocks_basanite	363,599,008	6	11.1	Moderate	17.45	7.09		17.45	17.45	10.36	10.36
109	volcanic rocks_dacite	10,567,400,448	59	5.1	Low	14.35	8.09		14.35	14.35	6.26	6.26
110	volcanic rocks_felsic composition lithologies	5,362,160,128	62	5.2	Low	15.74	8.56		15.74	15.74	7.18	7.18
111	volcanic rocks_greenstone	5,540,669,952	15	4.9	Low	10.24	6.95		10.24	10.24	3.29	3.29
112	volcanic rocks_intermediate composition lithologi	6,223,240,192	126	13.7	Moderate	14.00	8.80		14.00	14.00	5.20	5.20
113	volcanic rocks_mafic composition lithologies	56,834,498,560	296	5.8	Low	14.31	8.74		14.31	14.31	5.57	5.57
114	volcanic rocks_mixed lithologies	115,082,002,432	746	5.4	Low	13.27	8.15		13.27	13.27	5.12	5.12
115	volcanic rocks_pillow lavas	15,229,400,064	471	3.7	Low	17.29	9.01		17.29	17.29	8.28	8.28
116	volcanic rocks_rhyodacite	9,860,119,552	11	0.4	Low	18.66	9.27		18.66	18.66	9.39	9.39
117	volcanic rocks_rhyolite	30,387,599,360	85	2.8	Low	13.95	8.45		13.95	13.95	5.50	5.50
118	volcanic rocks_trachyandesite	3,172,489,984	16	5.5	Low	9.60	5.70		9.60	9.60	3.90	3.90
119	volcanic rocks_trachyrhyodacite	753,340,032	0	5.5	Low	9.60	5.70	volcanic rocks_trachyandesite	9.60	9.60	3.90	3.90
120	volcanic rocks_tuff	515,476,992	3	6.3	Low	11.68	7.28		11.68	11.68	4.40	4.40
121	volcanic rocks_volcanic rocks	1,781,510,016	199	38.5	High	11.51	6.37		11.51	11.51	5.15	5.15
122	volcaniclastic rocks_airfall deposits	13,443,399,680	0	0.1	Low	12.02	6.62		12.02	12.02	5.41	5.41
123	volcaniclastic rocks_andesite	605,153,984	6	1.4	Low	18.34	9.10		18.34	18.34	9.24	9.24
124	volcaniclastic rocks_ash-flow tuff	122,157,998,080	183	0.9	Low	14.68	9.26		14.68	14.68	5.43	5.43

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Table B.1. Generalized Geologic Unit Details *(continued)*

	Generalized Geology	Unit Area, ft^2	Landslide Frequency	Landslide Area/ Geologic Unit Area	Landslide Density Class	Slope Mean, deg	Slope STD, deg	Substitution Unit if No Landslides	Slope High => Mean, deg	Slope Moderate (Upper Bound) < Mean, deg	Slope Moderate (Lower Bound) => (Mean-STD), deg	Slope Low < (Mean-STD), deg
125	volcaniclastic rocks_basalt	606,001,024	57	45.4	High	16.20	10.15		16.20	16.20	6.05	6.05
126	volcaniclastic rocks_brecciated rock	1,614,680,064	1	0.2	Low	14.35	6.64		14.35	14.35	7.71	7.71
127	volcaniclastic rocks_coarse grained sediments	6,551,580,160	80	14.0	Moderate	14.03	7.82		14.03	14.03	6.20	6.20
128	volcaniclastic rocks_felsic composition lithologi	17,828,900,864	63	8.2	Moderate	13.56	8.58		13.56	13.56	4.98	4.98
129	volcaniclastic rocks_fine grained sediments	5,601,990,144	13	3.8	Low	10.76	6.72		10.76	10.76	4.03	4.03
130	volcaniclastic rocks_intermediate composition lit	1,384,550,016	9	1.1	Low	17.97	10.30		17.97	17.97	7.68	7.68
131	volcaniclastic rocks_mafic composition lithologies	584,782,016	0	10.9	Moderate	19.39	11.13	volcaniclastic rocks_mixed grained sediments	19.39	19.39	8.26	8.26
132	volcaniclastic rocks_mixed grained sediments	415,331,008	66	10.9	Moderate	19.39	11.13		19.39	19.39	8.26	8.26
133	volcaniclastic rocks_mixed lithologies	80,244,998,144	951	7.5	Moderate	14.31	9.00		14.31	14.31	5.31	5.31
134	volcaniclastic rocks_mudflow breccia	6,151,810,048	298	15.0	Moderate	19.08	10.85		19.08	19.08	8.22	8.22
135	volcaniclastic rocks_palagonite tuff	5,483,970,048	7	0.6	Low	16.42	8.59		16.42	16.42	7.83	7.83
136	volcaniclastic rocks_rhyodacite	388,414,016	5	4.4	Low	13.56	8.58	volcaniclastic rocks_felsic composition lithologi	13.56	13.56	4.98	4.98
137	volcaniclastic rocks_sandstone	349,228,000	172	39.9	High	13.07	8.11		13.07	13.07	4.96	4.96
138	volcaniclastic rocks_sedimentary rocks	2,261,890,048	258	36.9	High	11.60	6.89		11.60	11.60	4.71	4.71
139	volcaniclastic rocks_tuff	51,977,400,320	586	13.0	Moderate	15.65	9.21		15.65	15.65	6.45	6.45

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Table B.1. Generalized Geologic Unit Details *(continued)*

	Generalized Geology	Unit Area, ft^2	Landslide Frequency	Landslide Area/ Geologic Unit Area	Landslide Density Class	Slope Mean, deg	Slope STD, deg	Substitution Unit if No Landslides	Slope High => Mean, deg	Slope Moderate (Upper Bound) < Mean, deg	Slope Moderate (Lower Bound) => (Mean-STD), deg	Slope Low < (Mean-STD), deg
140	volcaniclastic rocks_volcaniclastic rocks	1,195,510,016	50	8.0	Moderate	12.35	6.78		12.35	12.35	5.57	5.57
141	volcaniclastic rocks_welded tuff	21,104,300,032	124	4.9	Low	13.70	8.11		13.70	13.70	5.59	5.59
142	sediments_ coarse grained sediments	15,792,900,096	14	0.4	Low	10.54	7.64	sediments_ mixed grained sediments	10.54	10.54	2.89	2.89
143	sediments_ fine grained sediments	82,409,603,072	196	0.3	Low	10.54	7.64	sediments_ mixed grained sediments	10.54	10.54	2.89	2.89
144	sediments_ ice	167,380,992	0	2.1	Low	10.54	7.64	sediments_ mixed grained sediments	10.54	10.54	2.89	2.89
145	sediments_ metamorphic rocks	69,495,000	9	1.7	Low	22.02	7.46		22.02	22.02	14.56	14.56
146	sediments_ mixed grained sediments	374,805,987,328	1192	2.1	Low	10.54	7.64		10.54	10.54	2.89	2.89
147	sediments_ mudflow breccia	83,508,000	0	2.1	Low	10.54	7.64	sediments_ mixed grained sediments	10.54	10.54	2.89	2.89
148	sediments_ turbidite	94,284,304	0	2.1	Low	10.54	7.64	sediments_ mixed grained sediments	10.54	10.54	2.89	2.89

Appendix C. Landslide susceptibility exposure details

C.1 Oregon cities

Table C.1 data are also available in Excel spreadsheet format (C_1_Cities_LS_Suscep.xlsx) in the digital appendix folder.

Table C.1. Landslide Susceptibility Exposure of Oregon Cities

			Landslide Susceptibility Exposure, ft^2				Landslide Susceptibility Exposure, %			
	City	Area, ft^2	Low	Moderate	High	Very High	Low	Moderate	High	Very High
1	Adair Village	6,502,473	4,831,914	1,650,107	20,451		74.3%	25.4%	0.3%	0.0%
2	Adams	10,047,074	8,647,766	1,331,496	67,813		86.1%	13.3%	0.7%	0.0%
3	Adrian	6,791,006	4,631,765	2,086,046	73,195		68.2%	30.7%	1.1%	0.0%
4	Albany	493,730,826	383,109,043	101,264,716	9,348,456	08,611	77.6%	20.5%	1.9%	0.0%
5	Amity	17,399,913	14,141,678	2,539,206	719,029		81.3%	14.6%	4.1%	0.0%
6	Antelope	12,855,262	715,724	12,119,087	20,451		5.6%	94.3%	0.2%	0.0%
7	Arlington	90,501,540	57,117,272	22,823,796	10,560,473		63.1%	25.2%	11.7%	0.0%
8	Ashland	182,893,560	72,236,256	77,903,802	32,590,968	162,535	39.5%	42.6%	17.8%	0.1%
9	Astoria	284,243,880	117,733,720	56,341,536	62,951,654	47,216,969	41.4%	19.8%	22.1%	16.6%
10	Athena	14,999,561	13,719,732	1,269,065	10,764		91.5%	8.5%	0.1%	0.0%
11	Aumsville	30,637,393	28,494,299	1,961,184	181,910		93.0%	6.4%	0.6%	0.0%
12	Aurora	13,534,706	7,537,055	4,836,225	1,161,426		55.7%	35.7%	8.6%	0.0%
13	Baker City	201,005,707	141,939,825	34,968,716	24,097,166		70.6%	17.4%	12.0%	0.0%
14	Bandon	88,960,027	65,511,924	15,382,704	7,015,917	1,049,481	73.6%	17.3%	7.9%	1.2%
15	Banks	10,375,465	8,733,969	1,523,093	118,403		84.2%	14.7%	1.1%	0.0%
16	Barlow	1,498,532	1,466,241	32,292			97.8%	2.2%	0.0%	0.0%
17	Bay City	53,898,193	26,126,228	7,203,209	2,084,969	18,483,787	48.5%	13.4%	3.9%	34.3%
18	Beaverton	523,956,667	313,957,080	188,689,197	19,146,844	2,163,546	59.9%	36.0%	3.7%	0.4%
19	Bend	929,767,080	712,058,381	181,520,432	36,188,267		76.6%	19.5%	3.9%	0.0%
20	Boardman	112,562,441	97,905,224	13,755,201	902,016		87.0%	12.2%	0.8%	0.0%
21	Bonanza	22,832,023	17,094,858	5,045,045	692,119		74.9%	22.1%	3.0%	0.0%
22	Brookings	116,049,956	37,070,839	49,439,717	26,259,636	3,279,764	31.9%	42.6%	22.6%	2.8%
23	Brownsville	35,575,433	23,386,381	4,919,107	6,893,208	376,737	65.7%	13.8%	19.4%	1.1%
24	Burns	99,648,808	92,356,258	5,944,908	1,347,642		92.7%	6.0%	1.4%	0.0%
25	Butte Falls	10,731,642	8,982,506	1,049,481	699,654		83.7%	9.8%	6.5%	0.0%
26	Canby	121,922,939	108,736,073	10,961,966	2,224,900		89.2%	9.0%	1.8%	0.0%
27	Cannon Beach	40,483,346	18,734,865	10,650,889	2,574,727	8,522,864	46.3%	26.3%	6.4%	21.1%
28	Canyon City	38,600,926	3,751,689	12,492,594	18,997,225	3,359,416	9.7%	32.4%	49.2%	8.7%
29	Canyonville	26,805,376	11,220,310	7,987,898	7,597,168		41.9%	29.8%	28.3%	0.0%
30	Carlton	24,865,027	15,604,835	8,143,975	1,116,218		62.8%	32.8%	4.5%	0.0%
31	Cascade Locks	82,944,979	42,818,197	12,134,156	7,203,209	20,789,417	51.6%	14.6%	8.7%	25.1%
32	Cave Junction	49,309,811	36,907,633	8,973,872	3,428,305		74.8%	18.2%	7.0%	0.0%
33	Central Point	107,071,293	98,437,560	7,992,203	641,529		91.9%	7.5%	0.6%	0.0%
34	Chiloquin	21,205,490	16,301,452	3,749,070	1,154,968		76.9%	17.7%	5.4%	0.0%
35	Clatskanie	33,986,115	6,262,588	3,929,904	16,162,011	7,631,612	18.4%	11.6%	47.6%	22.5%

(table continued on next page)

Table C.1. Landslide Susceptibility Exposure of Oregon Cities *(continued)*

			Landslide Susceptibility Exposure, ft²				Landslide Susceptibility Exposure, %			
	City	Area, ft²	Low	Moderate	High	Very High	Low	Moderate	High	Very High
36	Coburg	28,193,496	26,240,923	1,925,664	26,910		93.1%	6.8%	0.1%	0.0%
37	Columbia City	32,536,182	20,209,352	9,157,935	3,154,902	13,993	62.1%	28.1%	9.7%	0.0%
38	Condon	22,758,604	21,568,116	1,190,488			94.8%	5.2%	0.0%	0.0%
39	Coos Bay	449,002,677	279,589,491	90,908,758	71,927,679	6,576,749	62.3%	20.2%	16.0%	1.5%
40	Coquille	76,098,101	20,009,517	25,322,099	24,715,015	6,051,470	26.3%	33.3%	32.5%	8.0%
41	Cornelius	56,007,097	50,756,461	4,685,530	565,105		90.6%	8.4%	1.0%	0.0%
42	Corvallis	398,128,460	255,682,099	133,975,164	8,280,676	190,521	64.2%	33.7%	2.1%	0.0%
43	Cottage Grove	106,649,738	83,241,462	20,213,547	3,194,729		78.1%	19.0%	3.0%	0.0%
44	Cove	22,377,224	11,365,744	8,262,378	2,749,103		50.8%	36.9%	12.3%	0.0%
45	Creswell	47,917,456	42,869,182	4,819,003	229,271		89.5%	10.1%	0.5%	0.0%
46	Culver	19,219,963	19,141,386	78,577			99.6%	0.4%	0.0%	0.0%
47	Dallas	135,561,360	91,209,743	18,193,161	26,158,455		67.3%	13.4%	19.3%	0.0%
48	Damascus	430,099,603	197,582,992	155,394,269	62,580,299	14,542,043	45.9%	36.1%	14.6%	3.4%
49	Dayton	21,139,259	15,029,663	3,943,897	2,165,699		71.1%	18.7%	10.2%	0.0%
50	Dayville	13,395,202	6,827,064	2,836,290	1,656,566	2,075,282	51.0%	21.2%	12.4%	15.5%
51	Depoe Bay	50,271,265	9,850,628	13,071,693	21,282,404	6,066,540	19.6%	26.0%	42.3%	12.1%
52	Detroit	26,659,361	12,120,547	9,056,754	5,482,060		45.5%	34.0%	20.6%	0.0%
53	Donald	7,787,724	7,728,523	59,202			99.2%	0.8%	0.0%	0.0%
54	Drain	17,288,670	8,406,291	6,081,609	2,800,769		48.6%	35.2%	16.2%	0.0%
55	Dufur	16,272,333	10,249,926	5,557,407	465,001		63.0%	34.2%	2.9%	0.0%
56	Dundee	38,346,886	22,888,834	13,042,630	2,415,421		59.7%	34.0%	6.3%	0.0%
57	Dunes City	96,073,828	30,985,538	51,467,638	13,596,972	23,681	32.3%	53.6%	14.2%	0.0%
58	Durham	11,438,791	7,886,700	2,501,533	1,050,558		68.9%	21.9%	9.2%	0.0%
59	Eagle Point	81,613,814	26,516,585	50,718,469	4,378,759		32.5%	62.1%	5.4%	0.0%
60	Echo	16,039,344	11,166,521	4,365,842	506,980		69.6%	27.2%	3.2%	0.0%
61	Elgin	27,061,424	22,334,991	4,066,605	659,828		82.5%	15.0%	2.4%	0.0%
62	Elkton	5,644,785	-04,115	5,373,344	275,556		-0.1%	95.2%	4.9%	0.0%
63	Enterprise	39,805,554	26,642,368	8,791,962	2,017,157	2,354,067	66.9%	22.1%	5.1%	5.9%
64	Estacada	62,896,341	37,640,978	9,205,296	14,402,112	1,647,955	59.8%	14.6%	22.9%	2.6%
65	Eugene	1,225,382,361	800,412,413	335,475,567	66,663,050	22,831,330	65.3%	27.4%	5.4%	1.9%
66	Fairview	96,035,709	60,730,083	30,284,262	5,021,364		63.2%	31.5%	5.2%	0.0%
67	Falls City	33,481,019	8,242,879	5,393,796	19,844,345		24.6%	16.1%	59.3%	0.0%
68	Florence	164,025,566	108,460,108	42,242,966	13,322,492		66.1%	25.8%	8.1%	0.0%
69	Forest Grove	171,253,021	128,102,657	26,048,663	15,285,829	1,815,872	74.8%	15.2%	8.9%	1.1%
70	Fossil	21,837,713	-59,310	14,032,910	515,591	7,348,522	-0.3%	64.3%	2.4%	33.7%
71	Garibaldi	37,176,767	14,712,486	2,939,624	7,083,729	12,440,928	39.6%	7.9%	19.1%	33.5%
72	Gaston	9,598,220	1,911,711	6,466,957	1,219,551		19.9%	67.4%	12.7%	0.0%
73	Gates	17,683,876	8,875,768	5,712,407	3,095,701		50.2%	32.3%	17.5%	0.0%
74	Gearhart	50,545,983	32,413,099	15,587,219	2,439,102	106,563	64.1%	30.8%	4.8%	0.2%
75	Gervais	10,716,349	10,579,647	136,702			98.7%	1.3%	0.0%	0.0%
76	Gladstone	69,974,152	49,557,167	15,533,399	3,233,479	1,650,107	70.8%	22.2%	4.6%	2.4%
77	Glendale	10,965,472	5,556,607	3,793,202	1,615,663		50.7%	34.6%	14.7%	0.0%

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Table C.1. Landslide Susceptibility Exposure of Oregon Cities *(continued)*

			Landslide Susceptibility Exposure, ft²				Landslide Susceptibility Exposure, %			
	City	Area, ft²	Low	Moderate	High	Very High	Low	Moderate	High	Very High
78	Gold Beach	74,149,696	24,899,424	22,029,419	21,461,085	5,759,768	33.6%	29.7%	28.9%	7.8%
79	Gold Hill	20,166,729	10,304,835	5,621,990	4,239,904		51.1%	27.9%	21.0%	0.0%
80	Granite	10,569,031	3,658,600	4,277,578	2,632,852		34.6%	40.5%	24.9%	0.0%
81	Grants Pass	306,611,299	223,194,222	63,034,536	20,382,541		72.8%	20.6%	6.6%	0.0%
82	Grass Valley	14,217,570	12,226,247	1,913,823	77,500		86.0%	13.5%	0.5%	0.0%
83	Greenhorn	2,409,944	603,760	1,526,322	279,862		25.1%	63.3%	11.6%	0.0%
84	Gresham	655,176,345	436,098,476	153,111,244	63,947,315	2,019,310	66.6%	23.4%	9.8%	0.3%
85	Haines	21,065,791	20,419,956	645,835			96.9%	3.1%	0.0%	0.0%
86	Halfway	10,412,591	10,412,591				100.0%	0.0%	0.0%	0.0%
87	Halsey	15,747,777	15,446,387	301,389			98.1%	1.9%	0.0%	0.0%
88	Happy Valley	255,471,143	91,850,017	124,068,061	38,962,127	590,939	36.0%	48.6%	15.3%	0.2%
89	Harrisburg	40,248,157	37,536,728	2,121,567	589,862		93.3%	5.3%	1.5%	0.0%
90	Helix	3,550,496	3,281,398	269,098			92.4%	7.6%	0.0%	0.0%
91	Heppner	34,307,735	7,345,215	19,437,469	7,525,050		21.4%	56.7%	21.9%	0.0%
92	Hermiston	222,701,378	203,323,110	18,250,210	1,128,058		91.3%	8.2%	0.5%	0.0%
93	Hillsboro	665,310,594	542,574,029	108,698,273	14,038,292		81.6%	16.3%	2.1%	0.0%
94	Hines	58,915,900	48,665,428	9,288,178	962,294		82.6%	15.8%	1.6%	0.0%
95	Hood River	93,822,728	55,837,965	27,591,132	10,039,499	354,133	59.5%	29.4%	10.7%	0.4%
96	Hubbard	19,587,769	18,157,245	1,060,245	370,279		92.7%	5.4%	1.9%	0.0%
97	Huntington	20,476,011	8,591,578	7,243,035	4,641,398		42.0%	35.4%	22.7%	0.0%
98	Idanha	23,496,523	7,018,053	6,146,193	4,926,642	5,405,636	29.9%	26.2%	21.0%	23.0%
99	Imbler	6,013,929	5,460,664	553,265			90.8%	9.2%	0.0%	0.0%
100	Independence	82,442,831	72,845,729	8,106,301	1,490,802		88.4%	9.8%	1.8%	0.0%
101	Ione	18,907,066	9,120,518	6,418,520	3,368,028		48.2%	33.9%	17.8%	0.0%
102	Irrigon	44,926,107	39,249,220	5,601,539	75,347		87.4%	12.5%	0.2%	0.0%
103	Island City	27,315,950	25,841,294	1,404,690	69,965		94.6%	5.1%	0.3%	0.0%
104	Jacksonville	53,163,321	26,784,206	16,949,930	9,429,186		50.4%	31.9%	17.7%	0.0%
105	Jefferson	22,291,901	20,144,501	1,961,184	186,216		90.4%	8.8%	0.8%	0.0%
106	John Day	68,803,023	24,160,781	16,949,930	13,350,478	14,341,834	35.1%	24.6%	19.4%	20.8%
107	Johnson City	1,896,509	1,401,369	440,244	54,896		73.9%	23.2%	2.9%	0.0%
108	Jordan Valley	57,948,263	41,288,959	10,098,701	6,560,603		71.3%	17.4%	11.3%	0.0%
109	Joseph	25,011,507	21,558,445	3,081,708	371,355		86.2%	12.3%	1.5%	0.0%
110	Junction City	90,422,755	86,214,066	4,204,383	04,306		95.3%	4.6%	0.0%	0.0%
111	Keizer	202,393,226	179,024,776	19,774,380	3,594,070		88.5%	9.8%	1.8%	0.0%
112	King City	19,890,612	14,204,038	5,278,622	407,952		71.4%	26.5%	2.1%	0.0%
113	Klamath Falls	573,575,428	270,337,773	190,949,618	112,154,565	133,472	47.1%	33.3%	19.6%	0.0%
114	La Grande	128,160,058	102,209,347	15,551,698	2,723,269	7,675,745	79.8%	12.1%	2.1%	6.0%
115	La Pine	194,669,670	190,154,210	4,343,238	172,223		97.7%	2.2%	0.1%	0.0%
116	Lafayette	24,326,932	12,673,923	8,983,560	2,669,450		52.1%	36.9%	11.0%	0.0%
117	Lake Oswego	317,377,635	133,455,774	138,422,812	40,859,804	4,639,245	42.0%	43.6%	12.9%	1.5%
118	Lakeside	63,150,962	37,569,453	11,946,864	12,281,622	1,353,024	59.5%	18.9%	19.4%	2.1%

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Table C.1. Landslide Susceptibility Exposure of Oregon Cities *(continued)*

			Landslide Susceptibility Exposure, ft²				Landslide Susceptibility Exposure, %			
	City	Area, ft²	Low	Moderate	High	Very High	Low	Moderate	High	Very High
119	Lakeview	68,487,997	50,159,211	8,448,593	9,880,193		73.2%	12.3%	14.4%	0.0%
120	Lebanon	189,742,294	162,255,572	11,720,822	10,530,334	5,235,566	85.5%	6.2%	5.5%	2.8%
121	Lexington	12,483,669	7,088,797	4,929,871	465,001		56.8%	39.5%	3.7%	0.0%
122	Lincoln City	166,883,441	38,264,399	40,029,906	82,727,110	5,862,026	22.9%	24.0%	49.6%	3.5%
123	Lonerock	28,613,118	4,259,771	19,695,803	4,657,544		14.9%	68.8%	16.3%	0.0%
124	Long Creek	28,142,077	25,190,613	2,951,464			89.5%	10.5%	0.0%	0.0%
125	Lostine	7,979,980	7,166,228	512,362	301,389		89.8%	6.4%	3.8%	0.0%
126	Lowell	31,684,873	14,358,206	14,528,050	2,798,617		45.3%	45.9%	8.8%	0.0%
127	Lyons	24,374,762	20,979,825	2,835,214	559,723		86.1%	11.6%	2.3%	0.0%
128	Madras	138,729,533	103,485,262	31,199,194	4,045,078		74.6%	22.5%	2.9%	0.0%
129	Malin	13,940,913	12,676,154	1,139,898	124,861		90.9%	8.2%	0.9%	0.0%
130	Manzanita	22,951,252	9,161,606	9,516,373	3,205,493	1,067,780	39.9%	41.5%	14.0%	4.7%
131	Maupin	39,844,166	10,625,532	13,266,520	14,532,355	1,419,760	26.7%	33.3%	36.5%	3.6%
132	Maywood Park	4,659,279	3,089,901	1,213,093	356,285		66.3%	26.0%	7.6%	0.0%
133	McMinnville	293,827,529	235,497,898	36,205,489	22,124,141		80.1%	12.3%	7.5%	0.0%
134	Medford	715,933,475	420,235,939	233,209,807	44,206,304	18,281,425	58.7%	32.6%	6.2%	2.6%
135	Merrill	12,240,962	11,840,545	400,417			96.7%	3.3%	0.0%	0.0%
136	Metolius	13,310,280	12,884,029	389,654	36,597		96.8%	2.9%	0.3%	0.0%
137	Mill City	23,105,987	17,208,440	3,908,376	1,989,171		74.5%	16.9%	8.6%	0.0%
138	Millersburg	126,183,608	101,937,899	20,647,333	3,598,375		80.8%	16.4%	2.9%	0.0%
139	Milton-Freewater	54,481,595	46,566,892	5,627,372	2,287,331		85.5%	10.3%	4.2%	0.0%
140	Milwaukie	137,561,959	88,671,201	42,977,065	5,913,692		64.5%	31.2%	4.3%	0.0%
141	Mitchell	35,606,271	3,513,672	17,432,153	14,660,446		9.9%	49.0%	41.2%	0.0%
142	Molalla	65,771,550	62,954,635	2,742,644	74,271		95.7%	4.2%	0.1%	0.0%
143	Monmouth	58,577,531	53,363,493	5,096,712	117,327		91.1%	8.7%	0.2%	0.0%
144	Monroe	13,254,822	9,940,614	3,213,027	101,181		75.0%	24.2%	0.8%	0.0%
145	Monument	14,182,111	8,142,480	5,018,135	1,021,495		57.4%	35.4%	7.2%	0.0%
146	Moro	13,725,435	5,044,342	8,647,726	33,368		36.8%	63.0%	0.2%	0.0%
147	Mosier	17,517,333	5,163,593	1,751,288	1,362,711	9,239,741	29.5%	10.0%	7.8%	52.7%
148	Mt. Angel	29,486,393	26,246,456	3,094,624	145,313		89.0%	10.5%	0.5%	0.0%
149	Mt. Vernon	19,248,051	11,231,091	3,812,577	4,204,383		58.3%	19.8%	21.8%	0.0%
150	Myrtle Creek	68,324,272	28,436,449	25,831,232	13,122,283	934,307	41.6%	37.8%	19.2%	1.4%
151	Myrtle Point	44,648,927	15,969,564	18,379,377	6,276,436	4,023,550	35.8%	41.2%	14.1%	9.0%
152	Nehalem	7,452,353	286,818	122,709	1,337,954	5,704,873	3.8%	1.6%	18.0%	76.6%
153	Newberg	162,397,179	121,280,118	32,637,253	7,938,384	541,425	74.7%	20.1%	4.9%	0.3%
154	Newport	291,240,190	128,789,101	56,861,433	83,676,487	21,913,169	44.2%	19.5%	28.7%	7.5%
155	North Bend	141,780,912	98,812,458	31,691,105	11,277,349		69.7%	22.4%	8.0%	0.0%
156	North Plains	25,226,515	20,045,845	4,900,808	279,862		79.5%	19.4%	1.1%	0.0%
157	North Powder	17,417,513	16,018,205	1,182,954	216,355		92.0%	6.8%	1.2%	0.0%
158	Nyssa	43,306,926	37,732,296	4,272,196	1,302,433		87.1%	9.9%	3.0%	0.0%
159	Oakland	20,565,744	11,379,823	7,687,585	1,498,336		55.3%	37.4%	7.3%	0.0%

(table continued on next page)

Table C.1. Landslide Susceptibility Exposure of Oregon Cities *(continued)*

			Landslide Susceptibility Exposure, ft²				Landslide Susceptibility Exposure, %			
	City	Area, ft²	Low	Moderate	High	Very High	Low	Moderate	High	Very High
160	Oakridge	58,231,688	33,767,472	17,015,590	7,448,626		58.0%	29.2%	12.8%	0.0%
161	Ontario	147,310,728	134,593,168	11,133,113	1,584,448		91.4%	7.6%	1.1%	0.0%
162	Oregon City	278,148,504	200,125,223	44,903,805	22,695,705	10,423,771	71.9%	16.1%	8.2%	3.7%
163	Paisley	11,938,629	10,117,375	1,325,037	496,216		84.7%	11.1%	4.2%	0.0%
164	Pendleton	317,155,211	172,742,283	114,561,375	29,851,553		54.5%	36.1%	9.4%	0.0%
165	Philomath	56,547,689	39,803,350	15,219,093	1,525,246		70.4%	26.9%	2.7%	0.0%
166	Phoenix	37,694,474	28,640,949	7,841,509	1,212,016		76.0%	20.8%	3.2%	0.0%
167	Pilot Rock	41,472,261	27,447,962	11,241,828	2,782,471		66.2%	27.1%	6.7%	0.0%
168	Port Orford	45,796,683	15,320,823	15,566,767	13,785,340	1,123,752	33.5%	34.0%	30.1%	2.5%
169	Portland	4,040,518,130	2,541,540,271	908,393,310	532,641,343	57,943,206	62.9%	22.5%	13.2%	1.4%
170	Powers	18,246,359	10,057,176	5,096,712	3,092,471		55.1%	27.9%	16.9%	0.0%
171	Prairie City	26,784,825	17,776,509	5,233,413	3,774,903		66.4%	19.5%	14.1%	0.0%
172	Prescott	2,095,752	896,652	714,724	484,376		42.8%	34.1%	23.1%	0.0%
173	Prineville	311,169,408	238,844,541	44,168,630	21,280,251	6,875,986	76.8%	14.2%	6.8%	2.2%
174	Rainier	136,298,546	41,892,593	46,345,093	48,060,860		30.7%	34.0%.	35.3%	0.0%
175	Redmond	455,144,170	395,260,231	56,622,474	3,261,465		86.8%	12.4%	0.7%	0.0%
176	Reedsport	63,755,190	30,629,256	17,448,299	15,677,636		48.0%	27.4%	24.6%	0.0%
177	Richland	2,779,004	2,779,004				100.0%	0.0%	0.0%	0.0%
178	Riddle	17,157,224	9,676,307	5,325,983	2,154,935		56.4%	31.0%	12.6%	0.0%
179	Rivergrove	4,977,219	3,387,389	1,266,912	322,917		68.1%	25.5%	6.5%	0.0%
180	Rockaway Beach	43,858,941	26,590,399	11,645,475	3,403,548	2,219,518	60.6%	26.6%	7.8%	5.1%
181	Rogue River	26,623,249	16,521,319	7,051,438	3,050,492		62.1%	26.5%	11.5%	0.0%
182	Roseburg	296,511,002	183,883,902	74,873,761	35,088,195	2,665,144	62.0%	25.3%	11.8%	0.9%
183	Rufus	37,553,807	17,712,691	13,598,048	6,243,068		47.2%	36.2%	16.6%	0.0%
184	Salem	1,368,874,853	949,019,916	318,283,449	48,539,854	53,031,634	69.3%	23.3%	3.5%	3.9%
185	Sandy	93,736,907	48,967,651	27,663,250	14,060,896	3,045,110	52.2%	29.5%	15.0%	3.2%
186	Scappoose	75,080,604	54,400,979	14,984,440	5,695,185		72.5%	20.0%	7.6%	0.0%
187	Scio	11,469,571	10,650,438	625,383	193,750		92.9%	5.5%	1.7%	0.0%
188	Scotts Mills	10,197,012	3,015,331	1,055,940	332,605	5,793,137	29.6%	10.4%	3.3%	56.8%
189	Seaside	111,642,929	78,840,988	17,355,729	2,811,533	12,634,678	70.6%	15.5%	2.5%	11.3%
190	Seneca	22,717,797	14,015,175	6,352,860	2,349,762		61.7%	28.0%	10.3%	0.0%
191	Shady Cove	56,666,101	30,130,909	19,105,941	7,429,251		53.2%	33.7%	13.1%	0.0%
192	Shaniko	13,861,168	12,090,504	1,305,662	465,001		87.2%	9.4%	3.4%	0.0%
193	Sheridan	54,273,946	43,691,945	7,600,397	2,981,603		80.5%	14.0%	5.5%	0.0%
194	Sherwood	120,961,557	80,332,101	35,162,466	5,454,073	12,917	66.4%	29.1%	4.5%	0.0%
195	Siletz	17,593,580	12,045,860	3,767,369	1,780,351		68.5%	21.4%	10.1%	0.0%
196	Silverton	97,150,554	65,299,067	25,007,793	6,796,333	47,361	67.2%	25.7%	7.0%	0.0%
197	Sisters	53,371,760	51,004,776	2,192,609	174,375		95.6%	4.1%	0.3%	0.0%
198	Sodaville	8,456,767	2,131,894	4,736,121	757,779	830,974	25.2%	56.0%	9.0%	9.8%
199	Spray	7,642,839	2,615,017	4,653,238	374,584		34.2%	60.9%	4.9%	0.0%
200	Springfield	440,460,888	356,261,275	45,690,647	21,466,467	17,042,499	80.9%	10.4%	4.9%	3.9%

(table continued on next page)

Table C.1. Landslide Susceptibility Exposure of Oregon Cities *(continued)*

			Landslide Susceptibility Exposure, ft²				Landslide Susceptibility Exposure, %			
	City	Area, ft²	Low	Moderate	High	Very High	Low	Moderate	High	Very High
201	St. Helens	165,426,372	128,332,861	30,277,804	6,090,221	725,488	77.6%	18.3%	3.7%	0.4%
202	St. Paul	8,154,929	7,510,170	582,328	62,431		92.1%	7.1%	0.8%	0.0%
203	Stanfield	42,092,309	36,924,555	5,005,218	162,535		87.7%	11.9%	0.4%	0.0%
204	Stayton	81,891,198	69,275,895	10,983,494	1,631,809		84.6%	13.4%	2.0%	0.0%
205	Sublimity	25,724,506	24,010,892	1,684,552	29,063		93.3%	6.5%	0.1%	0.0%
206	Summerville	7,261,527	7,075,312	186,216			97.4%	2.6%	0.0%	0.0%
207	Sumpter	60,793,097	18,653,464	16,410,658	11,405,439	14,323,536	30.7%	27.0%	18.8%	23.6%
208	Sutherlin	176,078,361	88,751,832	59,725,710	27,600,819		50.4%	33.9%	15.7%	0.0%
209	Sweet Home	161,643,770	116,812,083	27,699,847	12,919,922	4,211,918	72.3%	17.1%	8.0%	2.6%
210	Talent	36,432,983	27,418,208	7,751,092	1,263,683		75.3%	21.3%	3.5%	0.0%
211	Tangent	104,961,049	100,998,854	3,650,042	312,153		96.2%	3.5%	0.3%	0.0%
212	The Dalles	193,454,116	105,916,614	59,777,376	13,001,727	14,758,398	54.8%	30.9%	6.7%	7.6%
213	Tigard	329,116,905	177,830,144	132,030,125	19,109,170	147,466	54.0%	40.1%	5.8%	0.0%
214	Tillamook	49,863,373	45,146,627	4,453,030	263,716		90.5%	8.9%	0.5%	0.0%
215	Toledo	64,963,983	17,166,839	8,963,108	25,535,225	13,298,811	26.4%	13.8%	39.3%	20.5%
216	Troutdale	167,509,670	110,101,431	42,834,982	12,436,622	2,136,636	65.7%	25.6%	7.4%	1.3%
217	Tualatin	227,130,320	156,641,776	62,537,243	7,951,301		69.0%	27.5%	3.5%	0.0%
218	Turner	40,337,405	25,713,556	9,772,554	2,917,020	1,934,275	63.7%	24.2%	7.2%	4.8%
219	Ukiah	6,169,580	5,476,384	504,827	188,368		88.8%	8.2%	3.1%	0.0%
220	Umatilla	132,316,242	101,592,812	27,788,111	2,935,318		76.8%	21.0%	2.2%	0.0%
221	Union	69,457,696	62,206,050	6,793,104	458,543		89.6%	9.8%	0.7%	0.0%
222	Unity	17,890,847	15,738,065	2,069,900	82,882		88.0%	11.6%	0.5%	0.0%
223	Vale	31,736,557	28,101,584	3,372,333	262,639		88.5%	10.6%	0.8%	0.0%
224	Veneta	71,679,252	56,935,923	14,484,994	258,334		79.4%	20.2%	0.4%	0.0%
225	Vemonia	47,639,672	10,445		43,249,392	4,379,835	0.0%	0.0%	90.8%	9.2%
226	Waldport	85,619,621	34,431,845	22,837,789	26,364,046	1,985,941	40.2%	26.7%	30.8%	2.3%
227	Wallowa	17,076,179	12,211,968	3,455,215	1,408,996		71.5%	20.2%	8.3%	0.0%
228	Warrenton	495,000,314	406,918,159	72,004,102	16,078,053		82.2%	14.5%	3.2%	0.0%
229	Wasco	28,223,080	17,443,024	10,707,938	72,118		61.8%	37.9%	0.3%	0.0%
230	Waterloo	3,424,384	3,045,494	349,827	29,063		88.9%	10.2%	0.8%	0.0%
231	West Linn	223,398,149	78,826,992	98,247,592	35,138,786	11,184,779	35.3%	44.0%	15.7%	5.0%
232	Westfir	8,733,352	2,184,589	5,121,469	1,427,295		25.0%	58.6%	16.3%	0.0%
233	Weston	15,553,290	6,992,752	8,320,503	240,035		45.0%	53.5%	1.5%	0.0%
234	Wheeler	14,299,955	672,844	709,342	3,102,159	9,815,610	4.7%	5.0%	21.7%	68.6%
235	Willamina	26,402,748	6,912,535	2,196,914	17,293,298		26.2%	8.3%	65.5%	0.0%
236	Wilsonville	207,231,898	153,329,464	42,435,640	11,331,168	135,625	74.0%	20.5%	5.5%	0.1%
237	Winston	72,606,099	30,059,591	10,319,361	32,227,148		41.4%	14.2%	44.4%	0.0%
238	Wood Village	26,028,757	13,864,462	10,616,445	1,547,850		53.3%	40.8%	5.9%	0.0%
239	Woodburn	148,853,259	136,877,332	10,912,452	1,063,474		92.0%	7.3%	0.7%	0.0%
240	Yachats	25,746,552	8,388,670	6,518,624	8,374,322	2,464,935	32.6%	25.3%	32.5%	9.6%
241	Yamhill	14,049,006	10,313,929	3,532,715	202,362		73.4%	25.1%	1.4%	0.0%
242	Yoncalla	18,183,525	15,602,339	2,289,484	291,702		85.8%	12.6%	1.6%	0.0%

C.2 Oregon counties

Table C.2 data are also available in Excel spreadsheet format (C_2_Counties_LS_Suscep.xlsx) in the digital appendix folder.

Table C.2. Landslide Susceptibility Exposure of Oregon Counties

			Landslide Susceptibility Exposure, ft²				Landslide Susceptibility Exposure, %				
	County	Area, ft²	Low	Moderate	High	Very High	Low	Moderate	High	Very High	High + Very High
1	Baker	85,745,041,556	18,427,313,309	28,591,102,078	36,652,548,721	2,074,077,447	21.5%	33.3%	42.7%	2.4%	45.2%
2	Benton	18,898,991,855	4,992,678,348	6,847,896,474	6,304,116,636	754,300,397	26.4%	36.2%	33.4%	4.0%	37.3%
3	Clackamas	52,482,820,515	12,355,700,886	16,302,031,666	18,117,009,949	5,708,078,013	23.5%	31.1%	34.5%	10.9%	45.4%
4	Clatsop	22,700,260,108	2,057,579,309	2,998,727,490	8,227,272,218	9,416,681,090	9.1%	13.2%	36.2%	41.5%	77.7%
5	Columbia	18,493,573,546	3,374,518,239	4,776,747,887	8,769,151,149	1,573,156,271	18.2%	25.8%	47.4%	8.5%	55.9%
6	Coos	45,354,938,031	5,041,191,570	9,481,330,213	27,924,790,190	2,907,626,058	11.1%	20.9%	61.6%	6.4%	68.0%
7	Crook	83,235,830,831	31,141,381,608	32,866,611,254	15,526,337,997	3,701,499,972	37.4%	39.5%	18.7%	4.4%	23.1%
8	Curry	45,638,104,103	2,650,164,204	9,240,540,460	29,689,033,857	4,058,365,582	5.8%	20.2%	65.1%	8.9%	73.9%
9	Deschutes	85,109,220,479	56,546,695,507	21,081,050,738	7,454,901,368	26,572,866	66.4%	24.8%	8.8%	0.0%	8.8%
10	Douglas	141,317,397,747	12,133,858,652	34,455,769,154	86,836,593,291	7,891,176,650	8.6%	24.4%	61.4%	5.6%	67.0%
11	Gilliam	33,662,136,614	12,523,087,774	10,703,927,449	10,212,038,271	223,083,120	37.2%	31.8%	30.3%	0.7%	31.0%
12	Grant	126,193,657,306	21,247,595,262	47,465,778,299	49,675,296,954	7,804,986,790	16.8%	37.6%	39.4%	6.2%	45.5%
13	Hamey	285,145,843,006	179,502,123,490	70,358,116,375	33,801,473,019	1,484,130,121	63.0%	24.7%	11.9%	0.5%	12.4%
14	Hood River	14,582,414,844	1,451,272,957	4,745,622,963	7,427,134,785	958,384,139	10.0%	32.5%	50.9%	6.6%	57.5%
15	Jackson	78,133,339,144	13,872,632,498	24,452,787,551	34,772,529,510	5,035,389,585	17.8%	31.3%	44.5%	6.4%	50.9%
16	Jefferson	49,946,523,725	16,986,526,937	16,904,142,211	14,442,672,705	1,613,181,872	34.0%	33.8%	28.9%	3.2%	32.1%
17	Josephine	45,768,477,096	5,686,920,023	8,136,650,857	31,328,675,574	616,230,642	12.4%	17.8%	68.5%	1.3%	69.8%
18	Klamath	171,143,448,274	102,628,506,245	48,063,317,411	19,450,752,096	1,000,872,523	60.0%	28.1%	11.4%	0.6%	11.9%
19	Lake	233,060,448,824	158,329,067,591	51,170,622,619	20,371,153,624	3,189,604,990	67.9%	22.0%	8.7%	1.4%	10.1%
20	Lane	128,802,991,658	16,755,013,466	38,682,477,990	64,663,344,708	8,702,155,495	13.0%	30.0%	50.2%	6.8%	57.0%
21	Lincoln	27,673,176,599	1,939,016,555	5,560,163,586	17,098,652,531	3,075,343,928	7.0%	20.1%	61.8%	11.1%	72.9%
22	Linn	64,272,873,796	18,507,907,440	13,731,267,567	23,983,676,960	8,050,021,829	28.8%	21.4%	37.3%	12.5%	49.8%
23	Malheur	276,601,766,018	141,882,833,248	85,058,608,415	45,456,525,427	4,203,798,928	51.3%	30.8%	16.4%	1.5%	18.0%
24	Marion	33,185,295,063	14,072,342,462	7,642,297,819	9,550,677,782	1,919,977,000	42.4%	23.0%	28.8%	5.8%	34.6%
25	Morrow	56,628,190,492	24,805,570,909	20,356,455,504	11,380,627,588	85,536,491	43.8%	35.9%	20.1%	0.2%	20.2%
26	Multnomah	12,223,672,777	4,712,992,825	3,638,767,903	3,250,418,931	621,493,118	38.6%	29.8%	26.6%	5.1%	31.7%
27	Polk	20,738,900,872	6,469,153,617	4,251,225,794	9,539,951,545	478,569,915	31.2%	20.5%	46.0%	2.3%	48.3%
28	Sherman	23,057,239,569	11,360,531,905	6,323,824,280	5,342,690,616	30,192,769	49.3%	27.4%	23.2%	0.1%	23.3%
29	Tillamook	31,340,756,476	2,581,502,742	2,662,963,451	19,610,618,770	6,485,671,513	8.2%	8.5%	62.6%	20.7%	83.3%
30	Umatilla	89,769,773,294	31,779,595,578	31,033,819,776	26,074,546,107	881,811,833	35.4%	34.6%	29.0%	1.0%	30.0%
31	Union	56,832,962,984	13,721,146,622	21,385,787,806	18,471,463,366	3,254,565,190	24.1%	37.6%	32.5%	5.7%	38.2%
32	Wallowa	87,790,890,515	14,105,102,624	22,837,879,148	49,487,844,531	1,360,064,213	16.1%	26.0%	56.4%	1.5%	57.9%
33	Wasco	66,503,203,674	18,224,397,082	27,164,026,064	17,382,971,537	3,731,808,991	27.4%	40.8%	26.1%	5.6%	31.8%
34	Washington	20,258,824,921	6,371,254,612	5,934,460,272	7,147,799,469	805,310,569	31.4%	29.3%	35.3%	4.0%	39.3%
35	Wheeler	47,835,198,973	4,792,578,409	17,939,448,483	19,167,910,975	5,935,261,107	10.0%	37.5%	40.1%	12.4%	52.5%
36	Yamhill	20,024,032,738	5,285,461,212	4,235,189,720	9,399,065,951	1,104,315,854	26.4%	21.2%	46.9%	5.5%	52.5%

C.3 Oregon watersheds

Table C.3 data are also available in Excel spreadsheet format (C_3_Watersheds_LS_Suscep.xlsx) in the digital appendix folder. Landslide Susceptibility Zones are 1: Low; 2: Moderate; 3: High; 4: Very High. Also see Figures 7 and 8 in the main text.

Table C.3. Landslide Susceptibility Exposure of Oregon Watersheds

	Watershed Name	Area, ft²	Minimum Landslide Susceptibility Zone Value	Maximum Landslide Susceptibility Zone Value	Mean Landslide Susceptibility Zone Value
1	Abernethy Creek-Willamette River	3,796,649,711	1	4	1.72
2	Abiqua Creek-Pudding River	7,803,107,412	0	4	1.77
3	Agency Creek-South Yamhill River	3,897,263,211	1	4	2.78
4	Alder Creek-Pritchard Creek	3,890,099,829	1	3	2.19
5	Alkali Canyon-Umatilla River	5,759,238,880	1	3	1.72
6	Alkali Lake	6,428,647,545	1	4	1.30
7	Althouse Creek	1,318,699,582	0	4	2.00
8	Alvord Lake	12,058,663,527	0	4	1.88
9	Anna River-Summer Lake	11,230,222,391	1	4	1.61
10	Antelope Creek	9,536,669,629	1	3	1.15
11	Antelope Creek	4,382,826,439	1	4	2.13
12	Bakeoven Creek	4,278,018,244	1	4	1.76
13	Baldock Slough-Powder River	3,156,271,313	1	4	1.52
14	Bear Creek	10,081,026,412	0	4	2.54
15	Bear Creek	3,037,011,491	1	4	1.94
16	Bear Creek	2,016,650,908	1	3	2.75
17	Bear Creek	6,016,835,402	0	4	2.05
18	Beaver Creek	4,650,424,787	1	3	1.82
19	Beaver Creek-Frontal Columbia River	4,256,493,652	0	4	2.05
20	Beaver Creek-Frontal Pacific Ocean	1,851,713,356	0	4	2.64
21	Beaver Creek-Grande Ronde River	5,733,475,460	1	4	2.29
22	Beaver Marsh	8,734,962,817	1	3	1.39
23	Beech Creek	3,082,511,616	1	4	2.52
24	Big Alvord Creek	7,638,464,791	1	4	1.59
25	Big Butte Creek	6,896,471,848	1	4	2.05
26	Big Creek	2,389,165,091	1	4	2.28
27	Big Creek-Burnt River	4,098,152,224	1	4	2.23
28	Big Creek-Frontal Columbia River	3,252,238,032	0	4	2.84
29	Big Creek-Middle Fork John Day River	4,857,660,201	1	4	2.42
30	Big Creek-North Fork John Day River	4,602,223,996	1	4	2.75
31	Big Elk Creek	2,477,174,052	1	4	3.16
32	Big Springs Creek-Klamath Marsh	2,791,526,521	1	3	1.15
33	Big Stick Creek	3,796,797,177	1	3	1.21
34	Birch Creek	7,929,956,867	1	4	2.10
35	Birch Creek-Snake River	3,926,550,735	0	4	1.66
36	Blue River	2,566,780,377	1	4	2.92
37	Breitenbush River	3,018,714,996	1	4	2.79
38	Bridge Creek	7,501,660,871	1	4	2.61
39	Bridge Creek-Middle Fork John Day River	3,408,182,337	1	4	2.19
40	Briggs Creek	1,907,167,946	1	4	2.73
41	Browns Creek-Deschutes River	5,718,945,257	1	3	1.61
42	Buck Creek	2,793,408,052	1	3	1.46
43	Buck Hollow Creek	5,517,944,300	1	3	1.53
44	Buckaroo Lake	5,178,670,149	1	3	1.31

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Table C.3. Landslide Susceptibility Exposure of Oregon Watersheds *(continued)*

	Watershed Name	Area, ft²	Minimum Landslide Susceptibility Zone Value	Maximum Landslide Susceptibility Zone Value	Mean Landslide Susceptibility Zone Value
45	Bull Run River	3,876,322,023	1	4	2.41
46	Burnt River	6,731,254,435	0	4	2.49
47	Burnt River Canyon-Burnt River	2,336,819,118	0	4	2.55
48	Butte Creek	5,055,656,952	1	4	2.41
49	Butte Creek-Pudding River	3,067,502,420	1	4	1.80
50	Buzzard Creek	6,810,359,489	1	3	1.15
51	Cabin Creek-Grande Ronde River	4,722,481,632	1	4	2.25
52	Calapooya Creek	6,857,483,889	0	4	2.49
53	Camp Creek	2,262,079,906	1	4	2.48
54	Camp Creek	4,863,132,573	1	4	2.08
55	Camp Creek-Middle Fork John Day River	5,488,710,595	1	4	2.53
56	Campbell Lake	8,267,485,111	1	4	1.41
57	Canton Creek	1,768,298,432	1	4	2.84
58	Canyon Creek	3,221,005,470	1	4	2.84
59	Cedar Island-Deschutes River	5,357,294,013	0	3	2.32
60	Chain Lakes-Sunset Valley	2,071,156,121	1	3	1.13
61	Chehalem Creek-Willamette River	7,495,200,372	1	4	1.55
62	Chesnimnus Creek	5,348,766,843	1	3	1.85
63	Chetco River	9,818,687,311	0	4	2.80
64	Chimney Rock-Crooked River	2,605,451,878	1	4	1.55
65	Christmas Lake Valley	6,415,157,136	1	4	1.22
66	Clark Branch-South Umpqua River	2,595,620,122	1	4	2.59
67	Clarks Creek-Burnt River	2,638,884,583	1	4	2.49
68	Clarno Rapids-John Day River	3,156,409,091	1	4	3.41
69	Clatskanie River	2,680,708,834	1	4	2.48
70	Claw Creek	2,591,418,968	1	3	1.65
71	Clearwater River	2,147,429,191	1	4	2.09
72	Clover Creek	4,693,550,394	1	3	2.22
73	Clover Swale	4,691,034,868	1	3	1.16
74	Cold Springs Canyon	5,591,352,016	1	3	1.76
75	Collawash River	4,245,413,282	1	4	3.28
76	Coos Bay-Frontal Pacific Ocean	6,603,879,701	0	4	2.25
77	Coquille River	4,863,618,026	0	4	2.38
78	Cottonwood Creek	6,360,566,888	0	4	1.98
79	Cottonwood Creek	6,490,380,724	1	4	2.23
80	Cow Creek	2,195,369,495	1	4	1.64
81	Crabtree Creek	4,342,301,393	1	4	2.27
82	Crane Creek	3,817,101,141	1	4	1.86
83	Crater Lake-Williamson River	4,584,608,857	1	4	1.45
84	Crescent Creek	5,205,802,738	1	3	1.74
85	Crooked Creek	2,075,338,977	1	4	2.46
86	Crowley Creek	10,618,434,015	0	4	1.45
87	Crump Lake	9,390,382,704	1	4	1.56
88	Dairy Creek	6,444,061,464	1	4	2.07
89	Days Creek-South Umpqua River	6,168,192,128	1	4	2.75
90	Deadwood Creek	1,637,946,401	1	3	2.76
91	Deep Canyon	4,245,446,651	1	3	1.52
92	Deep Creek	7,544,169,706	1	4	1.72
93	Deep Creek	2,413,520,591	1	3	1.61
94	Deep Creek-South Yamhill River	3,316,881,773	1	4	2.23
95	Deer Creek	3,164,914,733	1	4	2.54
96	Deer Creek-South Umpqua River	4,795,051,916	1	4	2.21

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Table C.3. Landslide Susceptibility Exposure of Oregon Watersheds *(continued)*

	Watershed Name	Area, ft²	Minimum Landslide Susceptibility Zone Value	Maximum Landslide Susceptibility Zone Value	Mean Landslide Susceptibility Zone Value
97	Deschutes River-Charleton Creek	7,166,475,930	0	4	1.78
98	Desolation Creek	3,033,113,879	1	4	2.60
99	Diamond Lake	1,868,718,182	1	4	1.66
100	Drews Creek-Frontal Goose Lake	7,361,370,521	1	4	1.89
101	Drift Creek	1,930,819,487	1	4	2.79
102	Dry Creek	8,332,692,881	1	3	1.11
103	Dry Creek-Fort Rock Valley	7,479,968,363	1	3	1.26
104	Dry Creek-Jordan Creek	5,374,434,464	1	3	1.24
105	Dumont Creek-South Umpqua River	4,308,602,819	1	4	2.86
106	Duncan Creek-Silver Lake	3,389,943,967	1	3	1.31
107	Eagle Creek	5,381,969,201	0	4	2.63
108	Eagle Creek	2,507,079,424	1	4	2.34
109	East Fork Coquille River	3,744,936,657	0	4	2.74
110	East Fork Hood River	4,399,821,577	0	4	2.44
111	Eight Mile Creek-Middle Fork John Day River	2,639,528,265	1	4	2.34
112	Eightmile Canyon	7,076,460,576	1	4	1.55
113	Eightmile Creek	3,295,062,250	1	4	2.31
114	Elk Creek	2,368,434,876	1	4	2.84
115	Elk Creek	8,149,532,028	1	4	2.54
116	Elk Creek	3,724,006,233	1	4	2.79
117	Elk River	2,544,431,269	0	4	2.76
118	Emigrant Creek	7,381,668,027	1	4	1.74
119	Euchre Creek-Frontal Pacific Ocean	2,452,125,356	0	4	2.77
120	Evans Creek	6,248,387,566	1	4	2.55
121	Fall Creek	5,392,645,924	1	4	2.65
122	Fall River-Deschutes River	5,122,149,932	1	3	1.42
123	Fanno Creek-Tualatin River	2,679,762,686	1	4	1.65
124	Ferry Canyon-John Day River	6,025,865,246	1	4	2.12
125	Fields Creek-John Day River	4,826,632,153	1	4	2.74
126	Fifteenmile Creek	6,989,369,777	0	4	2.03
127	Fire Lake	3,954,593,951	1	3	1.19
128	Fish Creek	2,342,528,296	1	4	2.40
129	Fishhole Creek	2,836,736,021	1	4	1.65
130	Five Points Creek-Grande Ronde River	3,808,662,235	1	4	2.10
131	Five Rivers	3,328,293,670	0	4	2.73
132	Flybee Lake	3,312,028,325	1	4	1.20
133	Fourmile Creek	3,222,517,799	1	4	2.09
134	Gales Creek	2,090,612,966	1	4	2.66
135	Gerber Reservoir-Miller Creek	7,669,261,415	1	4	1.35
136	Gold Hill-Rogue River	5,929,647,727	1	4	2.29
137	Granite Creek	4,113,927,811	1	4	2.45
138	Grants Pass-Rogue River	2,345,224,656	1	4	2.15
139	Grass Valley Canyon	5,919,470,450	1	3	1.41
140	Grave Creek	4,554,590,463	1	4	2.72
141	Griffin Creek-Upper Malheur River	3,721,133,345	1	3	1.85
142	Grindstone Creek	2,995,117,275	1	3	1.69
143	Grossman Creek-Grande Ronde River	5,003,868,549	1	4	2.57
144	Grub Creek-John Day River	6,520,250,575	1	4	2.31
145	Hamilton Creek-South Santiam River	5,141,554,033	0	4	2.29
146	Harney Lake-Malheur Lake	11,608,559,849	1	3	1.11
147	Hay Creek	3,843,718,139	1	4	2.35
148	Hayden Island-Columbia River	809,201,723	0	3	0.27

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Table C.3. Landslide Susceptibility Exposure of Oregon Watersheds *(continued)*

	Watershed Name	Area, ft²	Minimum Landslide Susceptibility Zone Value	Maximum Landslide Susceptibility Zone Value	Mean Landslide Susceptibility Zone Value
149	Headwaters Malheur River	6,323,796,293	1	4	1.97
150	Headwaters McKenzie River	10,045,690,647	1	4	2.13
151	Headwaters Middle Fork Willamette River	4,941,448,633	1	4	2.71
152	Headwaters Middle Santiam River	2,906,570,119	1	4	2.90
153	Headwaters Nehalem River	6,216,217,467	1	4	2.87
154	Headwaters North Fork John Day River	3,121,137,909	1	4	2.34
155	Headwaters North Santiam River	6,378,725,605	1	4	2.52
156	Headwaters North Umpqua River	3,340,692,619	1	3	1.94
157	Headwaters Rogue River	10,828,597,213	1	4	2.01
158	Headwaters Silvies River	4,416,993,244	1	4	1.86
159	Headwaters Umatilla River	3,781,367,111	1	4	2.65
160	Hellgate Canyon-Rogue River	4,068,850,707	1	4	2.71
161	Hidden Lake	2,556,026,154	1	3	1.10
162	Hills Creek	1,675,895,643	1	4	3.06
163	Hills Creek Reservoir-Middle Fork Willamette River	4,782,968,351	1	4	2.79
164	Hog Creek-Lower Malheur River	4,630,797,873	0	4	2.11
165	Hog Creek-Williamson River	6,278,703,043	1	3	1.44
166	Home Creek-Garrison Lake	5,856,130,219	1	4	1.29
167	Honey Creek	4,690,717,333	1	4	1.69
168	Hood River	2,205,879,377	0	4	2.24
169	Horse Creek	4,436,704,116	1	4	2.37
170	Horse Heaven Creek-Crooked River	7,102,718,060	1	4	2.37
171	Horseshoe Bend-Rogue River	4,537,293,936	1	4	2.88
172	Hunt Ditch-Umatilla River	5,345,806,768	0	3	1.26
173	Hunter Creek	1,240,343,696	0	4	2.94
174	Hunter Creek-Lower Malheur River	4,522,619,497	0	4	2.55
175	Indian Creek	1,341,753,725	1	4	2.73
176	Indian Creek-Grande Ronde River	4,190,966,194	0	4	1.97
177	Indigo Creek	2,134,593,228	1	4	2.90
178	Jack Creek-Williamson River	10,267,756,577	1	3	1.29
179	Jackass Creek	5,414,636,593	1	3	1.29
180	Jackson Creek	4,463,730,143	1	4	3.21
181	Jackson Creek-Owyhee River	9,294,447,200	0	4	1.78
182	Jackson Creek-Williamson River	7,449,826,184	1	3	1.49
183	Jenny Creek	5,830,457,216	0	4	1.87
184	John Day River	2,259,188,720	0	3	1.75
185	John Day River-Johnson Creek	4,365,067,063	1	4	2.66
186	Johnson Creek	2,620,480,449	1	4	1.59
187	Johnston Gulch Reservoir-Lower Malheur River	3,709,922,732	1	4	1.62
188	Jordan Creek-Sheep Spring Creek	5,817,156,252	0	4	1.28
189	Josephine Creek-Illinois River	3,563,531,398	0	4	2.73
190	Jumpoff Joe Creek	3,038,800,453	1	4	2.31
191	Juniper Basin Creek-Upper Malheur River	3,589,439,054	1	4	2.01
192	Juniper Butte-Crooked River	2,733,439,078	0	4	1.53
193	Juniper Canyon	4,227,758,317	1	3	1.27
194	Juniper Creek-Dry Valley	6,448,349,806	1	4	1.27
195	Kahler Creek-John Day River	8,611,853,821	1	4	2.60
196	Kiger Creek-Diamond Canal	6,002,187,872	1	4	1.78
197	Kilchis River	1,798,109,082	1	4	2.95
198	Kit Canyon-Frontal Blue Joint Lake	6,592,260,059	0	4	1.27
199	Klondike Creek-Illinois River	2,925,568,421	1	4	2.89
200	Kotzman Basin	6,660,684,085	1	3	1.28

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Table C.3. Landslide Susceptibility Exposure of Oregon Watersheds *(continued)*

	Watershed Name	Area, ft²	Minimum Landslide Susceptibility Zone Value	Maximum Landslide Susceptibility Zone Value	Mean Landslide Susceptibility Zone Value
201	Ladd Creek	2,555,651,570	1	4	2.01
202	Lake Creek	3,244,514,927	1	4	2.69
203	Lake Ewauna-Klamath River	3,393,168,835	1	4	1.50
204	Langell Valley-Lost River	4,274,079,729	0	4	1.51
205	Lawson Creek-Illinois River	1,794,674,319	0	4	2.63
206	Laycock Creek-John Day River	4,713,908,178	1	4	2.56
207	Little Applegate River	3,152,286,513	1	4	2.74
208	Little Butte Creek	10,411,768,011	0	4	2.39
209	Little Fall Creek	1,635,326,465	1	4	2.48
210	Little Malheur River	3,767,242,708	1	4	2.38
211	Little Nestucca River	1,716,921,212	0	4	3.28
212	Little North Santiam River	3,146,268,411	1	4	3.06
213	Little River	5,746,945,417	1	4	2.67
214	Little Sandy Reservoir-Lower Malheur River	2,608,739,176	1	4	1.74
215	Little Tank Creek-Big Tank Creek	3,858,349,522	1	3	1.36
216	Little Walker Mountain	3,782,497,322	1	3	1.50
217	Lobster Creek	1,931,050,911	1	4	2.69
218	Long Creek	5,682,730,081	1	4	1.94
219	Long Lake Valley-Upper Klamath Lake	11,699,613,920	0	4	1.60
220	Long Prairie	7,599,314,296	1	3	1.25
221	Long Tom River	11,478,156,151	0	4	1.88
222	Lookingglass Creek	2,638,772,639	1	4	2.48
223	Lookout Point Reservoir-Middle Fork Willamette River	4,450,360,290	1	4	2.58
224	Lost Creek-Rogue River	1,398,046,824	1	4	2.39
225	Lostine River	2,530,957,006	1	3	2.56
226	Love Creek-Powder River	3,831,796,032	1	4	2.00
227	Lower Alsea River	4,341,839,621	0	4	2.74
228	Lower Applegate River	3,949,189,391	1	4	2.48
229	Lower Beaver Creek	3,542,473,960	1	3	1.57
230	Lower Big Sheep Creek	5,648,409,352	1	3	2.36
231	Lower Bully Creek	4,956,597,760	1	4	1.89
232	Lower Butter Creek	3,531,757,411	1	4	2.04
233	Lower Calapooia River	2,387,617,240	1	4	1.32
234	Lower Camas Creek	6,834,251,064	1	4	1.67
235	Lower Catherine Creek	3,641,172,560	1	4	1.65
236	Lower Chewaucan River	7,965,092,423	1	4	1.74
237	Lower Clackamas River	5,147,580,747	1	4	1.85
238	Lower Coast Fork Willamette River	3,881,798,701	0	4	1.90
239	Lower Cow Creek	4,821,177,003	1	3	1.22
240	Lower Cow Creek	4,463,805,490	1	4	2.75
241	Lower Crooked Creek	7,308,456,214	1	3	1.44
242	Lower Crooked Valley-Crooked River	4,386,190,161	1	4	1.79
243	Lower Donner und Blitzen River	3,710,164,920	1	3	1.17
244	Lower Dry Creek	6,790,902,644	0	4	1.80
245	Lower Dry River	9,099,154,344	1	4	1.32
246	Lower Guano Slough	5,884,873,089	1	3	1.14
247	Lower Imnaha River	6,403,188,744	1	3	2.74
248	Lower Joseph Creek	4,565,450,173	0	3	2.44
249	Lower Little Deschutes River	4,802,265,889	1	4	1.50
250	Lower Metolius River	6,349,262,629	1	4	1.99
251	Lower Molalla River	4,022,603,566	1	4	1.71

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Table C.3. Landslide Susceptibility Exposure of Oregon Watersheds *(continued)*

	Watershed Name	Area, ft²	Minimum Landslide Susceptibility Zone Value	Maximum Landslide Susceptibility Zone Value	Mean Landslide Susceptibility Zone Value
252	Lower Nehalem River	3,052,273,639	0	4	2.84
253	Lower North Fork Crooked River	1,956,068,391	1	4	2.01
254	Lower North Fork John Day River	5,090,858,168	1	4	2.26
255	Lower North Fork Malheur River	6,109,767,775	0	4	2.21
256	Lower North Santiam River	3,171,230,995	0	4	1.45
257	Lower North Umpqua River	4,634,988,263	1	4	2.32
258	Lower Ochoco Creek	3,256,599,569	1	4	2.18
259	Lower Powder River	2,678,855,288	1	4	2.38
260	Lower Rock Creek	6,397,400,989	1	3	1.98
261	Lower Sandy River	1,946,250,629	1	4	1.94
262	Lower Siletz River-Frontal Pacific Ocean	5,330,529,550	0	4	2.66
263	Lower Silver Creek	6,647,655,448	1	3	1.09
264	Lower Silvies River	7,885,787,160	1	4	1.27
265	Lower Siuslaw River	4,813,935,045	0	4	2.65
266	Lower Smith River	6,133,170,669	1	4	2.77
267	Lower South Fork Crooked River	7,231,415,678	1	4	1.52
268	Lower South Fork John Day River	3,773,935,708	1	4	2.43
269	Lower South Fork Malheur River	7,732,679,146	1	4	1.87
270	Lower Sycan River	6,386,293,710	1	3	1.41
271	Lower Trout Creek	1,622,401,161	1	4	2.25
272	Lower Umpqua River	2,976,301,960	0	3	2.56
273	Lower Wallowa River	4,813,106,223	1	3	2.13
274	Lower Willow Creek	3,799,353,606	1	3	1.65
275	Lower Willow Creek	3,078,750,706	0	4	1.65
276	Lower Yaquina River	2,207,864,242	0	4	2.68
277	Luckiamute River	8,787,194,692	1	4	2.19
278	Malheur Gap	1,721,646,568	1	3	1.38
279	Malheur Slough	6,640,847,275	1	4	1.47
280	Marys River	8,445,112,237	0	4	2.19
281	Mayfield Pond-Central Oregon Canal	1,977,222,704	1	3	1.05
282	McKay Creek	5,551,669,784	1	3	2.29
283	McKay Creek	2,763,927,854	1	4	2.57
284	McKenzie Canyon-Deschutes River	9,507,903,078	1	4	1.24
285	McKenzie River	7,197,933,458	1	4	2.48
286	Meacham Creek	4,972,289,389	1	4	2.59
287	Meadow Creek	5,053,516,010	1	3	1.91
288	Miami River	1,004,343,884	1	4	2.95
289	Middle Applegate River	3,600,881,091	1	4	2.67
290	Middle Chewaucan River	2,192,994,976	1	4	2.13
291	Middle Clackamas River	6,039,249,092	1	4	3.00
292	Middle Cow Creek	4,932,330,524	1	4	2.75
293	Middle Donner und Blitzen River	6,471,257,561	1	4	1.48
294	Middle Fork Coquille River	8,596,632,575	0	4	2.69
295	Middle Imnaha River	3,829,800,403	1	3	2.70
296	Middle Little Deschutes River	2,118,768,126	1	3	1.20
297	Middle Nehalem River	4,962,681,523	1	4	3.07
298	Middle North Santiam River	2,471,815,777	1	4	2.76
299	Middle North Umpqua River	6,317,679,163	1	4	2.91
300	Middle Sandy River	1,780,150,574	1	4	2.27
301	Middle Siletz River	1,808,091,533	1	4	2.73
302	Middle Silver Creek	7,778,017,813	0	3	1.38
303	Middle Silvies River	3,490,542,398	1	3	1.85

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Table C.3. Landslide Susceptibility Exposure of Oregon Watersheds *(continued)*

	Watershed Name	Area, ft²	Minimum Landslide Susceptibility Zone Value	Maximum Landslide Susceptibility Zone Value	Mean Landslide Susceptibility Zone Value
304	Middle South Fork John Day River	5,298,659,764	1	4	2.66
305	Middle Sycan River	6,280,044,227	1	3	1.30
306	Middle Wallowa River	3,701,612,993	1	3	1.92
307	Middle Willow Creek	5,376,490,371	1	4	2.02
308	Middle Willow Creek	3,569,832,591	1	3	1.64
309	Middle Willow Creek	2,852,947,546	1	4	2.45
310	Mill Creek	1,994,287,808	1	4	2.77
311	Mill Creek	3,008,381,642	1	3	1.72
312	Mill Creek	3,129,524,072	1	4	1.40
313	Mill Creek	3,750,162,535	1	4	2.87
314	Mill Creek	1,491,787,567	1	3	2.62
315	Millicoma River	4,211,515,576	0	4	2.83
316	Minam River	6,660,325,647	1	4	2.66
317	Mission Creek-Umatilla River	5,724,485,442	1	4	1.95
318	Mohawk River	4,991,696,719	1	4	2.73
319	Mosby Creek	2,645,719,666	1	4	2.68
320	Mountain Creek	5,117,292,179	1	4	2.31
321	Mud Creek-Grande Ronde River	6,716,980,413	1	4	2.21
322	Mud Springs Creek	2,567,414,371	1	4	1.77
323	Muddy Creek-John Day River	9,334,585,822	1	4	2.75
324	Muddy Creek-Willamette River	13,091,538,232	1	4	1.36
325	Murderers Creek	3,699,204,030	1	4	2.73
326	Myrtle Creek	3,321,939,734	1	4	2.70
327	Necanicum River-Frontal Pacific Ocean	3,814,143,219	0	4	3.29
328	Nestucca River-Frontal Pacific Ocean	7,178,555,190	0	4	3.12
329	New River-Frontal Pacific Ocean	4,339,744,964	0	4	2.70
330	North Basin	7,668,836,240	1	4	1.44
331	North Fork Burnt River	5,407,936,059	0	4	2.27
332	North Fork Coquille River	4,286,794,060	0	4	2.73
333	North Fork Middle Fork Willamette River	6,949,932,962	1	4	2.34
334	North Fork of Nehalem River	2,711,313,860	0	4	3.39
335	North Fork Siuslaw River	1,832,505,158	1	4	2.97
336	North Fork Sprague River	5,777,852,910	1	3	1.60
337	North Powder River	3,270,353,693	1	4	2.19
338	North Unit Diversion Dam-Deschutes River	4,407,386,454	1	3	1.42
339	North Yamhill River	4,942,973,879	1	4	2.44
340	Oak Grove Fork Clackamas River	3,941,202,570	1	4	2.16
341	Olalla Creek-Lookingglass Creek	4,496,507,326	1	4	2.43
342	Otis Creek	4,309,714,731	1	3	1.90
343	Paulina Creek	2,256,787,291	1	3	1.46
344	Peters Creek Sink	3,579,009,901	1	3	1.02
345	Pine Creek	3,204,463,492	0	4	1.93
346	Pine Creek	4,680,611,097	0	3	1.76
347	Pine Creek	8,430,325,854	1	4	2.41
348	Pine Hollow	3,645,328,506	1	4	2.10
349	Pine Lake-Devils Garden	7,356,404,053	1	3	1.28
350	Pistol River	2,933,019,199	0	4	2.85
351	Plympton Creek-Frontal Columbia River	1,369,018,710	0	4	2.62
352	Post Lake	1,950,086,886	0	3	1.45
353	Potamus Creek-North Fork John Day River	8,077,133,967	1	4	2.11
354	Potter Canyon-Deschutes River	2,549,226,591	1	4	1.40
355	Poverty Basin	3,490,693,092	1	3	1.20

(continued on next page)

Table C.3. Landslide Susceptibility Exposure of Oregon Watersheds *(continued)*

	Watershed Name	Area, ft²	Minimum Landslide Susceptibility Zone Value	Maximum Landslide Susceptibility Zone Value	Mean Landslide Susceptibility Zone Value
356	Prineville Reservoir-Crooked River	2,356,074,677	1	4	2.13
357	Pudding Creek-Middle Fork Willamette River	1,535,282,376	0	4	1.93
358	Quail Creek	3,968,834,604	1	4	1.93
359	Quartz Creek-McKenzie River	2,080,579,925	1	4	2.80
360	Quartzville Creek-Green Peter Lake	4,768,311,134	1	4	2.90
361	Rabbit Creek	7,763,096,880	1	4	1.30
362	Rattlesnake Creek	8,299,496,981	1	3	1.43
363	Reynolds Creek-John Day River	4,646,353,876	1	4	2.43
364	Rhea Creek	6,358,048,133	1	4	2.12
365	Rickreall Creek-Willamette River	5,394,978,464	1	4	1.73
366	Riddle Creek	5,358,509,259	1	3	1.52
367	Rock Creek	3,138,840,236	1	4	2.53
368	Rock Creek	2,387,290,018	1	4	1.50
369	Rock Creek	1,201,537,646	1	4	2.76
370	Rock Creek	2,732,269,041	1	4	2.93
371	Rock Creek	8,052,233,813	1	4	1.14
372	Rock Creek-Buck Creek	8,288,921,439	1	3	1.26
373	Rock Creek-Frontal Pacific Ocean	1,790,195,455	0	4	2.71
374	Rock Creek-Powder River	5,258,647,080	1	4	1.85
375	Rock Creek-Tualatin River	4,213,627,455	0	4	1.68
376	Rogue River	3,604,797,001	0	4	2.56
377	Row River	7,800,160,253	1	4	2.92
378	Ruckles Creek-Powder River	7,260,255,423	0	4	1.79
379	Ryegrass Creek-Owyhee River	8,148,585,880	1	4	1.29
380	Sage Hen Creek	3,758,265,607	1	4	1.44
381	Sagehen Waterhole	3,441,271,674	0	3	1.08
382	Salmon Creek	3,577,187,571	1	4	2.76
383	Salmon River	3,212,104,792	1	4	2.59
384	Salmon River	2,073,858,939	1	4	2.91
385	Salmonberry River	1,986,122,306	1	4	2.83
386	Salt Creek	3,152,860,229	1	4	2.63
387	Salt Creek	2,726,643,821	1	4	1.93
388	Sand Canyon-Lake Abert	7,495,207,907	0	3	1.29
389	Sand Hollow	4,663,324,257	1	4	1.49
390	Sand Hollow Creek	4,599,381,247	1	4	1.74
391	Sand Hollow Creek-Owyhee River	6,279,629,816	1	4	1.93
392	Sand Lake-Frontal Pacific Ocean	2,351,293,348	0	4	2.78
393	Scappoose Creek-Frontal Columbia River	5,368,308,723	0	4	2.12
394	Scoggins Creek-Tualatin River	4,334,551,377	1	4	2.35
395	Scott Canyon-John Day River	7,193,650,498	1	3	2.07
396	Seekseequa Creek-Deschutes River	2,613,572,172	1	4	1.74
397	Sellers Creek	2,388,653,805	1	3	1.35
398	Senecal Creek-Pudding River	1,478,884,867	1	4	1.19
399	Service Creek-John Day River	7,350,022,131	1	4	2.67
400	Shady Cove-Rogue River	3,236,698,175	1	4	2.19
401	Shallow Lake-Slickey Lake	10,574,793,893	1	3	1.35
402	Shasta Costa Creek-Rogue River	1,962,018,681	1	4	2.83
403	Shitike Creek-Deschutes River	6,318,028,990	1	4	1.81
404	Siltcoos River-Frontal Pacific Ocean	3,634,237,373	0	4	2.42
405	Silver Creek	2,249,680,958	1	4	2.88
406	Silver Creek	10,565,708,076	1	3	1.32
407	Sixes River	3,758,267,760	0	4	2.85

(continued on next page)

Table C.3. Landslide Susceptibility Exposure of Oregon Watersheds *(continued)*

	Watershed Name	Area, ft^2	Minimum Landslide Susceptibility Zone Value	Maximum Landslide Susceptibility Zone Value	Mean Landslide Susceptibility Zone Value
408	Sixmile Canyon	4,223,556,086	0	4	1.25
409	Skull Creek	3,409,032,686	1	3	1.84
410	Skull Creek-Owyhee River	5,560,743,760	1	4	1.48
411	Soldiers Cap	5,690,409,054	1	3	1.12
412	South Fork Beaver Creek	2,873,315,017	1	3	2.07
413	South Fork Burnt River	3,271,619,529	1	4	2.29
414	South Fork Coos River	6,975,872,910	1	4	2.77
415	South Fork Coquille River	7,972,073,895	1	4	2.73
416	South Fork McKenzie River	5,994,102,023	0	4	2.70
417	South Fork Rogue River	7,005,115,225	0	4	2.18
418	South Fork Sprague River	5,303,250,572	1	4	1.62
419	South Santiam River	4,437,332,729	1	4	2.76
420	South Santiam River-Foster Reservoir	1,591,465,683	1	4	3.09
421	Spencer Creek	2,364,615,840	1	4	1.87
422	Sprague River	15,456,924,768	1	4	1.57
423	Squaw Lake-Capehart Lake	1,692,845,573	1	3	1.16
424	Stage Gulch	3,099,542,275	1	3	1.24
425	Stair Creek-Rogue River	1,592,312,803	1	4	2.82
426	Steamboat Creek	4,564,677,324	0	4	2.90
427	Stinkingwater Creek	4,547,628,366	1	4	1.71
428	Sucker Creek	2,682,037,100	1	4	2.62
429	Summit Creek-Storehouse Canyon	7,338,695,268	1	4	1.98
430	Sutton Creek-Powder River	5,044,158,942	1	4	2.19
431	Swan Lake Valley	3,621,926,688	1	4	1.84
432	Tenmile Creek-Frontal Pacific Ocean	3,017,067,041	0	4	2.78
433	Tenmile Creek-Frontal Pacific Ocean	2,762,969,866	0	4	2.54
434	Thirtymile Creek	7,596,500,610	1	4	2.16
435	Thomas Creek	7,886,490,044	1	4	1.92
436	Thomas Creek	4,048,788,931	0	4	2.35
437	Thorn Lake	12,503,835,181	1	3	1.16
438	Three Fingers Gulch-Owyhee River	8,146,030,528	1	4	2.40
439	Tillamook Bay-Frontal Pacific Ocean	926,582,166	0	4	1.65
440	Tillamook River	1,714,566,068	0	4	3.07
441	Tired Horse Lake	7,574,107,370	1	3	1.24
442	Trail Creek	1,539,832,281	1	4	2.55
443	Trask River	4,860,356,561	0	4	2.82
444	Tumalo Creek	1,654,705,809	1	3	1.92
445	Twelvemile Creek	3,919,127,942	1	4	1.47
446	Twelvemile Creek-Coyote Lake	7,674,482,988	1	3	1.41
447	Twin Lakes	3,756,613,347	1	4	1.44
448	Tygh Creek	3,513,133,693	1	4	2.33
449	Umpqua River-Sawyers Rapids	2,767,747,966	1	4	2.80
450	Upper Alsea River	3,541,424,479	0	4	2.58
451	Upper Applegate River	2,280,065,324	1	4	2.86
452	Upper Beaver Creek	2,706,825,309	1	3	1.61
453	Upper Big Sheep Creek	3,894,271,920	1	3	2.51
454	Upper Bully Creek	6,678,088,252	0	4	2.07
455	Upper Butter Creek	9,001,633,316	1	4	2.21
456	Upper Calapooia River	7,993,351,994	1	4	2.35
457	Upper Camas Creek	4,562,420,132	1	4	1.98
458	Upper Catherine Creek	5,110,144,942	1	4	2.38
459	Upper Chewaucan River	5,272,500,232	1	4	2.11

(continued on next page)

Table C.3. Landslide Susceptibility Exposure of Oregon Watersheds *(continued)*

	Watershed Name	Area, ft²	Minimum Landslide Susceptibility Zone Value	Maximum Landslide Susceptibility Zone Value	Mean Landslide Susceptibility Zone Value
460	Upper Clackamas River	4,395,708,687	1	4	2.25
461	Upper Coast Fork Willamette River	4,245,164,636	1	4	2.39
462	Upper Cow Creek	2,069,740,667	1	4	2.65
463	Upper Crooked Creek	9,029,700,212	1	3	1.54
464	Upper Donner und Blitzen River	5,835,981,255	1	3	1.79
465	Upper Dry Creek	5,783,801,047	1	4	1.57
466	Upper Dry River	11,844,830,912	0	3	1.41
467	Upper Grande Ronde River	5,825,143,074	1	4	2.47
468	Upper Guano Slough	8,655,378,769	1	3	1.24
469	Upper Imnaha River	3,936,656,971	1	4	2.64
470	Upper Joseph Creek	5,457,229,387	1	3	2.25
471	Upper Little Deschutes River	3,447,611,617	1	3	1.60
472	Upper Metolius River	6,135,153,381	1	4	2.10
473	Upper Middle John Day	3,082,532,068	1	4	2.56
474	Upper Molalla River	5,640,439,753	1	4	2.70
475	Upper Nehalem River	4,905,472,415	0	4	2.88
476	Upper North Fork Crooked River	4,938,031,091	1	4	1.95
477	Upper North Fork Malheur River	4,793,466,392	1	3	2.14
478	Upper North Santiam River	3,109,342,816	1	4	2.90
479	Upper North Umpqua River	2,830,923,509	1	4	2.57
480	Upper Ochoco Creek	4,181,716,766	1	4	2.70
481	Upper Powder River	4,591,509,600	1	4	2.51
482	Upper Rock Creek	7,715,033,868	1	4	2.30
483	Upper Sandy River	1,489,025,547	1	4	2.76
484	Upper Siletz River	1,938,434,953	1	4	2.62
485	Upper Silver Creek	4,777,719,868	1	4	1.69
486	Upper Silvies River	6,766,785,027	1	4	1.89
487	Upper Siuslaw River	5,562,305,604	1	4	2.49
488	Upper Smith River	4,162,862,701	1	4	2.77
489	Upper South Fork Crooked River	8,636,376,162	1	3	1.27
490	Upper South Fork John Day River	4,120,445,359	1	4	2.22
491	Upper South Fork Malheur River	7,615,576,412	1	3	1.63
492	Upper South Umpqua River	3,799,649,613	1	4	2.90
493	Upper Sycan River	2,871,936,161	1	3	1.29
494	Upper Trout Creek	6,872,286,418	1	4	2.43
495	Upper Umpqua River	7,397,619,066	1	4	2.67
496	Upper Walla Walla River	4,438,691,134	0	3	2.60
497	Upper Wallowa River	6,877,294,866	1	4	2.03
498	Upper Willow Creek	4,915,021,080	1	3	1.93
499	Upper Willow Creek	4,097,509,619	1	4	2.36
500	Upper Yaquina River	2,316,931,717	1	4	2.80
501	Walker Creek	3,419,231,491	1	3	1.17
502	Wall Creek	5,589,211,074	1	3	2.12
503	Walls Lake Reservoir	10,413,534,369	0	3	1.19
504	Warm Springs Reservoir-Upper Malheur River	3,990,777,912	1	4	2.12
505	Warm Springs River	7,426,665,478	1	4	1.83
506	Watson Creek-Crooked River	2,565,035,547	1	4	1.60
507	West Fork Cow Creek	2,436,737,269	1	3	2.78
508	West Fork Hood River	2,852,977,685	0	4	2.69
509	West Little Owyhee River	8,635,305,152	0	4	1.18
510	West Tub Mountain Reservoir	2,029,648,330	1	3	1.75
511	Wheatgrass Lake	1,771,479,168	1	3	1.24

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Table C.3. Landslide Susceptibility Exposure of Oregon Watersheds *(continued)*

	Watershed Name	Area, ft²	Minimum Landslide Susceptibility Zone Value	Maximum Landslide Susceptibility Zone Value	Mean Landslide Susceptibility Zone Value
512	White Horse Rapids-Deschutes River	8,511,118,689	1	4	2.28
513	White River	7,721,064,887	0	4	1.86
514	Whitehorse Creek	5,257,611,592	1	4	1.71
515	Whychus Creek	7,175,323,864	1	3	1.74
516	Wildcat Creek	4,103,090,706	0	4	1.81
517	Wildcat Creek	1,518,866,336	1	3	2.67
518	Wildhorse Creek	5,465,362,597	1	3	1.52
519	Wiley Creek	1,771,934,481	1	4	2.84
520	Willamette River-Frontal Columbia River	3,429,236,546	0	4	1.50
521	Willamina Creek	2,342,889,964	1	4	2.85
522	Williams Creek	2,308,926,597	1	4	2.47
523	Willow Creek	2,334,249,773	1	4	1.95
524	Willow Creek	5,068,118,331	1	4	1.61
525	Willow Creek	6,648,401,387	1	4	1.49
526	Wilson Creek	3,896,067,341	1	3	1.13
527	Wilson River	5,360,862,249	1	4	2.99
528	Wolf Creek	4,148,873,923	1	4	2.33
529	Wolf Creek	1,651,096,670	1	3	2.49
530	Wolf Creek-Powder River	4,733,030,265	1	4	2.07
531	Wood River	5,270,962,070	1	4	1.67
532	Yachats River	1,214,490,936	0	4	2.81
533	Yamhill River	2,789,890,406	1	4	1.47
534	Yonna Valley-Lost River	6,289,041,779	0	4	1.66
535	Youngs River-Frontal Columbia River	5,859,665,087	0	4	3.17
536	Zigzag River	1,645,509,124	1	4	2.51

EARTHQUAKE REPORT

Coos County has relied on the following report to inventory potential earthquake hazards.

State of Oregon
Oregon Department of Geology and Mineral Industries
Vicki S. McConnell, State Geologist

OPEN-FILE REPORT O-13-06

GROUND MOTION, GROUND DEFORMATION, TSUNAMI INUNDATION, COSEISMIC SUBSIDENCE, AND DAMAGE POTENTIAL MAPS FOR THE 2012 OREGON RESILIENCE PLAN FOR CASCADIA SUBDUCTION ZONE EARTHQUAKES

by Ian P. Madin and William J. Burns
Oregon Department of Geology and Mineral Industries
800 NE Oregon Street, #28, Suite 965, OR 97232

2013

NOTICE

Disclaimer: The Oregon Department of Geology and Mineral Industries is publishing this map because the subject matter is consistent with the mission of the Department. The map is not intended to be used for site specific planning. It may be used as a general guide for emergency response planning. Maps in this publication depict landslide hazard areas on the basis of limited data as described further in the text. **The maps cannot serve as a substitute for site-specific investigations by qualified practitioners. Site-specific data may give results that differ from those shown on the maps.**

Oregon Department of Geology and Mineral Industries Open-File Report O-13-06
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1. INTRODUCTION

During the 2011 Oregon Legislative Assembly the House of Representatives passed House Resolution 3, which acknowledged the threat posed to Oregon by great subduction earthquakes from the Cascadia Subduction Zone that lies off the coast of Oregon, Washington, northern California, and British Columbia. The Resolution also charged the Oregon State Seismic Safety Policy Advisory Commission (OSSPAC) with the preparation of a resilience plan for Oregon (http://www.oregon.gov/OMD/OEM/Pages/osspac/osspac.aspx#Oregon_Resilience_Plan) that would estimate current vulnerabilities and recommend policies to address those vulnerabilities and increase the state's resilience to a great earthquake. OSSPAC developed a strategy that involved the use of several workgroups to look at different parts of the problem and populated these groups with volunteers from the engineering, planning, emergency management, architectural, business, and geoscience communities as well as members of the public and representatives of state and local government. The workgroups were:

- Cascadia Earthquake Scenario
- Business
- Energy
- Transportation
- Water and Wastewater
- Communication
- Critical Buildings
- Coastal Communities

The workgroups analyzed the vulnerability of their respective sectors to the chosen earthquake scenario, a magnitude 9.0 (M 9.0) great subduction earthquake off the coast of Oregon, accompanied by a large tsunami. The likelihood of this earthquake is currently estimated to be 7–12% in the next 50 years (Goldfinger and others, 2012); the magnitude is essentially the same as the 2011 Tohoku event (http://earthquake.usgs.gov/earthquakes/eqarchives/poster/2011/20110311.php). The geologic record of great subduction earthquakes in Oregon for the last 10,000 years (Goldfinger and others, 2012) suggests that this event is about average in size for the Cascadia Subduction Zone.

The Cascadia Earthquake Scenario workgroup was charged with developing a description of the likely ground motion (strength of shaking) and ground deformation (earth movements) to be expected from the scenario event, as well as maps of the likely tsunami inundation for coastal cities. Workgroup members were:

- Ian Madin, Oregon Department of Geology and Mineral Industries (DOGAMI), Chair
- Art Frankel, U.S. Geological Survey (USGS)
- Ivan Wong, URS Corporation
- Matthey Mabey, Oregon Department of Transportation
- Chris Goldfinger, Oregon State University
- George Priest, DOGAMI
- Yumei Wang, DOGAMI
- Bill Burns, DOGAMI

This report describes the data sources and methods used to prepare the scenario maps. The goal was to provide maps that were as detailed and accurate as possible, using published methodology, combined with the best available published and unpublished data sources as determined by the workgroup. We made no attempt to test and compare different methods or data sources, which was beyond the scope of the report. The maps initially were intended primarily for the use of the Oregon Resilience Plan (ORP) workgroups and OSSPAC. However, because the maps and data were widely distributed to workgroup participants, it was necessary to publish this documentation along with definitive digital versions of the maps. We also expect that the information will be useful to those interested in regional Cascadia ground motion and ground failure models.

The report first describes the methods used to prepare site condition maps: National Earthquake Hazards Reduction Program (NEHRP) site class (or V_{s30} values), liquefaction, and susceptibility landslide susceptibility. Data sources are introduced and described at the first instance in which they are used to prepare one of the site condition maps. For example, shear wave velocity data were used to make the NEHRP site class map, and it is described before the site class map; the statewide digital geologic map was used to develop the shear wave velocity database, so it is described in the beginning of that section. The report then describes the methods combining the site condition and ground motion input data to prepare the final maps.

Digital versions of the maps and GIS data described in this report are included on the publication DVD as a digital appendix. Maps are provided in pdf format, and the GIS data are provided in an Esri® version 10.1 geodatabase: `Oregon_Resilience_Plan_Ground_Motion_and_Ground_Failure_Maps.gdb`. Vector data are provided as feature classes in the geodatabase and raster data as raster datasets in the geodatabase. All feature classes and raster datasets are in Oregon Lambert Projection NAD 83 International Feet (EPSG 2292), and all rasters have a cell size of 30 m (98.4 ft). The maps have been prepared using data sources that have native resolutions in the range of several kilometers to tens of meters. **These maps are not appropriate for site specific investigations, and investigations using site specific data are likely to produce results that vary from what is shown on these maps.**

2. SITE CONDITION MAPS

2.1 Statewide NEHRP site class/V_{s30} map

The intensity of ground shaking during an earthquake depends on the geotechnical properties of the soil or bedrock at a particular site; NEHRP has classified building sites according to geotechnical properties, including average shear wave velocity (Building Seismic Safety Council, 1997):

- site class A hard rock
- site class B rock
- site class C very dense soil and soft rock
- site class D stiff soil
- site class E soft soil
- site class F soils susceptible to potential failure under seismic loading

In order to produce site condition maps, we created a new map of V_{s30}* shear wave velocity values for Oregon by combining a statewide digital geologic map with a catalog of measured shear wave velocity values, a statewide landslide inventory (SLIDO-2 [Burns and others, 2011]), and data from published hazard studies.

2.1.1 Shear wave velocity measurements

Since the early 1990s DOGAMI has been collecting shear wave velocity measurements throughout western Oregon to support a variety of earthquake hazard assessment projects. The data were collected using either a downhole geophone in purpose-built boreholes with fully grouted casings or with a geophone on the tip of a cone penetrometer. Additional data were derived from horizontal shear wave (SH) refraction profiles. Details of these procedures are provided by Mabey and others (1993) and Madin and Wang (1999). Many of these measurements were previously published (Mabey and others, 1993; Madin and Wang, 1999; Wang and Priest, 1995; Mabey and Madin, 1995); many others were used to make published hazard maps but were not included in those publications (Black and others, 2000a; Wang and Wang, 2000; Wang and others, 2001a,b), and some have never been published or used for a published map. Figure 1 shows the distribution of the 260 measurement sites in the database, and Figure 2 shows the format of the tabular data in the database.

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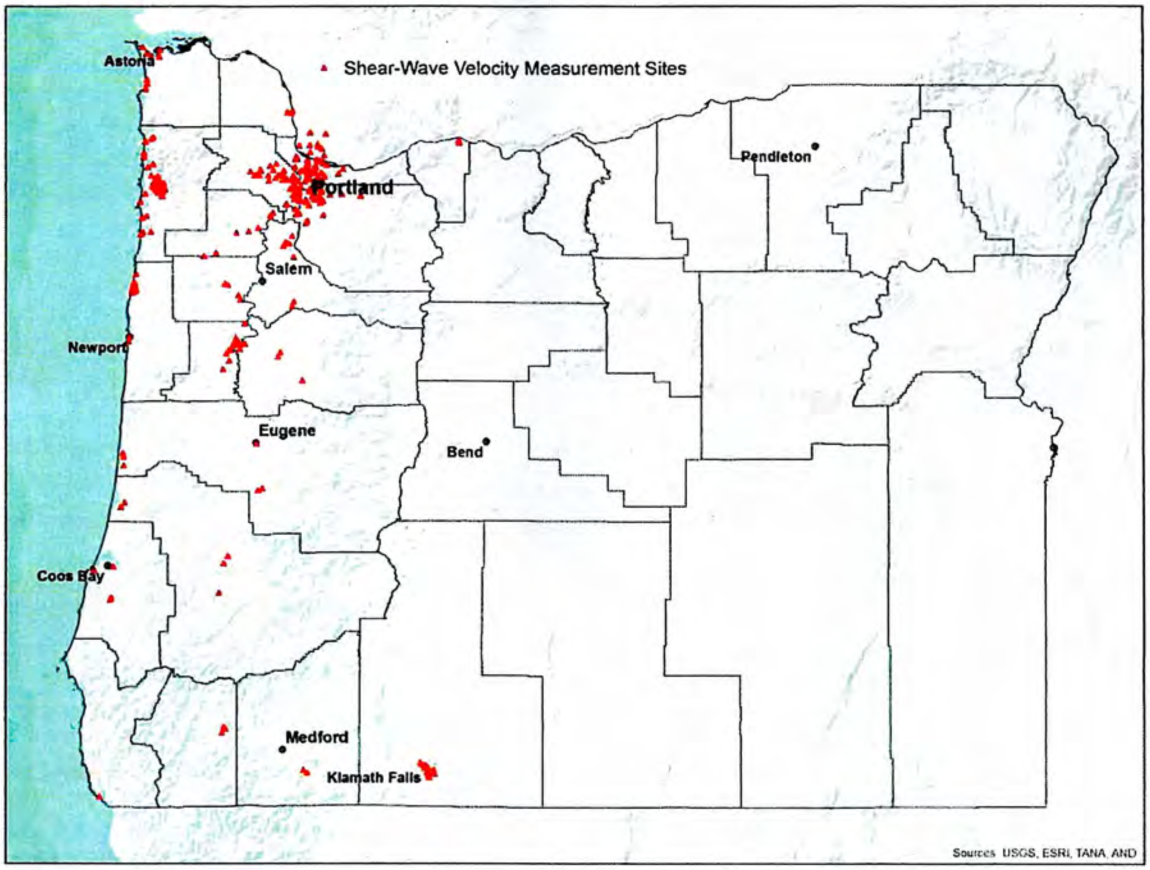
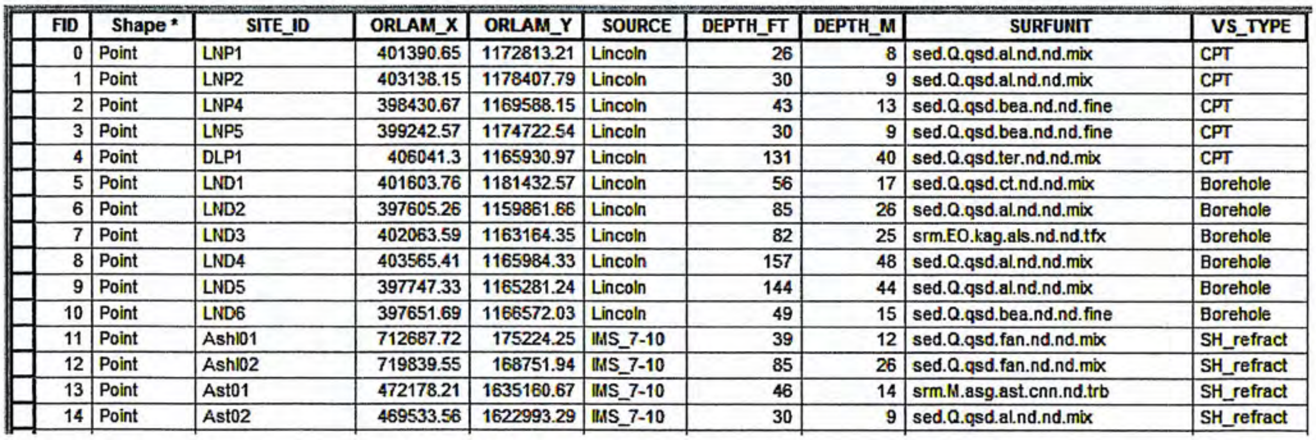
* The average shear wave velocity within 30 meters of the ground surface.



Sources USGS, ESRI, TANA, AND

Figure 1. Shear wave velocity measurement sites in Oregon.



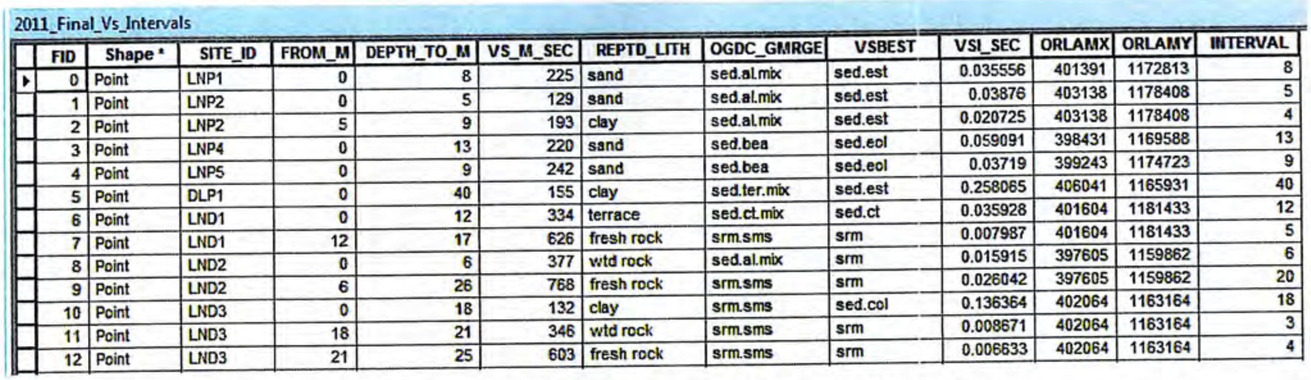
FID	Shape *	SITE_ID	ORLAM_X	ORLAM_Y	SOURCE	DEPTH_FT	DEPTH_M	SURFUNIT	VS_TYPE
0	Point	LNP1	401390.65	1172813.21	Lincoln	26	8	sed.Q.qsd.al.nd.nd.mix	CPT
1	Point	LNP2	403138.15	1178407.79	Lincoln	30	9	sed.Q.qsd.al.nd.nd.mix	CPT
2	Point	LNP4	398430.67	1169588.15	Lincoln	43	13	sed.Q.qsd.bea.nd.nd.fine	CPT
3	Point	LNP5	399242.57	1174722.54	Lincoln	30	9	sed.Q.qsd.bea.nd.nd.fine	CPT
4	Point	DLP1	406041.3	1165930.97	Lincoln	131	40	sed.Q.qsd.ter.nd.nd.mix	CPT
5	Point	LND1	401603.76	1181432.57	Lincoln	56	17	sed.Q.qsd.ct.nd.nd.mix	Borehole
6	Point	LND2	397605.26	1159861.66	Lincoln	85	26	sed.Q.qsd.al.nd.nd.mix	Borehole
7	Point	LND3	402063.59	1163164.35	Lincoln	82	25	srm.EO.kag.als.nd.nd.tfx	Borehole
8	Point	LND4	403565.41	1165984.33	Lincoln	157	48	sed.Q.qsd.al.nd.nd.mix	Borehole
9	Point	LND5	397747.33	1165281.24	Lincoln	144	44	sed.Q.qsd.al.nd.nd.mix	Borehole
10	Point	LND6	397651.69	1166572.03	Lincoln	49	15	sed.Q.qsd.bea.nd.nd.fine	Borehole
11	Point	Ashl01	712687.72	175224.25	IMS_7-10	39	12	sed.Q.qsd.fan.nd.nd.mix	SH_refract
12	Point	Ashl02	719839.55	168751.94	IMS_7-10	85	26	sed.Q.qsd.fan.nd.nd.mix	SH_refract
13	Point	Ast01	472178.21	1635160.67	IMS_7-10	46	14	srm.M.asg.ast.cnn.nd.trb	SH_refract
14	Point	Ast02	469533.56	1622993.29	IMS_7-10	30	9	sed.Q.qsd.al.nd.nd.mix	SH_refract

Figure 2. Shear wave velocity measurement site database structure.

At most sites numerous measurement intervals are recorded. For downhole measurements the interval is based on regular depth intervals, and for SH refraction sites it is based on the number of significant velocity changes encountered. At SH refraction sites the thickness of the deepest unit is always unconstrained, and these intervals are assigned a thickness of 1 m. The measured interval database includes 2,974 measured intervals. The structure of the database is shown in Figure 3.

In both the site and interval databases the geology of the site is keyed to the Oregon Geologic Data Compilation, release 5 (OGDC-5 [Ma and others, 2009]; hereafter referred to as OGDC), which is a digital geologic map and database covering the entire state and depicting the best available geologic mapping an any location (Figure 4).

OGDC contains thousands of geologic units uniquely defined by the authors of its component maps, and these units have been assigned to a much smaller number of



2011_Final_Vs_Intervals

	FID	Shape *	SITE_ID	FROM_M	DEPTH_TO_M	VS_M_SEC	REPTD_LITH	OGDC_GMRGE	VSBEST	VSI_SEC	ORLAMX	ORLAMY	INTERVAL
▸	0	Point	LNP1	0	8	225	sand	sed.al.mix	sed.est	0.035556	401391	1172813	8
	1	Point	LNP2	0	5	129	sand	sed.al.mix	sed.est	0.03876	403138	1178408	5
	2	Point	LNP2	5	9	193	clay	sed.al.mix	sed.est	0.020725	403138	1178408	4
	3	Point	LNP4	0	13	220	sand	sed.bea	sed.eol	0.059091	398431	1169588	13
	4	Point	LNP5	0	9	242	sand	sed.bea	sed.eol	0.03719	399243	1174723	9
	5	Point	DLP1	0	40	155	clay	sed.ter.mix	sed.est	0.258065	406041	1165931	40
	6	Point	LND1	0	12	334	terrace	sed.ct.mix	sed.ct	0.035928	401604	1181433	12
	7	Point	LND1	12	17	626	fresh rock	srm.sms	srm	0.007987	401604	1181433	5
	8	Point	LND2	0	6	377	wtd rock	sed.al.mix	srm	0.015915	397605	1159862	6
	9	Point	LND2	6	26	768	fresh rock	srm.sms	srm	0.026042	397605	1159862	20
	10	Point	LND3	0	18	132	clay	srm.sms	sed.col	0.136364	402064	1163164	18
	11	Point	LND3	18	21	346	wtd rock	srm.sms	srm	0.008671	402064	1163164	3
	12	Point	LND3	21	25	603	fresh rock	srm.sms	srm	0.006633	402064	1163164	4

Figure 3. Shear wave velocity measurement interval database structure.

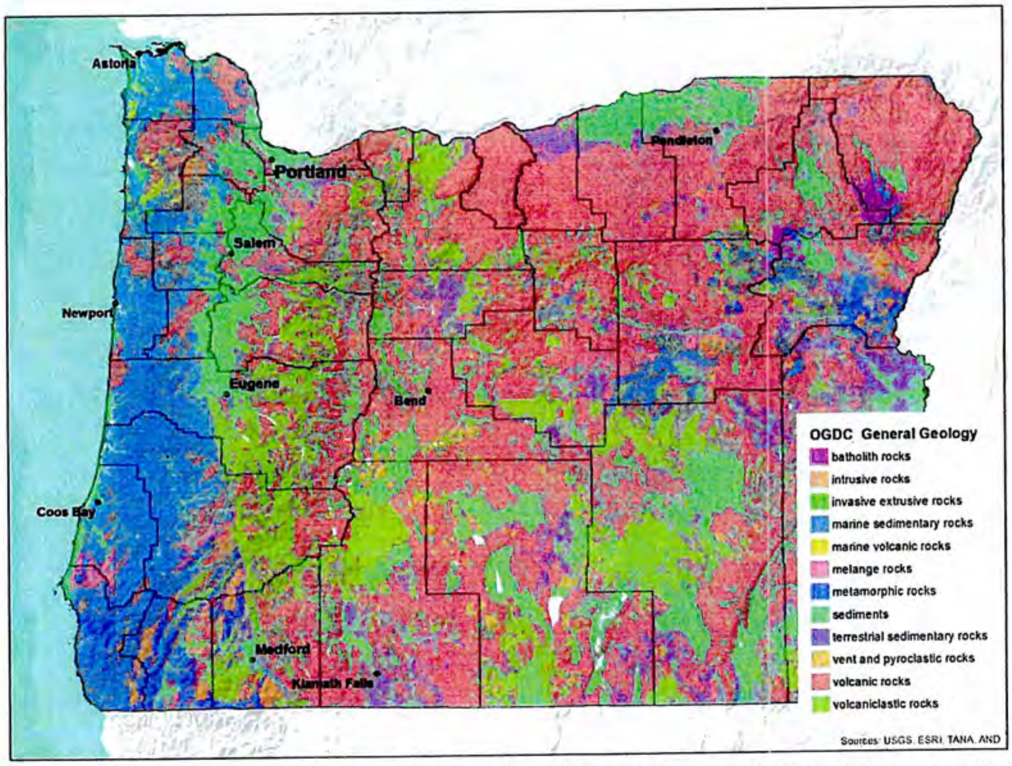


Figure 4. Map displaying Oregon Geologic Data Compilation (Ma and others, 2009) "General Geology" attribute.

"Geologic Merge" units based on expert opinion. The merge units are based on general geology (igneous, sedimentary, etc.), age, stratigraphic name (group, formation, etc), and rock type (basalt, gravel, serpentinite, etc.). The values in these fields are concatenated into a Geologic Merge Unit label that serves as a map unit label and simplifies queries. Surficial deposits are a special case; these are assigned a General Geology attribute of "sediment" and are assigned a formation attribute that designates origin (landslide, beach, glacial till, etc). The V_S measurement sites are attributed with the Merge Unit label of the OGDC polygon that the site falls in. The V_S measurement intervals are attributed with interpreted values for General Geology and Rock Type. The interpreted OGDC values for each measurement interval were used to aggregate the measurements by geologic type, and the velocity was averaged for each type. Averages were calculated as:

$$V_{su} = \Sigma d_{iu} / \Sigma t_{iu}$$

where V_{su} is the average shear wave velocity for a given unit, d_{iu} is the thickness of each measurement interval for a given unit, and t_{iu} is the interval travel time for each unit, calculated by dividing each interval thickness by the measured velocity. The resultant velocity averages are shown in Table 1.

The V_S site and interval databases are provided as feature classes named Oregon_Vs_Measurement_Sites and Oregon_Vs_Measurement_Intervals in the Esri geodatabase included in the appendix of this publication.

Table 1. NEHRP site class, measured V_{s30}, liquefaction susceptibility, and U.S. Geological Survey Pacific Northwest V_{s30} values for OGDC (Ma and others, 2009) and SLIDO-2 (Burns and others, 2011) units.

OGDC Geo_Genl_U	OGDC Formation	OGDC G_Rock_Typ	Unit Vs avg (m/sec)	NEHRP Site Class	Liquefaction susceptibility	PNW_Vs30
Units with measured velocity						
intrusive	all W of Cascades		756	C	0	464
sediments	alluvium	coarse	194	D	3	301
sediments	alluvium	fine	157	E	4	163
sediments	alluvium	mixed	189	D	3	301
sediments	beach		314	D	3	301
sediments	colluvium		141	E	3	163
sediments	coastal terrace		389	D	2	301
sediments	eolian		240	D	4	301
sediments	estuarine		139	F	5	98
sediments	lateritic		323	D	1	301
sediments	loess		277	D	4	301
sediments	Missoula flood	gravel	412	C	2	464
sediments	Missoula flood	silt	236	D	4	301
sediments	artificial fill		190	F	5	98
sediments	marsh		162	F	5	98
sediments	alluvial fan		307	D	2	301
sediments	fluvial terrace		267	D	2	301
marine sedimentary	all		623	C	0	464
terrestrial sedimentary	all	coarse	589	C	0	464
terrestrial sedimentary	all	fine	414	C	0	464
volcaniclastic	all		401	C	0	464
volcanic	all W of Cascades		716	C	0	464
sediments with inferred velocity						
sediments	alluvium			E	4	163
sediments	Bonnevile Flood			D	4	301
sediments	alluvial fan-delta			D	3	301
sediments	glacial till			C	2	464
sediments	glacial outwash			D	2	301
sediments	lacustrine			E	3	163
sediments	landslide			F	3	98
sediments	mine tailings			D	4	301
sediments	older fluvial and lacustrine			C	1	464
sediments	older alluvial fan			C	1	464
sediments	playa lake			E	4	163
sediments	pluvial lake			D	3	301
sediments	older fluvial terrace			C	1	464
sediments	Holocene glacial till			D	3	301
sediments	Holocene glacial outwash			D	3	301
sediments	Holocene lacustrine			E	4	163
sediments	spring precipitate			D	2	301
volcaniclastic	Holocene ash fall			D	2	301
volcaniclastic	Holocene lahar			D	2	301
rocks with inferred velocity						
invasive				C	0	464
metamorphic	W of Cascades			C	0	464
melange				C	0	464
marine volcanic				C	0	464
volcanic vent				C	0	464
batholith				B	0	686
intrusive	E of Cascades			B	0	686
metamorphic	E of Cascades			B	0	686
volcanic	E of Cascades			B	0	686
SLIDO-2 Units						
landslide				F	3	98
Talus-Colluvium				E	3	163
Fan				D	2	301

2.1.2 NEHRP site class and V_{s30} values

We assigned NEHRP site class values to each unit with measured velocity following values from the NEHRP guidelines (Building Seismic Safety Council, 1997): class E < 180 m/sec < class D < 300 m/sec < class C < 760 m/sec < class B, with class F used for units with special characteristics, such as landslide deposits.

For OGDC units for which no measured values were available, we inferred NEHRP site classes based on descriptions in the NEHRP guidelines (Building Seismic Safety Council, 1997) and values from similar studies in Utah, California and Washington (McDonald and Ashland, 2008; Palmer and others, 2004; Bilderback and others, 2008; Wills and Clahan, 2006). Some rock units (volcanic, metamorphic, and intrusive) were assigned different NEHRP site classes depending on location in the state. In general, rocks east of the Cascade Range are far less weathered than those to the west, reflecting a long-term climatic effect of the Cascade Range rain shadow. In western Oregon these rocks were assigned NEHRP site class C, and in the east, NEHRP site class B. Both the measured and inferred values assume that the assigned V_s and NEHRP site class values represent the entire upper 30 m of the soil/rock column.

We updated OGDC with new lidar-based surficial geologic mapping for the Southern Willamette Valley (McClaughry and others, 2010), Hood River Valley (McClaughry and others, 2012), and Medford-Ashland urban area (Wiley and others, 2011). These data provide much better resolution and accuracy for Quaternary deposits in the area and have attributes consistent with OGDC. The locations and sources of data for the NEHRP site class map are shown in Figure 5.

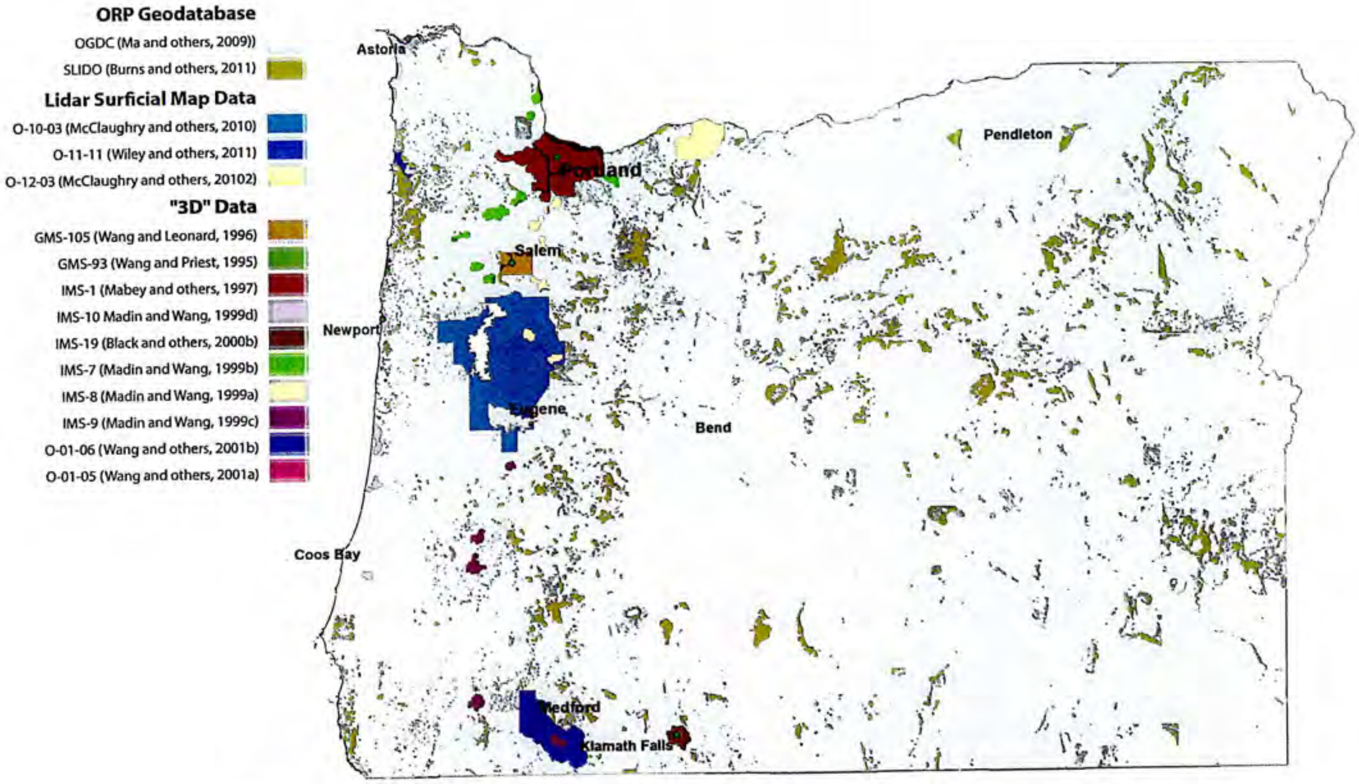


Figure 5. Spatial data sources for NEHRP site class map. OGDC and lidar-based surficial map data are described in section 2.1.1, SLIDO data in section 2.1.3, and "3D" data in section 2.1.4.

It is important to note that we are assigning V_{s30} values for polygons of the measured or inferred units with the implicit assumption that the measured velocity is constant to a depth of 30 m, a condition that is probably rarely true for Quaternary surficial deposits. In most cases, units with very low measured values (like alluvium) will overlie higher-velocity sediment or rock at depths less than 30 m. Therefore, these V_{s30} designations are conservative (likely to be lower than the true value and thus generally producing greater shaking amplification).

2.1.3 Incorporation of SLIDO-2 data

In addition to OGDC, DOGAMI has published the second release of the Statewide Landslide Information Database for Oregon (SLIDO-2; Burns and others, 2011) (Figure 6).

This database, although derived in part from OGDC, contains thousands of mapped landslide deposits that are not in OGDC. Because the SLIDO-2 data are more complete, we stamp these deposit polygons onto the GIS data derived purely from OGDC, with the stamped polygons replacing underlying polygons. SLIDO-2 has three general categories of deposit, which are assigned NEHRP site class/ V_{s30} values as follows:

Landslide deposits	NEHRP site class F
Talus/colluvium	NEHRP site class E
Alluvial and debris fans	NEHRP site class D

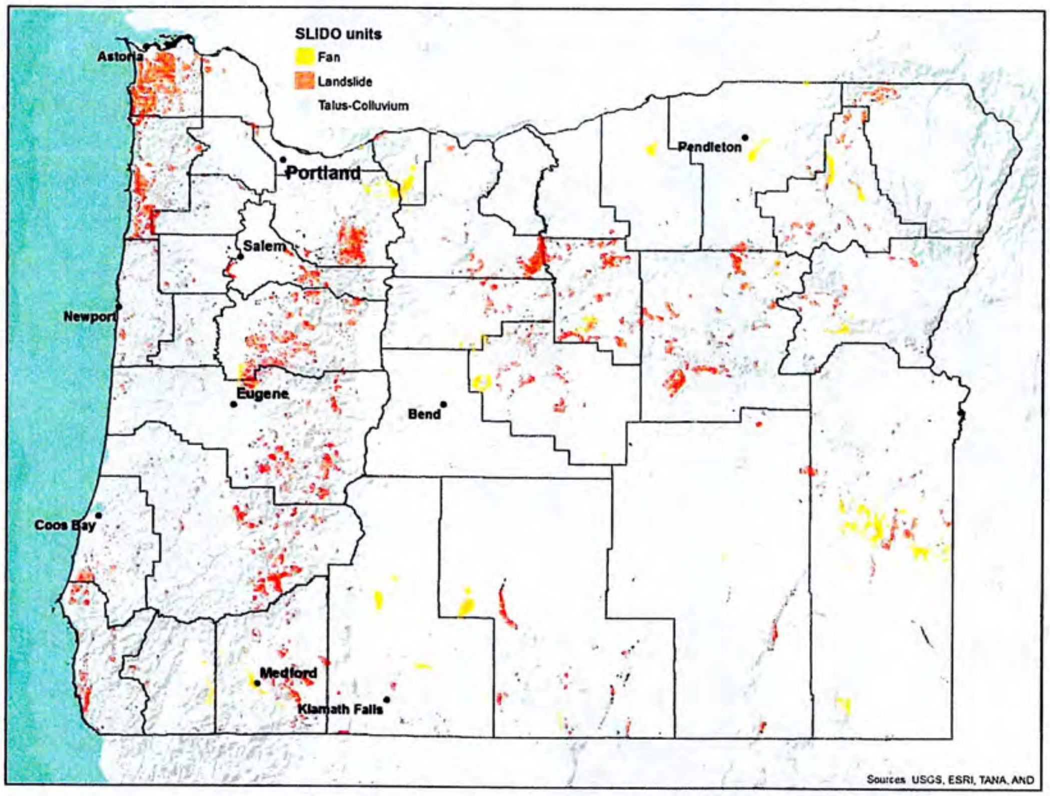


Figure 6. Landslide polygons used for the SLIDO-2 (Burns and others, 2011) NEHRP site class map.

2.1.4 Incorporation of "3D" study data

Numerous studies (e.g., Mabey and others, 1993; Madin and Wang, 1999a,b,c; Wang and Wang, 2000) provide maps of NEHRP site class derived from three-dimensional geologic models based on interpretation of borehole data in Oregon. Because these studies are more detailed and take into account velocity change with depth, we consider these published values to be more reliable than the values estimated by the procedure outlined in section 2.1.2. The NEHRP site class values from these studies are stamped onto the GIS data derived from all of the other data sources, replacing the underlying data. Not all studies provided site class information in NEHRP terms, so Table 2 shows how the values from each study were translated for the NEHRP site classes. The DOGAMI "3D" sources and extents are shown in Figure 5.

Table 2. Assignment of NEHRP site classes and V_{s30} values from published 3D studies.

"3D" Publication	Publication unit category	NEHRP Class	Vs30
IMS-1	1	C	464
IMS-1	2	D	301
IMS-1	3	E	163
IMS-7, 8, 9, 10	B	B	686
IMS-7, 8, 9, 10	C	C	464
IMS-7, 8, 9, 10	D	D	301
IMS-7, 8, 9, 10	E	E	163
IMS-14	1	D	301
IMS-14	2	C	464
IMS-14	3	B	686
IMS-19	1	B	686
IMS-19	2	C	464
IMS-19	3	D	301
GMS-93	1	B	686
GMS-93	2	C	464
GMS-93	3	D	301
GMS-105	1	C	464
GMS-105	2	D	301
GMS-105	3	E	163
GMS-105	4	E	163
O-01-06	B	B	686
O-01-06	C	C	464
O-01-06	D	D	301
O-01-05	B	B	686
O-01-05	C	C	464
O-01-05	D	D	301

Publications (in chronological order):
GMS-93, Siletz Bay area (Wang and Priest, 1995)
GMS-105, Salem area (Wang and Leonard, 1996)
IMS-1, Portland metro area (Mabey and others, 1997)
IMS-7, Dallas, Hood River, McMinnville-Dayton-Lafayette, Monmouth-Independence, Newburg-Dundee, Sandy, Sheridan-Willamina, and St. Helens-Columbia City-Scappoose areas (Madin and Wang, 1999a)
IMS-8, Canby-Barlow-Aurora, Lebanon, Silverton-Mt. Angel, Stayton-Sublimity-Aumsville, Sweet Home and Woodburn-Hubbard areas (Madin and Wang, 1999b)
IMS-09, Ashland, Cottage Grove, Grants Pass, Roseburg, and Sutherlin-Oakland areas (Madin and Wang, 1999c)
IMS-10, Astoria-Warrenton, Brookings, Coquille, Florence-Dunes City, Lincoln City, Newport, Reedsport-Winchester Bay, Seaside-Gearhart-Cannon Beach and Tillamook areas (Madin and Wang, 1999d)
IMS-14, Eugene area (Black and others, 2000a)
IMS-19, Klamath Falls area (Black and others, 2000b)
O-01-05, Eastern Benton County area (Wang and others, 2001a)
O-01-06, Tillamook area (Wang and others, 2001b)

2.1.5 Final Oregon NEHRP site class map

The final product (Figure 7) is a single Esri-format polygon file that is attributed with the source of each polygon (OGDC, SLIDO-2, or published study), the NEHRP site class, and for polygons from OGDC the Geologic Merge Unit Label. Within the feature class, all polygons of like Geologic Merge Unit have been combined into a single polygon, as have all polygons of like unit from SLIDO-2 and the 3D studies. The NEHRP site class data are provided as a feature class named Oregon_NEHRP_Site_Class in the geodatabase included in the appendix.

In order to conform as much as possible to existing USGS maps we also assigned V_{s30} values to the five NEHRP site classes following the values used in the V_{s30} model for the Pacific Northwest by the USGS (Figure 8, Table 1) and Pacific Northwest Seismic Network (Art Frankel, USGS, personal communication, 2012). The selected values were F = 98 m/sec, E = 163 m/sec, D = 301 m/sec, C = 464 m/sec, and B = 686 m/sec.

The philosophy behind the creation of this map was to use accepted methodology and published data as much as possible and to try to avoid subjective decisions where possible. It was also the intent to produce a map with conservative NEHRP site class values as we prefer that any significant deviations from what the map shows would tend to reduce seismic hazard (have a higher NEHRP site class or V_{s30} value). Recent NEHRP-funded work by the Washington Division of Geology and Earth Resources (DGER) provides an opportunity for an independent check of the map (Cakir and Walsh, 2012). DGER collected V_{s30} profiles adjacent to many of the seismograph stations of the Pacific

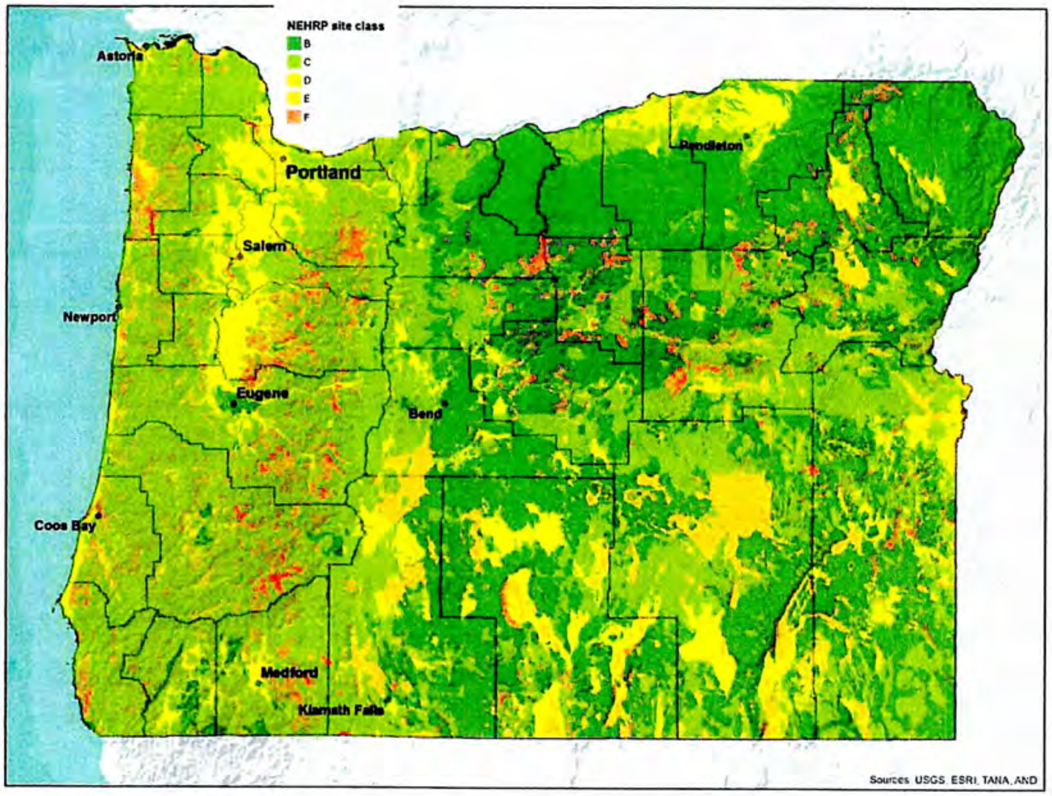


Figure 7. New NEHRP site class for Oregon. In comparison with the gridded USGS map in Figure 8, this map clearly represents geologic differences in site class with much greater resolution.

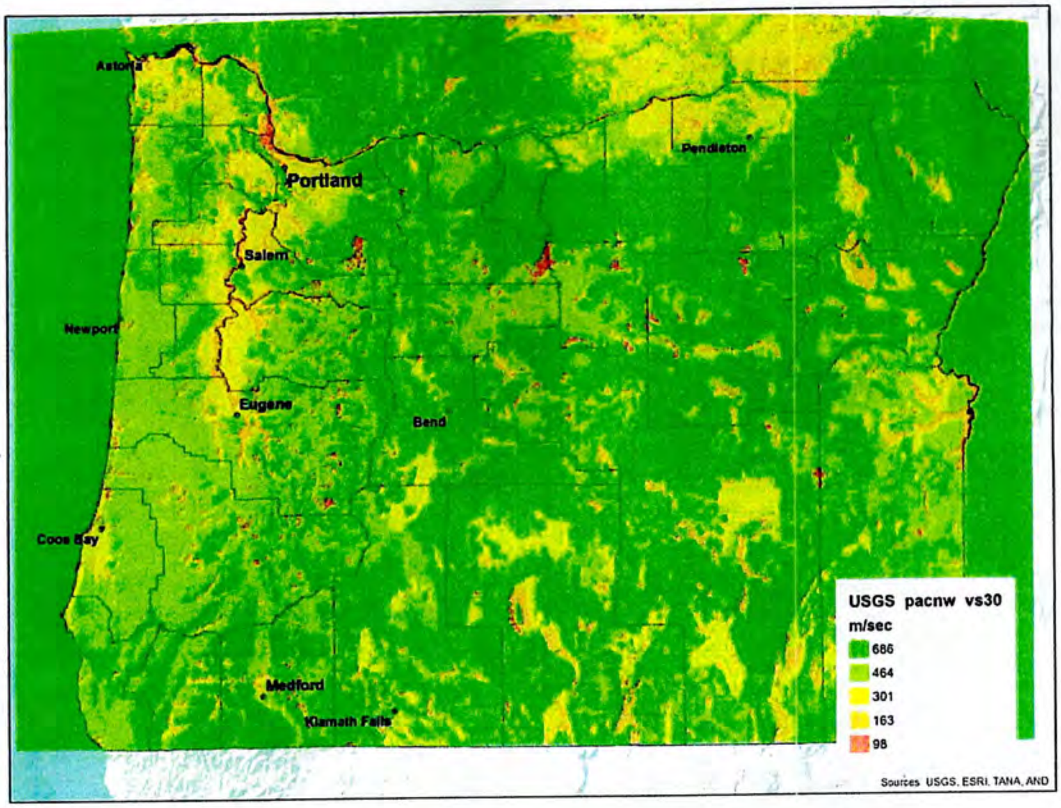


Figure 8. U.S. Geological Survey Pacific Northwest gridded V_{s30} data for Oregon.

Northwest Seismic Network using Multichannel Analysis of Surface Waves (MASW), Microtremor Array Measurements (MAM), P- and S-wave refraction methods to estimate near-surface P- and S-wave velocity (V_P and V_s) profiles, and ambient noise measurements to estimate deeper shear-wave profiles by using the joint inversion of MASW and Horizontal to Vertical Spectral Ratio (HVSR) resonant frequencies. We compared their measured V_{s30} values with those predicted by our map, and the results are summarized in Table 3. At 5 of 11 sites, the model returns the same NEHRP site class as the measurements; at all other sites (bold, red text in table) the model returns a site class with a lower shear wave velocity. This reflects the fact that the model extends the estimated surface unit velocity to the full 30-m depth and underscores that fact that the model is conservative.

Table 3. Comparison of V_{s30} profiles measured by Cakir and Walsh (2012) and values from this study.

Site	Measured V_{s30}	Measured NEHRP Site Class	Modeled NEHRP Site Class (This Study)	Modeled USGS V_{s30}
ALVY	471	C	C	464
BUCK	1522	**B-A**	**C**	464
COLT	499	C	C	464
EYES	334	D	D	301
HAO	730	**C**	**D**	301
KEEL	233	D	D	301
LANE	504	**C**	**D**	301
MONO	231	D	D	301
MRIN	452	**C**	**D**	301
PERL	353	**D**	**E**	163
PGO	320	**D**	**C**	464

Bold, red text indicates that the model returned a site class with a lower shear-wave velocity.

As noted, the site class variables mapped using OGDC and SLIDO-2 data are conservative, because they assume that the velocity of the surface geologic unit extends to the full depth of 30 m. One approach to try to make the map more representative of the actual geology would be to use water well data and our OGDC-linked velocity values to construct synthetic V_{s30} profiles. DOGAMI developed this technique to create site-specific V_{s30} data for a statewide school and critical facility vulnerability study (Lewis, 2007). The Oregon Water Resources Department maintains an online database of over 400,000 water well and geotechnical boring logs (http://apps.wrd.state.or.us/apps/gw/well_log/). Many of these logs have sufficient location information to allow them to be placed on a map with an accuracy of a few meters to a few tens of meters. DOGAMI staff interpreted the driller's lithologic logs and assigned each interval to a simple set of geologic units (sand, clay, sandstone, basalt, etc.) and then assigned a V_s value to each of those geologic units based in part on our V_s database and in part on the literature (Building Seismic Safety Council, 1997). We then were able to use the interval thickness and velocity data from each hole to calculate a synthetic V_{s30} value for that borehole. The online well log database provides a virtually unlimited opportunity to create synthetic profiles throughout the state, and future versions of this map will incorporate such data.

Another refinement we would consider using in a future map would be to try to map actual V_{s30} values for the OGDC units for which there is measured data, rather than binning the velocities to correspond to the bins defining the NEHRP site classes. Finally, a new map should include any recent DOGAMI lidar-based surficial geologic mapping (Ma and others, 2012).

2.2 Statewide liquefaction susceptibility map

We made a new liquefaction susceptibility map for Oregon by estimating susceptibility for various geologic units in OGDC, SLIDO-2, and recently published lidar-based surficial geology maps (see Figure 6 for data sources used for this map) then combining the polygons from those digital maps with data from the published hazards studies described in section 2.1. We assigned the OGDC geologic units a liquefaction susceptibility value of 0 (None), 1 (Very Low), 2 (Low), 3 (High), 4 (Very High) using the scheme of Youd and Perkins (1978) (Table 4), modified with our understanding of Oregon geology and by review of data from Washington (Palmer and others, 2004).

Table 4. Liquefaction susceptibility of select cohesionless sediments (Youd and Perkins, 1978).

Type of Deposit	General Distribution of Cohesionless Sediments in Deposits	Likelihood That Cohesionless Sediments When Saturated Would Be Susceptible to Liquefaction (by Age of Deposit)			
		Modern <500 yr	Holocene <11 ka	Pleistocene 11 ka-2 Ma	Pre-Pleistocene >2 Ma
(a) Continental Deposits					
River channel	locally variable	very high	high	low	very low
Flood plain	locally variable	high	moderate	low	very low
Alluvian fan and plain	widespread	moderate	low	low	very low
Marine terraces and plains	widespread	—	low	very low	very low
Delta and fan-delta	widespread	high	moderate	low	very low
Lacustrine and playa	variable	high	moderate	low	very low
Colluvium	variable	high	moderate	low	very low
Talus	widespread	low	low	very low	very low
Dunes	widespread	high	moderate	low	very low
Loess	variable	high	high	high	unknown
Glacial till	variable	low	low	very low	very low
Tuff	rare	low	low	very low	very low
Tephra	widespread	high	high	?	?
Residual soils	rare	low	low	very low	very low
Sebka	locally variable	high	moderate	low	very low
(b) Coastal Zone					
Delta	widespread	very high	high	low	very low
Esturine	locally variable	high	moderate	low	very low
Beach					
High wave energy	widespread	moderate	low	very low	very low
Low wave energy	widespread	high	moderate	low	very low
Lagoonal	locally variable	high	moderate	low	very low
Fore shore	locally variable	high	moderate	low	very low
(c) Artificial					
Uncompacted fill	variable	very high	—	—	—
Compacted fill	variable	low	—	—	—

The assigned values are shown in Table 1. As with the NEHRP site class map, we added the data from SLIDO-2 to the map, superseding underlying OGDC values; the susceptibility assignments for the SLIDO-2 units are also shown in Table 1. We also added data from the published hazard studies listed in the previous section, and those data superseded both the SLIDO-2 and OGDC data. The assignment of liquefaction susceptibility classes to the hazard classes in each published study is shown in Table 5.

The new liquefaction susceptibility map is shown in Figure 9.

Table 5. Assignment of liquefaction susceptibility classes and V_{s30} values from published DOGAMI 3D studies.

DOGAMI "3D" Publication	Publication Unit Category	Liquefaction Susceptibility, This Report
IMS-1	high	high
	moderate	moderate
	low	low
	none	none
IMS-7, IMS-8, IMS-9, and IMS-10	high	high
	moderate	moderate
	low	low
	none	none
IMS-14	not used	not used
IMS-19	low	low
	none	none
GMS-93	high	high
	moderate	moderate
	low	low
	none	none
GMS-105	0	none
	1	none
	2	moderate
	3	high
	4	high
	5	high
O-01-06	high	high
O-01-05	high	high
	moderate	moderate
	low	low

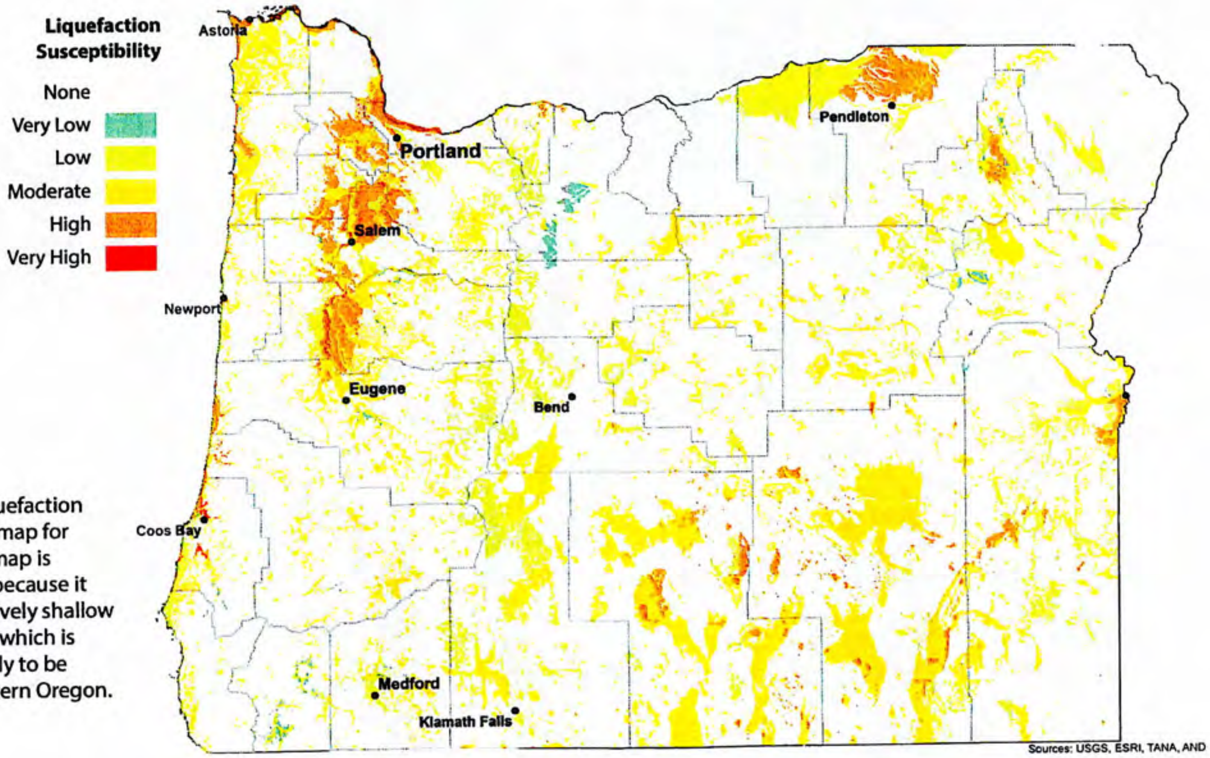


Figure 9. Liquefaction susceptibility map for Oregon. This map is conservative because it assumes relatively shallow groundwater, which is much less likely to be correct in eastern Oregon.

It should be noted that in many instances, the liquefaction susceptibility values from the published "3D" studies are significantly lower than the surrounding data based on OGDC and SLIDO. This is in part because the OGDC assignments assumed saturation, whereas the detailed studies typically looked at realistic depths to groundwater in assessing overall liquefaction potential, and those studies also considered Standard Penetration Test values and V_s data where available. This suggests that, overall, the susceptibility map based on OGDC and SLIDO-2 is conservative.

Future refinements of this susceptibility map would include the use of water well logs to constrain the thickness of liquefiable deposits, and development of seasonal groundwater level maps.

The liquefaction susceptibility data are provided as a feature class named Oregon_Liquefaction_Susceptibility in the Esri geodatabase included in the appendix.

2.3 Statewide landslide susceptibility map

We made a new statewide landslide susceptibility map for Oregon by following the methodology outlined in the FEMA HAZUS-MH 2.0 technical manual (FEMA 2011; hereafter called HAZUS-MH) with some modifications based on the spatial distribution of mapped landslides in OGDC and SLIDO-2. Table 6 shows the classification scheme used in HAZUS-MH, which recognizes three geologic groups and six slope classes.

We divided the geologic units in OGDC into the three geologic groups defined in Table 6. For surficial units (units classified as sediments in the OGDC General Geology field [Geo_Genl_U]), the units were assigned to a HAZUS-MH geologic group based on the Formation field of OGDC, as shown in Table 7.

The remaining OGDC units were classified based on the combination of the General Geology and Rock Type (G_Rock_Typ) fields as shown in Table 7. These assignments were based on our knowledge of the various rock types in OGDC.

Table 6. Landslide susceptibility of geologic groups (HAZUS-MH 2.0 Table 4-15 [FEMA, 2011]).

Geologic Group		Slope Angle, degrees					
		0-10	10-15	15-20	20-30	30-40	>40
(a) DRY (groundwater below level of sliding)							
A	Strongly Cemented Rocks (crystalline rocks and well-cemented sandstone, $c'=300$ psf, $\phi'=35^{\circ}$)	None	None	I	II	IV	VI
B	Weakly Cemented Rocks and Soils (sandy soils and poorly cemented sandstone, $c'=0, \phi'=35^{\circ}$)	None	III	IV	V	VI	VII
C	Argillaceous Rocks (shales, clayey soil, existing landslides, poorly compacted fills, $c'=0$ $\phi'=20^{\circ}$)	V	VI	VII	IX	IX	IX
(b) WET (groundwater level at ground surface)							
A	Strongly Cemented Rocks (crystalline rocks and well-cemented sandstone, $c'=300$ psf, $\phi'=35^{\circ}$)	None	III	VI	VII	VIII	VIII
B	Weakly Cemented Rocks and Soils (sandy soils and poorly cemented sandstone, $c'=0$, $\phi'=35^{\circ}$)	V	VIII	IX	IX	IX	X
C	Argillaceous Rocks (shales, clayey soil, existing landslides, poorly compacted fills, $c'=0$ $\phi'=20^{\circ}$)	VII	IX	X	X	X	X

Table 7. HAZUS-MH (FEMA, 2011) Geologic Group assignments for OGDC units.

OGDC Geo_Genl_U	OGDC Formation	OGDC G_Rock_Typ	HAZUS-MH Group
batholith rocks		all	A
intrusive rocks		all	A
invasive extrusive		all	B
melange rocks		all	B
metamorphic rocks		all but serpentine	A
metamorphic rocks		serpentine	B
sediments	nd	coarse-grained sediments	B
sediments	nd	mixed-grained sediments	B
sediments	nd	mudflow breccia	C
sediments	alluvial deposits		C
sediments	alluvial fan deposits		B
sediments	beach deposits		C
sediments	Bonneville Flood deposits		C
sediments	coastal terrace deposits		B
sediments	colluvial deposits		B
sediments	eolian deposits		C
sediments	estuarine deposits		C
sediments	fan delta deposits		B
sediments	glacial deposits		B
sediments	glacial outwash deposits		B
sediments	lacustrine deposits		C
sediments	landslide deposits		C
sediments	laterite deposits		B
sediments	loess		C
sediments	man-made fill deposits		C
sediments	marsh deposits		C
sediments	mine tailings		C
sediments	missoula Flood deposits		C
sediments	playa lake deposits		C
sediments	pluvial lake valley deposits		C
sediments	spring chemical sediments		B
sediments	terrace deposits		B
marine sedimentary rocks		basalt	B
marine sedimentary rocks		basaltic sandstone	B
marine sedimentary rocks		basin plain mudstone	C
marine sedimentary rocks		chert	B
marine sedimentary rocks		coarse-grained sediments	B
marine sedimentary rocks		conglomerate	B
marine sedimentary rocks		deltaic sandstone	B
marine sedimentary rocks		dolomite	A
marine sedimentary rocks		fine-grained sediments	C
marine sedimentary rocks		limestone	B
marine sedimentary rocks		marble	A
marine sedimentary rocks		mixed-grained sediments	B
marine sedimentary rocks		mudstone	C
marine sedimentary rocks		sandstone	B
marine sedimentary rocks		shelf sandstone	B
marine sedimentary rocks		siltstone	B
marine sedimentary rocks		slope channel sandstone	B
marine sedimentary rocks		slope mudstone	C
marine sedimentary rocks		tuffaceous sedimentary rocks	C
marine sedimentary rocks		turbidite	B
terrestrial sedimentary rocks		basaltic sandstone	B
terrestrial sedimentary rocks		coarse-grained sediments	B
terrestrial sedimentary rocks		conglomerate	B
terrestrial sedimentary rocks		fine-grained sediments	C
terrestrial sedimentary rocks		limestone	B
terrestrial sedimentary rocks		mixed-grained sediments	B
terrestrial sedimentary rocks		mixed lithologies	B
terrestrial sedimentary rocks		sandstone	B
terrestrial sedimentary rocks		tuffaceous sedimentary rocks	C
volcaniclastic rocks		airfall deposits	C
volcaniclastic rocks		fine-grained sediments	C
volcaniclastic rocks		mudflow breccia	C
volcaniclastic rocks		all others	B
volcanic rocks			B
vent pyroclastic rocks			A

2.3.1 Spatial statistics of mapped landslide deposits

The HAZUS-MH groups are very general, so we developed an empirical assessment of landslide susceptibility using the spatial relationship between mapped landslides in SLIDO-2 and the various geologic units in OGDC. We selected all polygons from OGDC that intersected a landslide polygons from SLIDO-2, grouped the intersecting polygons by Geologic Merge Unit, and then calculated the percentage of each unit (based on the polygon count) that intersected a landslide. Geologic Merge Units represented by fewer than 10 polygons in the entire database were not considered. The result yielded statistics for the spatial association of 732 of 1,923 OGDC units with existing landslides, which are summarized in Figure 10. We assume that if a particular geologic unit is highly spatially associated with landslides, then that unit must have relatively high susceptibility.

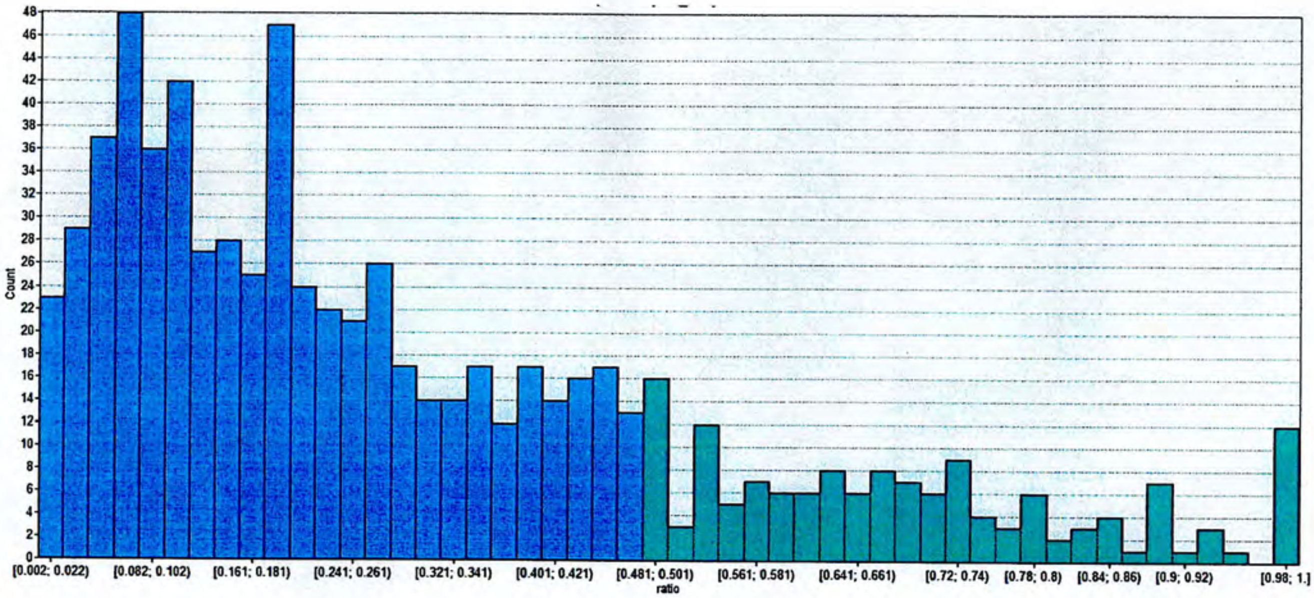


Figure 10. Histogram showing the frequency of the fraction of a unit's polygons that intersect a mapped landslide for 732 OGDC Geologic Merge Units.

Using the distribution shown in Figure 10, we assigned the 732 OGDC units to HAZUS-MH geologic groups on the basis of the percentage of polygons in contact with mapped landslides as follows:

0 to 20% association, HAZUS-MH group A
> 20% to 50% association, HAZUS-MH group B
> 50% association, HAZUS-MH group C

To make a statewide map of the HAZUS-MH geologic groups, we first stamped SLIDO-2 landslides onto the OGDC polygons with SLIDO-2 data superseding underlying OGDC data in areas of overlap, and then converted the polygons into a raster with 30 m (98.4 ft) cells for analysis. The resultant geologic group map is shown in Figure 11. The geologic group map is an interim product and is not provided in the appendix.

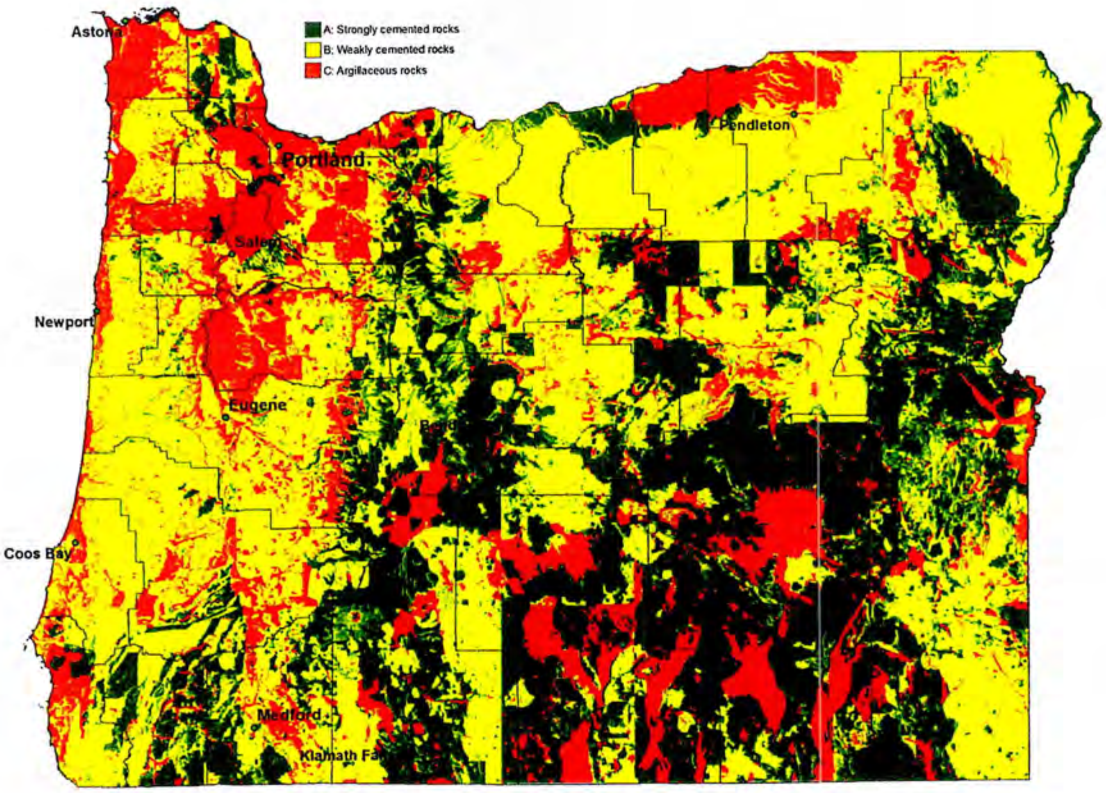


Figure 11. Geologic group map for HAZUS-MH landslide susceptibility calculation.

2.3.2 Slope classes

The HAZUS-MH methodology combines geologic groups with slope classes as defined in Table 6. To create the slope classes we prepared a statewide digital elevation model (DEM) with 30-m pixels that combined all of the available lidar-derived topography for Oregon with existing USGS National Elevation Database (NED) data. We first mosaicked all of the available lidar from DOGAMI's collection (about 22% of the state, largely in western Oregon), then resampled it from its original 1-m resolution to 30 m. The 30-m lidar raster was then stamped onto the statewide 30-m NED raster and reclassified according to the slope categories defined in Table 6. The resultant slope class map is shown in Figure 12. The slope class map is an interim product and is not provided in the appendix.

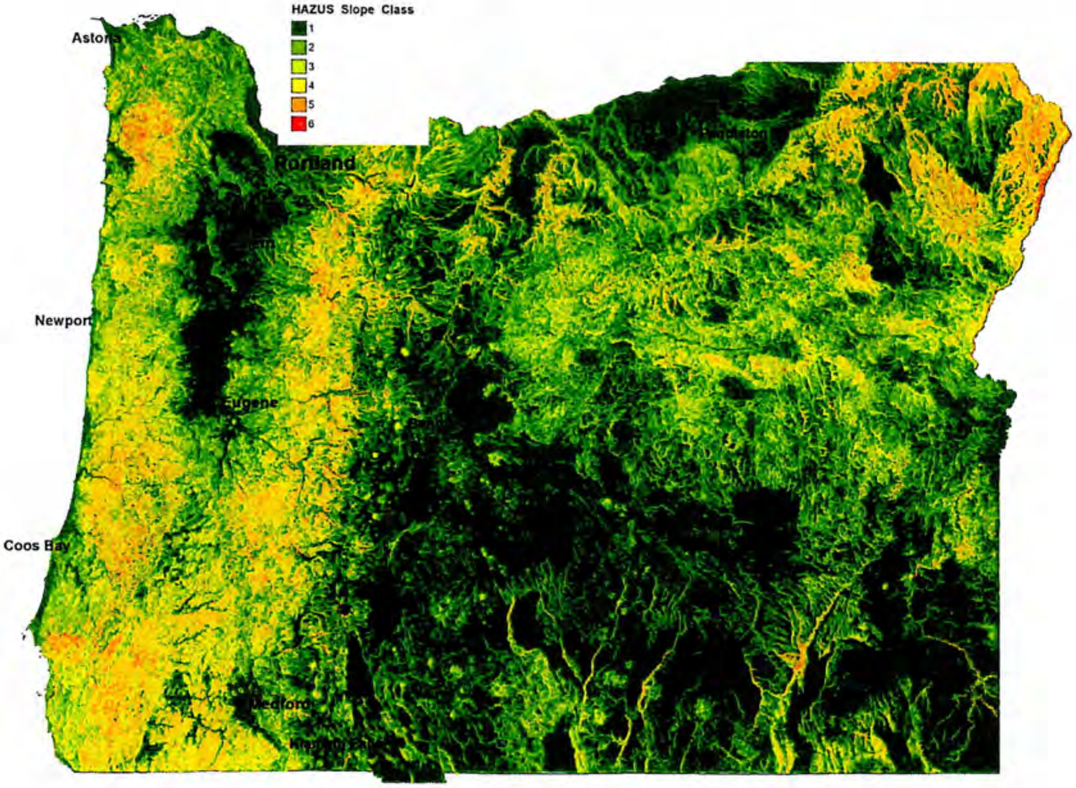


Figure 12. Slope class map for HAZUS-MH landslide susceptibility map.

2.3.3 Landslide susceptibility map

We used the slope class map (Figure 12) and geologic group map (Figure 11) described in the two preceding sections and the matrix in Table 6 to create the landslide susceptibility map. We chose to use matrix b (WET) from Table 6 because conditions in western Oregon are wet or very wet for a majority of the year, so the resultant map is therefore conservative. The geologic group map was attributed with values from 1 to 3, and the slope class map with values from 1 to 6. We multiplied the values in the geologic group map by 10 and added the values from the slope class map. The resulting raster therefore had unique values for each combination of geologic group and slope class, which were reclassified into a map with values of 3, 5, 6, 7, 8, 9, and 10, representing the possible values on the matrix. That final landslide susceptibility class map is shown in Figure 13.

One factor that may lead this map to underestimate susceptibility is that fact that the majority of landslides that exist in western Oregon are not represented in OGDC or SLIDO-2. Since 2007, DOGAMI has collected millions of acres of high-resolution lidar topography in western Oregon and has developed a protocol for creating detailed landslide inventory maps using the lidar data (Burns and Madin, 2009). Where this technique has been applied, even the best available pre-lidar landslide maps missed well over half of the landslides that could be found with lidar. In a pilot study in the Portland metro area, Burns (2007) found that it was possible to find three times as many landslides with lidar as it was with serial stereo air photos spanning the time interval from 1936 to 2000. Therefore it is likely that in most forested areas of Oregon, the actual number of landslides present far exceeds what is included in this map. A few lidar-based landslide inventories are included in SLIDO-2, but the vast majority of lidar data currently available in Oregon have not yet been analyzed for landslide inventory. A future upgrade for this landslide susceptibility map would incorporate detailed lidar-based landslide inventory for all critical areas.

The landslide susceptibility class data are provided as a feature class named Oregon_Landslide_Susceptibility in the Esri geodatabase included in the appendix.

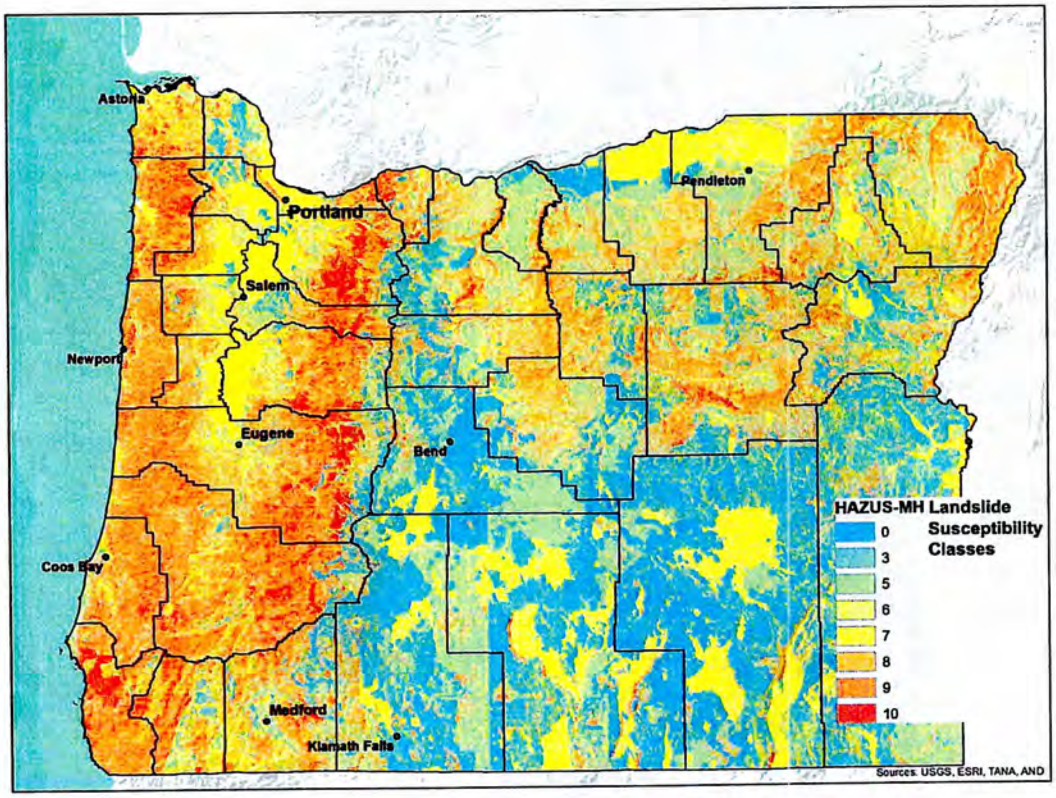


Figure 13. The landslide susceptibility class map derived from HAZUS-MH methodology.

3 GROUND MOTION MAPS

3.1 Peak ground acceleration (PGA)

PGA is a widely used measure of ground shaking for a range of geotechnical and structural engineering applications. The ORP PGA map used synthetic bedrock ground motions from a M 9.0 Cascadia earthquake that were provided by Arthur Frankel of the USGS (personal communication, 2012). These ground motions were based on the parameters of the USGS Cascadia M 9.0 scenario ShakeMap®. The synthetic bedrock motions derived from the ShakeMap scenario were adjusted for site effects using the relationships described by Boore and Atkinson (2008) and the new statewide NEHRP site class map described in section 2.1.5. We accomplished shaking amplification calculations for all of Oregon as a series of GIS-based raster operations using 30 m (98.4 ft) cell size. The process requires numerous GIS steps, which were incorporated into a geoprocessing model using the Esri ArcMap® program.

3.1.1 Bedrock shaking map

USGS staff (Arthur Frankel, personal communication, 2012) provided simulated bedrock (firm rock condition, V_{s30} = 760 m/sec) data for Oregon posted at 0.02-degree intervals. These points were projected to the state-standard Oregon Lambert projection (EPSG 2292), and the remainder of the calculations were carried out using the same projection. The projected points were imported into a triangular irregular network (TIN), and the TIN was exported to a raster with 30-m (98.4 ft) cells. The bedrock shaking map shows a fairly uniform gradient across the state, with maximum values of ~0.40 g along the coast (Figure 14).

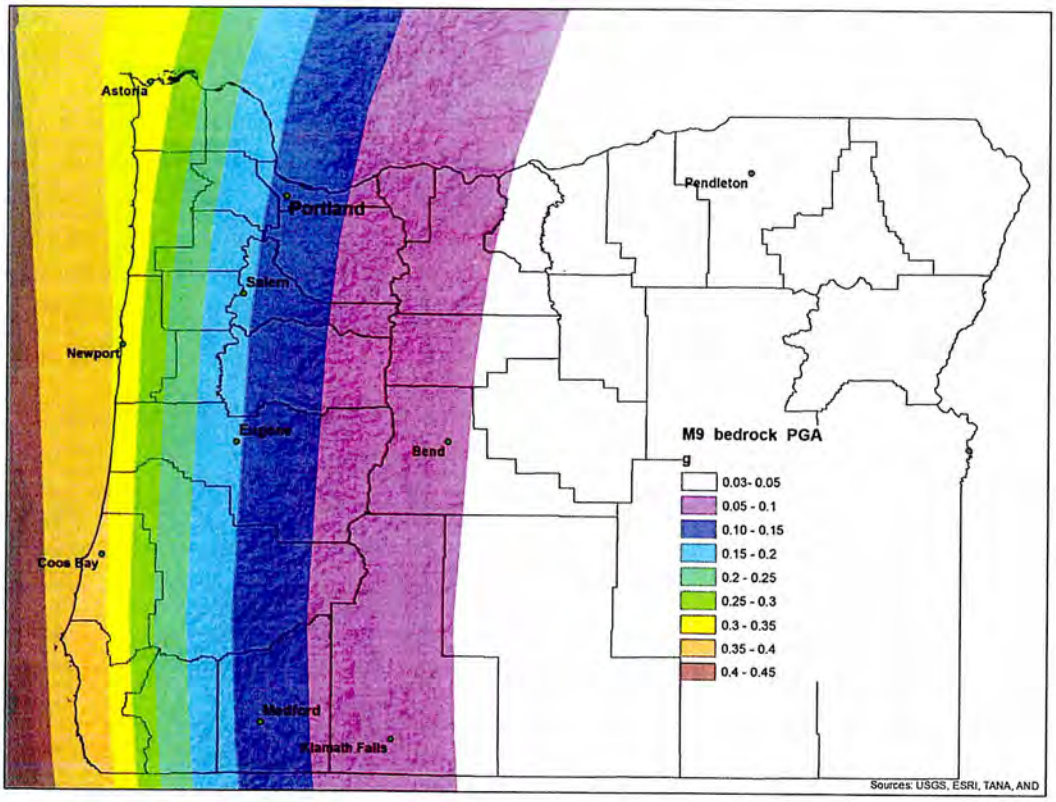


Figure 14. Bedrock (V_{s30} =760 m/sec) peak ground acceleration (PGA) map for the scenario magnitude 9.0 earthquake.

The Boore and Atkinson (2008) equations for the nonlinear component of amplification are calculated differently for three ranges of bedrock PGA (pga_b), so the bedrock raster was divided into three rasters:

$$pga_b \le 0.03\text{ g}$$

$$0.03\text{ g} < pga_b \le 0.09\text{ g}$$

$$0.09\text{ g} < pga_b$$

with zero values in areas outside of the respective pga_b range.

The bedrock shaking map is provided as a raster dataset named `Oregon_M_9_Scenario_Bedrock_PGA` in the Esri geodatabase included in the appendix.

3.1.2 Site-amplification calculations

To calculate site amplification, we used equation 6 of Boore and Atkinson (2008):

$$F_s = F_{lin} + F_{nl}$$

where the linear term F_{lin} is given by

$$F_{lin} = b_{lin} \ln (V_{s30} / V_{ref})$$

with b_{lin} a period-dependent coefficient that has a value of −0.36 for PGA (Table 3 of Boore and Atkinson, 2008) and $V_{ref} = 760$ m/sec. The nonlinear term F_{nl} is given by one of three equations, dependent upon the strength of the input bedrock ground motion p_{gab}:

For $pga_b \le 0.03$ g,

$$F_{nl} = b_{nl} [\ln (0.06 / 0.1)].$$

For $pga_b > 0.03$ g and ≤ 0.09 g,

$$F_{nl} = b_{nl} \ln (0.06 / 0.01) + c[\ln (p_{gab} / 0.03)]^2 + d[\ln (p_{gab} / 0.03)]^3.$$

For $pga_b > 0.09$ g,

$$F_{nl} = b_{nl} \ln (p_{gab} / 0.1).$$

The coefficients c and d are given by equations 9–12 of Boore and Atkinson (2008):

$$c = (3\Delta y - b_{nl} \Delta x) / \Delta x^2$$

and

$$d = (2\Delta y - b_{nl} \Delta x) / \Delta x^3$$

where

$$\Delta x = \ln (0.03\text{ g} / 0.09\text{ g}) = 0.69314$$

and

$$\Delta y = b_{nl} \ln (0.09\text{ g}/0.06\text{ g}).$$

Finally, b_{nl} is given by equations 13a–13c and Table 3 of Boore and Atkinson (2008):

For $V_{s30} < 180$ m/sec,

$$B_{nl} = -0.64.$$

For $V_{s30} > 180$ m/sec and ≤ 300 m/sec,

$$b_{nl} = (-0.64 - -0.140 \ln (V_{s30} / 300\text{ m/sec}) / \ln (180\text{ m/sec} / 300\text{ m/sec}) + -0.14.$$

For $V_{s30} > 300$ m/sec ≤ 760 m/sec,

$$b_{nl} = -0.14 \ln (V_{s30} / 760\text{ m/sec}) / \ln (300\text{ m/sec} / 760\text{ m/sec}).$$

Because there are only five possible values of V_{s30} in the site class map (Table 1), it is easy to construct a table (Table 8) of all the necessary values of b_{nl}, c, and d to calculate F_{nl} as a function of pga_b. It is also possible to calculate the necessary values of F_{lin} as a function of V_{s30}. Fields for these values were added to the polygons of the V_{s30} map, and then populated with the appropriate values for each value of V_{s30}. We then developed a multi-step geoprocessing model in ArcMap (Figure 15) that carried out all of the required calculations using the V_{s30} polygon map and the raster of pga_b values.

Table 8. Boore and Atkinson (2008) PGA site amplification coefficient values for V_{s30} values represented in the statewide V_{s30} map.

V_{s30}, m/sec	F_{lin}	c	d	b_{nl}
98	0.737406	-0.0624	-0.1388	-0.64
163	0.554245	-0.0624	-0.1388	-0.64
301	0.333435	-0.0136	-0.0302	-0.1394
464	0.177636	-0.0072	-0.0161	-0.0743
680	0.036879	-0.0015	-0.0033	-0.0154

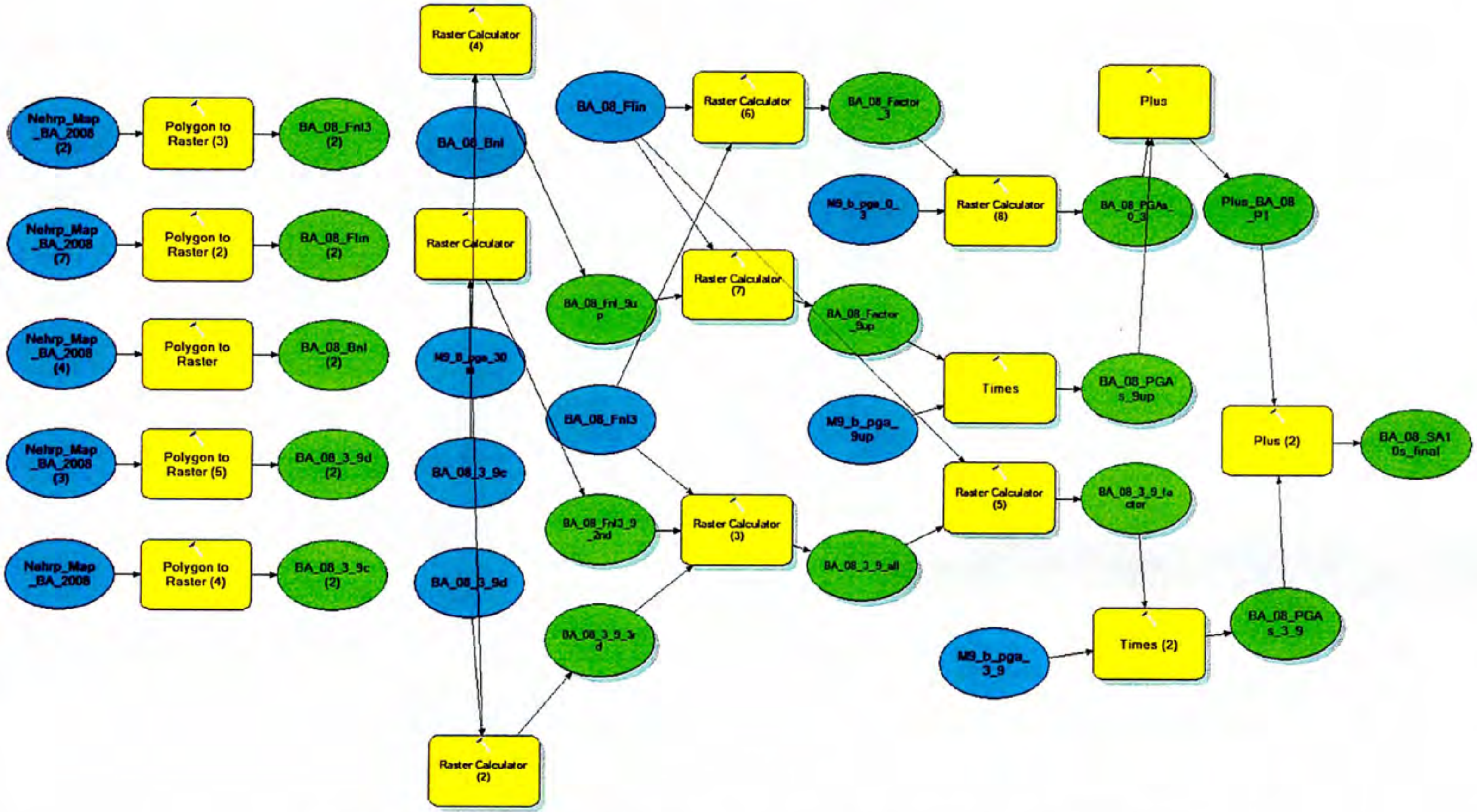


Figure 15. Esri ArcMap geoprocessing model for calculation of *pga* values with site amplification.

The model first creates rasters for B_{nl}, F_{lin}, c, and d values, then uses them to calculate F_{nl} as a function of pga_b using the three ranges for pga_b. Those values are then used to calculate the site amplification factors, F_s (Figure 16), which range from 0.73 to 2.9, and that are applied in turn to pga_b to produce the final site values for PGA, which are shown in Figure 17. The range of final site values is 0.01 g to 0.45 g, which is similar to the range of values for PGA from the published USGS Cascadia M 9.0 scenario (0.01 g to 0.49 g).

The map of site PGA is provided as a raster dataset named *Oregon_M_9_Scenario_Site_PGA* in the Esri geodatabase included in the appendix. For the ORP analysis, a map of site PGA covering the western half of the state was prepared and is provided as Plate 1 in the appendix.

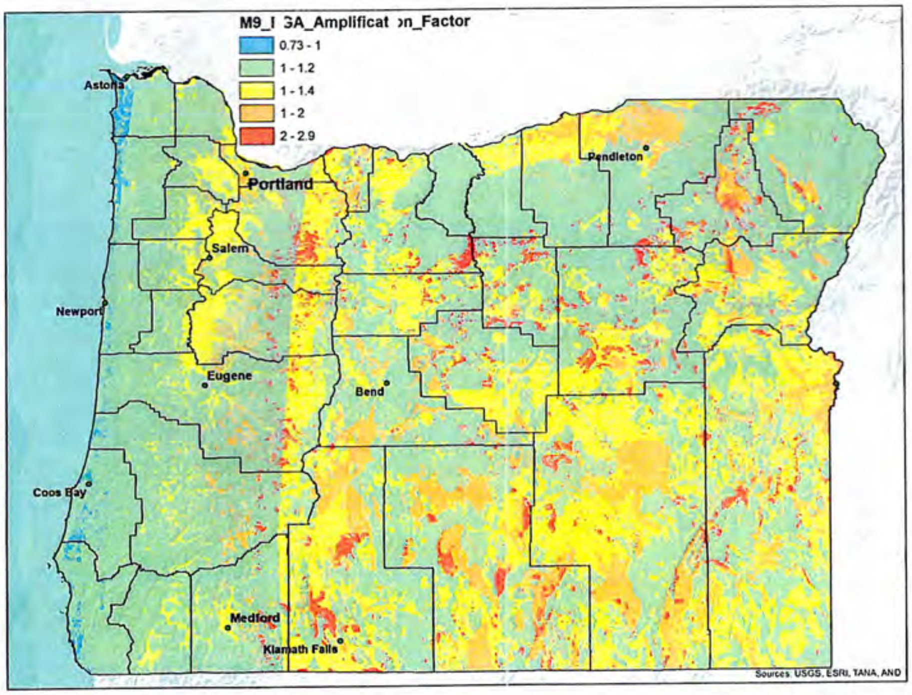


Figure 16. Site amplification factors for PGA for the scenario magnitude 9.0 earthquake.

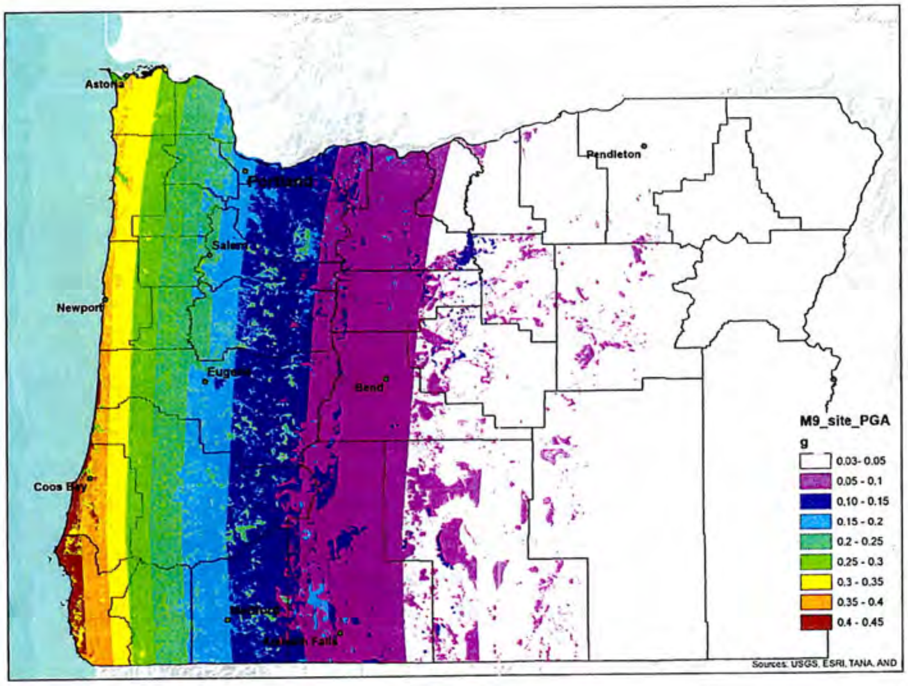


Figure 17. Site PGA map for the scenario magnitude 9.0 earthquake. (Also see Plate 1 in the appendix.)

3.2 Peak ground velocity (PGV)

We mapped scenario peak ground velocity values for Oregon by first calculating the 1-second period spectral acceleration (SA01) and then converting it to PGV using the relationship described by Newmark and Hall (1982). As with the PGA map, we used the model for the USGS Cascadia M 9.0 ShakeMap to calculate gridded bedrock SA01 values for Oregon (firm rock condition, V_{s30} = 760 m/sec), posted at 0.02-degree intervals. We followed the same procedure as described for the site PGA calculations above, simply using the 1-second period coefficients from Table 3 of Boore and Atkinson (2008). The resulting coeffiecents used for the SA01 amplification calculations are shown in Table 9. As with the PGA calculations, these values were inserted into the vector map of V_{s30} values, and then the geoprocessing model was applied to produce the final SA01 factor map (Figure 18) and site value map (Figure 19).

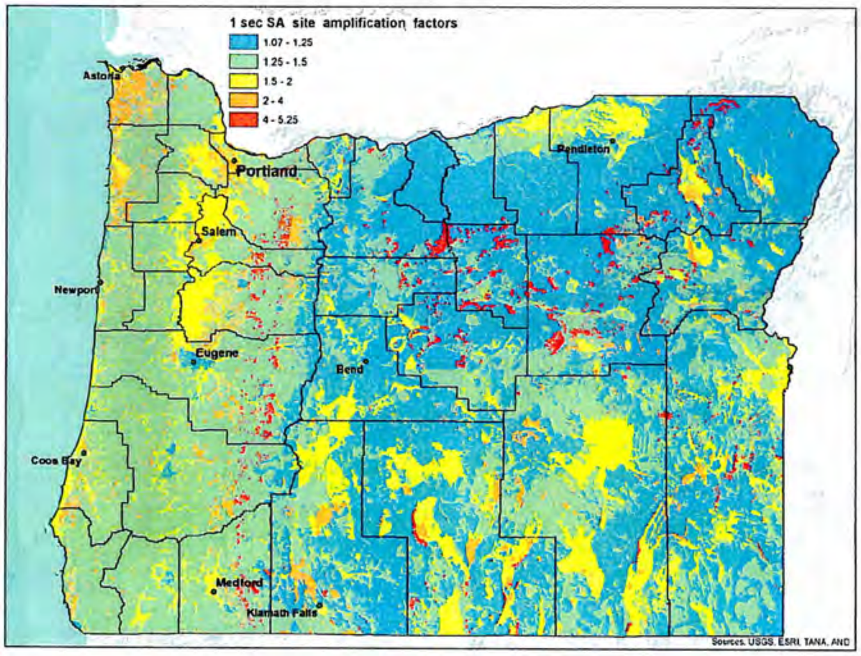


Figure 18. Site amplification values for SA01 (1-second spectral acceleration) for the scenario M 9.0 earthquake.

Table 9. Boore and Atkinson (2008) SA01 site amplification coefficient values for V_{s30} values represented in the statewide V_{s30} map.

V_{s30}, m/sec	F_{lin}	c	d	b_{nl}
98	1.433846	−0.4792	0.1556	−0.44
163	1.077698	−0.4792	0.1556	−0.44
301	0.648346	0.0000	0.0000	0
464	0.345404	0.0000	0.0000	0
680	0.071709	0.0000	0.0000	0

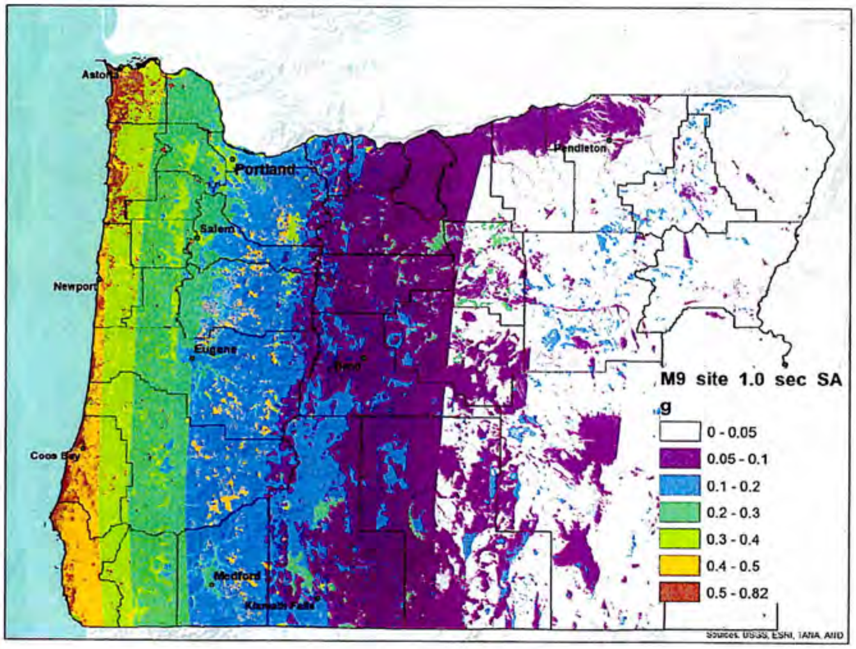


Figure 19. Site SA01 map for the scenario M 9.0 earthquake.

To convert the SA01 values to PGV, we used the Newmark and Hall (1982) relationship, which is

$$PGV = SA01 \cdot 94.666,$$

where PGV is in centimeters per second and SA01 is in g.

The resulting PGV map is shown in Figure 20 and has values that range from 1.6 cm/sec to 78 cm/sec. These values are also comparable to the published USGS M 9.0 ShakeMap values (1.9 cm/sec to 70.8 cm/sec).

The maps of bedrock SA01, site SA01, and PGV are provided as raster datasets in the Esri geodatabase included in the appendix and are named, respectively, *Oregon_M_9_Scenario_Bedrock_SA01*, *Oregon_M_9_Scenario_Site_SA01*, and *Oregon_M_9_Scenario_Site_PGV*. For the ORP analysis, a map of site PGA covering the western half of the state was prepared and is provided as Plate 2 in the appendix.

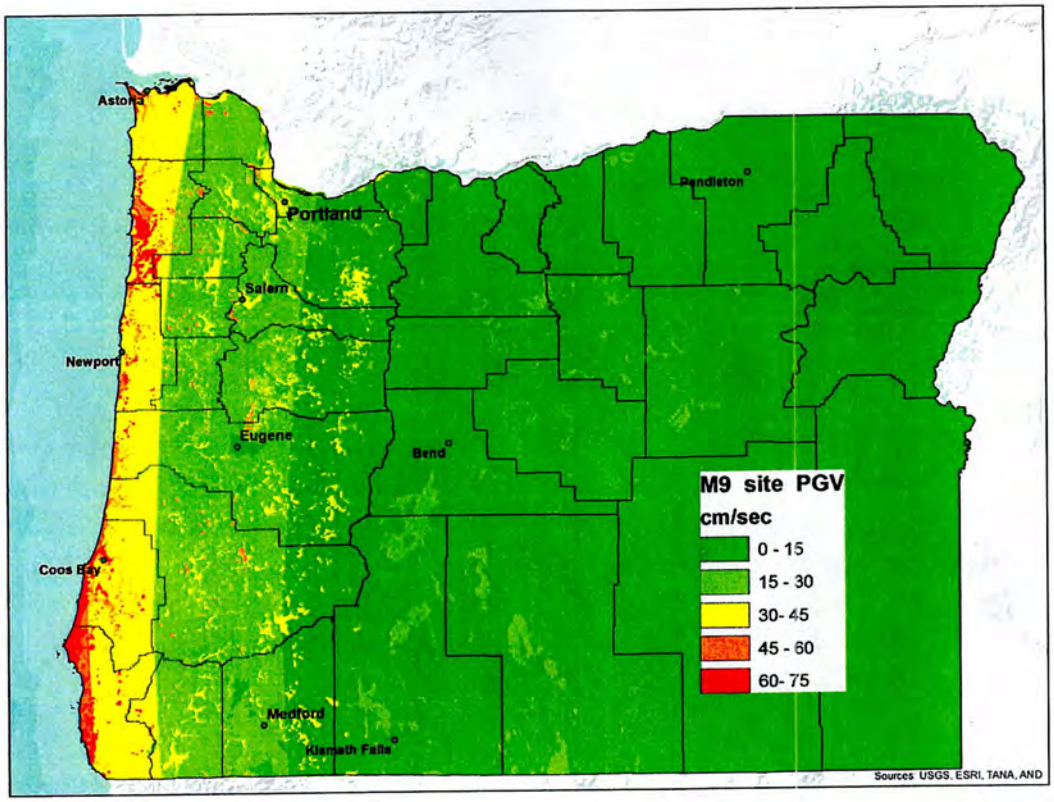


Figure 20. Site PGV map for the scenario M 9.0 earthquake. (Also see Plate 2 in the appendix.)

4 GROUND DEFORMATION MAPS

4.1 Liquefaction

We used the methods described in the HAZUS-MH technical manual (FEMA, 2011) to make a map of liquefaction probability and lateral spread permanent ground deformation (PGD). This approach provides results that are consistent and compatible with HAZUS-MH but that have much higher spatial resolution, so that important spatial variations in liquefaction susceptibility are reflected.

4.1.1 Probability of liquefaction

Equation 4-20 of the HAZUS-MH manual gives the relation between the probability of liquefaction of a deposit with a particular susceptibility category P_{lsc} and the strength and duration of shaking and the depth to the water table. The equation is

$$P_{lsc} = P_{lsca} \,/\, (K_m \cdot K_w) \cdot P_{ml}$$

where P_{lsca} is the conditional probability of liquefaction for a given susceptibility as a function of PGA, K_m is a moment magnitude correction factor, K_w is a ground water correction factor, and P_{ml} is the proportion of a map unit susceptible to liquefaction. P_{lsca} is given by Table 4.12 of the HAZUS-MH manual, shown here as Table 10.

Table 10. Equations for conditional liquefaction probability as a function of PGA (HAZUS-MH manual Table 4.12 [FEMA, 2011]).

Susceptibility Category	P_{lsca}	P_{ml}
Very High	$0 \le 9.09_{pga} - 0.82 \le 1$	0.25
High	$0 \le 7.67_{pga} - 0.92 \le 1$	0.2
Moderate	$0 \le 6.67_{pga} - 1 \le 1$	0.1
Low	$0 \le 5.57_{pga} - 1.18 \le 1$	0.05
Very Low	$0 \le 4.16_{pga} - 1.08 \le 1$	0.02
None	0	0

The factors for the equations shown in Table 10 were added as attribute fields with appropriate values for each susceptibility category in the vector landslide susceptibility map (section 2.3.3), and then the vector map was converted into rasters containing the factors with 30-m cells. A raster of P_{lsca} values was then calculated following the equations from Table 10, and using the PGA values derived in section 3.1. The moment magnitude correction factor is meant to account for the effect of duration on P_{lsc}, with the values of Table 10 calculated for a reference earthquake of M7.5. The equation is

$$K_m = 0.0027M^3 - 0.0267M^2 - 0.2055M + 2.198,$$

and for $M = 9.0$ the value is 0.8749. The groundwater correction factor is meant to account for how likely the deposit is to be saturated and is used only when depth to groundwater ≠ 5 ft. For these calculations, we use the HAZUS-MH default assumption of 5 ft to groundwater, so the K_w term is not needed. It should be noted that the assumption that groundwater is everywhere within 5 ft of the surface makes the liquefaction probability map more conservative.

Using rasters containing values for P_{lsca} and P_{ml} (K_m is constant), we calculated a raster of P_{lsc} values using an Esri geoprocessing model written for this purpose. The resulting map is shown in Figure 21 and has probability values that range from 0 to 0.27, or zero to 27 percent.

Note that this range of probability values is constrained by the range of P_{ml} values used by HAZUS-MH (Table 10 of this report) which do not exceed 0.25 (25% probability). The range of values in the final map is slightly higher due to the influence of K_w, but overall the map values are limited by P_{ml}, the assumed proportion of the deposit likely to liquefy.

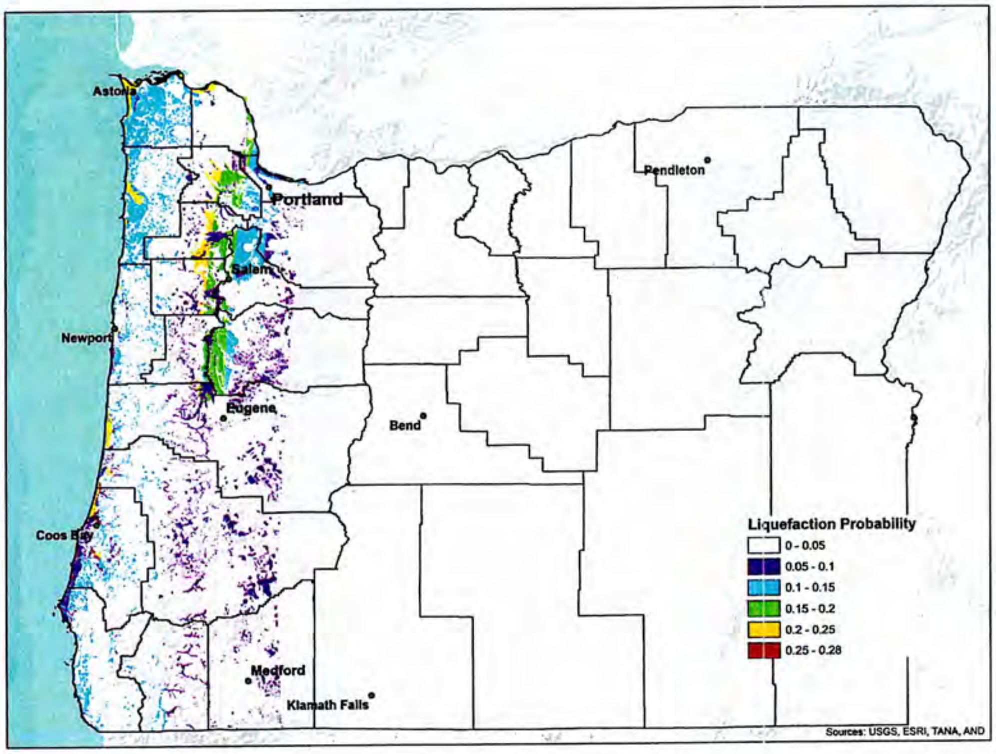
The factors required (Table 10) for the calculation of the liquefaction probability are included in fields in the feature class named Oregon_Liquefaction_Susceptibility in the Esri geodatabase included in the appendix. The final map of liquefaction probability is provided as a raster dataset named *Oregon_M_9_Scenario_Liquefaction_Probability* in the Esri geodatabase included in the appendix. For the ORP analysis, a map of liquefaction probability covering the western half of the state was prepared, and that map is provided as Plate 3 in the appendix.

4.1.2 Liquefaction-induced lateral spreading permanent ground deformation (PGD)

We calculated the likely extent of permanent ground deformation (PGD) due to liquefaction-induced lateral spreading using equation 4-23 of the HAZUS-MH manual and the liquefaction susceptibility map (section 2.2) and site PGA map (section 3.1) described above. The relation for lateral spread deformation for a given liquefaction susceptibility class is

$$PGD_{sc} = K_{\Delta} \cdot PGD_{sca}$$

Where PGD_{sca} is the expected displacement for a given susceptibility class as a function of PGA normalized by a threshold value PGA_t, and K_{Δ} is a displacement correction factor that is a function of magnitude. We added a field for PGA_t to the vector liquefaction susceptibility map and populated it with susceptibility-category-dependent values from Table 8. We then calculated displacement as a function of normalized PGA (PGA_n), using the formulas for different ranges of PGA_n shown in Table 11.



Sources: USGS, ESRI, TANA, AND

Figure 21. Liquefaction probability map for M 9.0 scenario earthquake. (Also see Plate 3 in the appendix.)

Table 11. Relationships between susceptibility category and threshold acceleration (PGA_t) for lateral spread deformation, and formulas for lateral spread displacement as a function of PGA normalized by threshold acceleration (PGA_n) (from HAZUS-MH Table 4-13 and Figure 4.9 {FEMA, 2011]).

Susceptibility Category	Threshold Ground Acceleration (PGA_t)	PGA_n (PGA/PGA_t)	Displacement (inches)
Very High	0.09 g	$1 < PGA/PGA_t \le 2$	$12 \cdot PGA_n - 12$
High	0.12 g	$2 < PGA/PGA_t \le 3$	$18 \cdot PGA_n - 24$
Moderate	0.15 g	$3 < PGA/PGA_t < 4$	$70 \cdot PGA_n - 180$
Low	0.21 g		
Very Low	0.29 g		

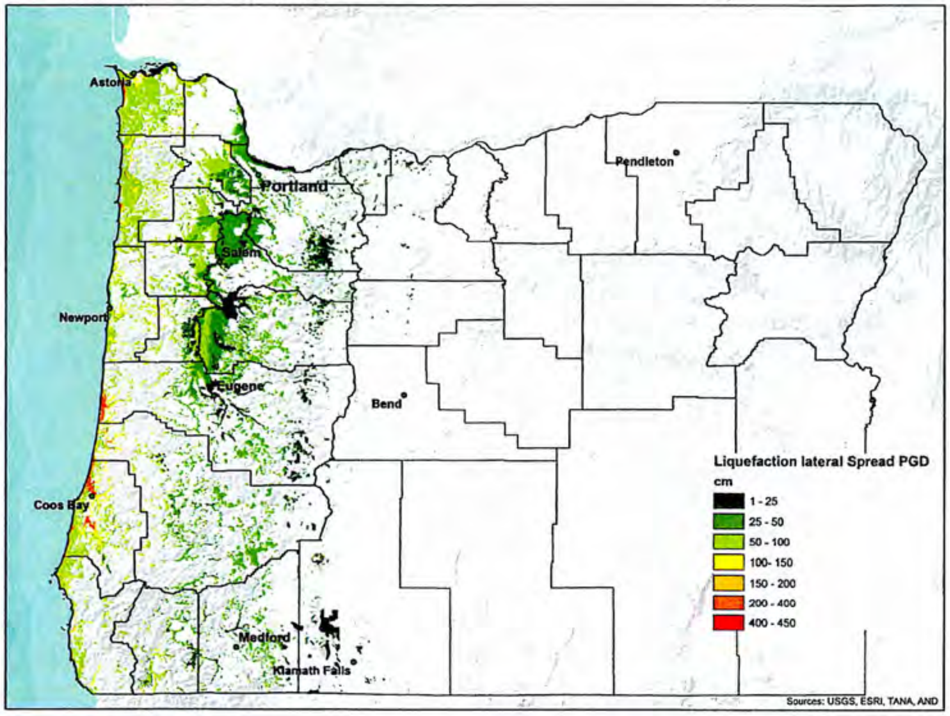
This resulted in a raster of PGD_{sca} values. K_Δ is given by

$$K_\Delta = 0.0086M^3 - 0.0914M^2 + 0.04698M - 0.9835,$$

which is equal to 2.1107 for $M = 9.0$. We then multiplied the raster of PGD_{sca} values by 2.1107 to arrive at the final raster of liquefaction-induced lateral spread PGD, which is shown in Figure 22.

As with previous GIS calculations, we constructed an Esri geoprocessing model to automatically carry out this sequence of calculations.

The factors required (Table 8) for the calculation of the liquefaction lateral-spread PGD are included in fields in the feature class named `Oregon_Liquefaction_Susceptibility` in the Esri geodatabase included in the appendix. The final map of liquefaction lateral spread PGD is provided as a raster dataset named *Oregon_M_9_Scenario_Liquefaction_PGD* in the Esri geodatabase included in the appendix. For the ORP analysis a map of liquefaction probability covering the western half of the state was prepared and is provided as Plate 4 in the appendix.



Sources: USGS, ESRI, TANA, AND

Figure 22. Liquefaction-induced lateral spread PGD map for the M 9.0 scenario earthquake; note that units are inches, following example of HAZUS-MH for this modeled parameter. (Also see Plate 4 in the appendix.)

4.2 Earthquake-induced landslides

We used the methods described in HAZUS-MH to make a map of earthquake-induced landslide probability and landslide permanent ground deformation (PGD). This approach provides results that are consistent and compatible with HAZUS-MH but that have much higher spatial resolution, so that important spatial variations in landslide susceptibility are reflected.

4.2.1 Probability of earthquake-induced landslides

Table 12. Critical acceleration values and likelihood of landslide values for landslide susceptibility categories.

Landslide Susceptibility Category	Critical Acceleration	Likelihood of Landslide
III	0.4 g	0.03
V	0.3 g	0.08
VI	0.25 g	0.1
VII	0.2 g	0.15
VIII	0.15 g	0.2
IX	0.1 g	0.25
X	0.05 g	0.3

The landslide probability map in HAZUS-MH is based on a landslide susceptibility map (section 2.3.3) and a map of site PGA (section 3.1). HAZUS-MH Table 4-17 (FEMA, 2011) lists the critical acceleration value to induce landsliding for the defined susceptibility categories; HAZUS-MH Table 4-18 gives the percentage of the area of a polygon of a given susceptibility class likely to landslide if the critical acceleration is exceeded. To produce the landslide probability map, we reclassified the landslide susceptibility raster into two new rasters, one giving the critical acceleration for each class, and the other giving the percentage likely to landslide, using the values shown in Table 12.

The raster of critical acceleration values was then divided into the site PGA raster (section 3.1) to produce a raster of the ratio of site PGA to critical acceleration, with values less than 1 indicating that earthquake-induced landsliding is possible (Figure 23).

Sources: USGS, ESRI, TANA, AND

Figure 23. Areas where critical acceleration for earthquake-induced landsliding is exceeded in the M 9.0 scenario.

This raster was then reclassified to have a value of 1 where the ratio was less than 1, and a value of zero for ratios equal to or greater than 1, thus producing a mask for areas where the critical acceleration is exceeded. This exceedance raster was then multiplied by the raster of landslide likelihood, to yield a final earthquake-induced landslide probability map as shown in Figure 24.

Unlike the liquefaction probability map, where values vary continuously, for landslides the probabilities are binned into the values shown in Table 12. It is important to note that the critical acceleration is almost universally exceeded along the Oregon coast and in the Coast Range, but the values of landslide likelihood from Table 12 cap the probability at 0.3. The critical acceleration is also commonly exceeded in the western slopes of the Cascade Range and is rarely exceeded east of the crest of the Cascade Range. It should also be noted that this calculation does not include a factor to adjust for earthquake magnitude or duration and is based only on PGA. Therefore it is likely that this map underestimates the landslide hazard. Existing landslides were given Class F in the NEHRP site class map, which means that the site PGA is strongly influenced by the very low V_{s30} assigned to this class. In coastal areas the result is to de-amplify that shaking on landslides, causing the landslide probability model to be less conservative (Figure 16). Farther from the earthquake source the Class F sites amplify shaking substantially, making the model more conservative. Finally, the landslide susceptibility map was made using universally wet conditions, which is a conservative assumption but is realistic for western Oregon for the majority of a typical year.

The factors required (Table 12) for the calculation of landslide probability are included in fields in the feature class named Oregon_Landslide_Susceptibility in the Esri geodatabase included in the appendix. The final map of landslide probability is provided as a raster dataset named *Oregon_M_9_Scenario_Landslide_Probability* in the Esri geodatabase included in the appendix. For the ORP analysis a map of landslide probability covering the western half of the state was prepared and is provided as Plate 5 in the appendix.

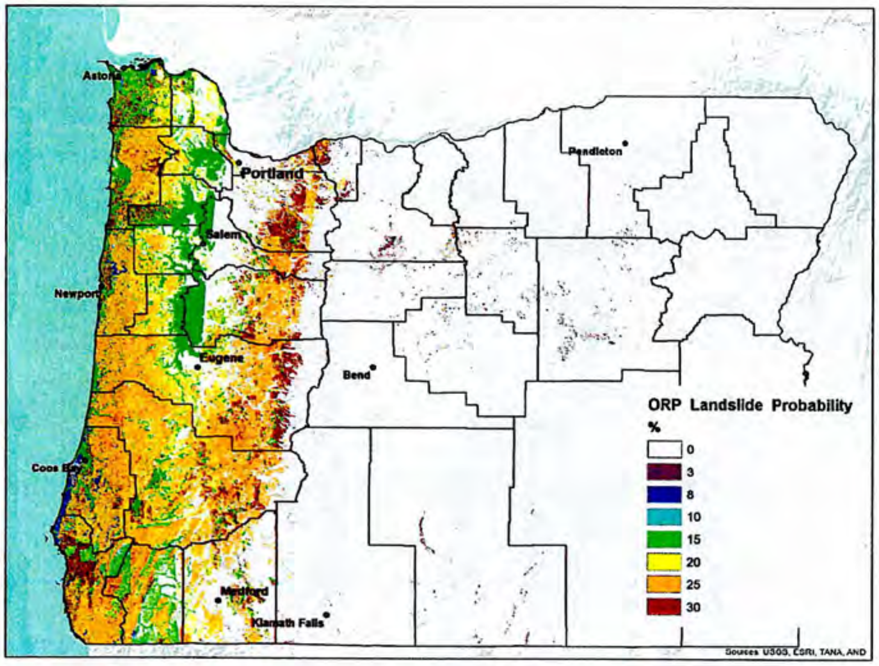


Figure 24. Landslide probability map for M 9.0 scenario earthquake. (Also see Plate 5 in the appendix.)

4.2.2 Earthquake-induced landslide PGD

The calculation of landslide PGD in HAZUS-MH is based on a landslide susceptibility map and a map of site PGA. We used the landsldie susceptibility map (section 2.3.3) and site PGA map (section 3.1) from this study to calculate landslide PGD for the Magnitude 9.0 Scenario. HAZUS-MH (FEMA, 2011) equation 4-25 gives the expected permanent ground displacement PGD as

$$\mathrm{s} = d_{ai} \cdot a_i \cdot n_M$$

where d_{ai} is a displacement factor as a function of the ratio of critical acceleration to induced acceleration a_i, and n_M is the number of cycles of shaking for a given earthquake magnitude. However, this equation appears to be incorrect, as the units do not balance (PGD [cm] <> d_{ai} [cm/cycle] · a_i [cm/sec^2] · n [cycles]). From the HAZUS-MH text and relations for d_{ai} shown in HAZUS-MH Figure 4-14, we believe that the correct equation is

$$PGD = d_{ai} \cdot n_M$$

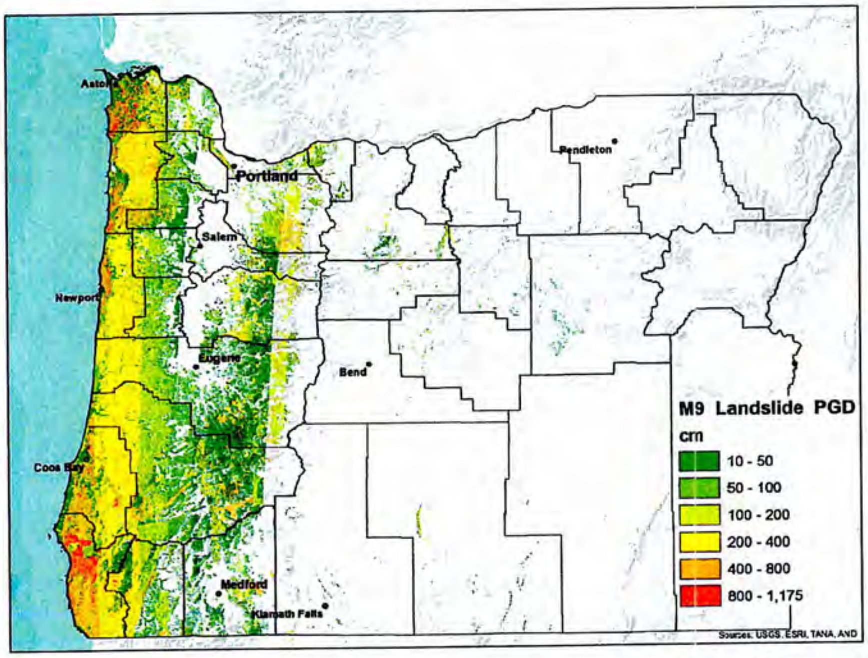
so that is what we used. Figure 4-14 in the HAZUS-MH manual shows the relationship between the amount of displacement per cycle and the ratio of the critical acceleration for initiating landsliding to the induced acceleration at the site. Ideally, the model uses the average acceleration within the slide mass, but we have simplified the model by assuming that the acceleration throughout the mass is equal to the surface value, which is a conservative assumption (subsurface acceleration is likely to be less than the surface value for deep-seated landslides). HAZUS-MH did not provide an equation for the relationship in Figure 4-14 of HAZUS-MH, so we digitized the upper bound values from the graph and fit a curve to it to yield the following relationship for the displacement factor:

$$d_a = 871.15x^5 + 2561.1x^4 - 2977.1x^3 + 1753.1x^2 - 548.58x + 77.92$$

where x is the ratio of the critical acceleration (from section 4.2.1) to site PGA (section 3.1) and where $x \leq 0.9$ (because the graph in HAZUS-MH Figure 4-14 is truncated at this value). Displacement values are very small for values of $x > 0.9$, so these were set to zero. The number of cycles, n_M, is given by

$$n_M = 0.3419M^3 - 5.5214M^2 + 33.6154M - 70.7692$$

where M is the earthquake magnitude; for this M 9.0 scenario, $n_M = 33.8$ cycles. We used this value for n_M and the raster of the ratio of critical acceleration to site PGA (section 4.2.1) to provide values of x and calculated PGD for the entire map area using a simple geoprocessing model. The resultant raster has values that range from 0 cm to 1,178 cm and is shown in Figure 25.



Sources: USGS, ESRI, TANA, AND

Figure 25. Earthquake-induced landslide permanent ground deformation (PGD) map for the M 9.0 scenario earthquake.

As with the landslide probability model, the fact that existing landslides were assigned NEHRP site class F makes the landslide PGD somewhat less conservative near the coast where bedrock PGA is high, and more conservative inland where lower bedrock PGA leads to higher site PGA for class F sites (Figure 16).

On the basis of these models, large areas of the Oregon coast and Coast Range have both high landslide probability and high PGD values Figure 25 shows the areas that have landslide probability ≥ 25% and PGD values > 200 cm. Most of the coast and western slopes of the Coast Range fall into this category, implying severe coseismic landslide hazards. Burns and others (2012) recently completed a detailed lidar-based landslide inventory for the Big Elk Creek basin and North Fork Siuslaw River basin, which lie entirely within this severe hazard zone. The inventory found over 1,178 landslides in Big Elk Creek basin, covering 35% of the total basin area, and in the North Fork Siuslaw basin there were 919 landslides covering 23% of the basin (Figure 26).

The average probability of the M 9.0 earthquake-induced landslide model for both basins is 22%. The average landslide PGD is 177 cm for the Big Elk basin and 244 cm for the North Fork basin. Although the results from these two basins suggest that the modeled values, although very high, are consistent with the actual occurrence of landslides, it should be noted that there is no direct evidence available as to the triggering factors for the existing slides. It should also be noted that in most well-studied cases of earthquake-induced landslides, the majority of slides are relatively shallow seated, whereas most of the slides identified by Burns and others (2012) are deep seated.

The final map of landslide PGD is provided as a raster dataset named *Oregon_M_9_Scenario_Landslide_PGD* in the Esri geodatabase included in the appendix. For the ORP analysis a map of landslide PGD covering the western half of the state was prepared and is provided Plate 6 in the appendix.

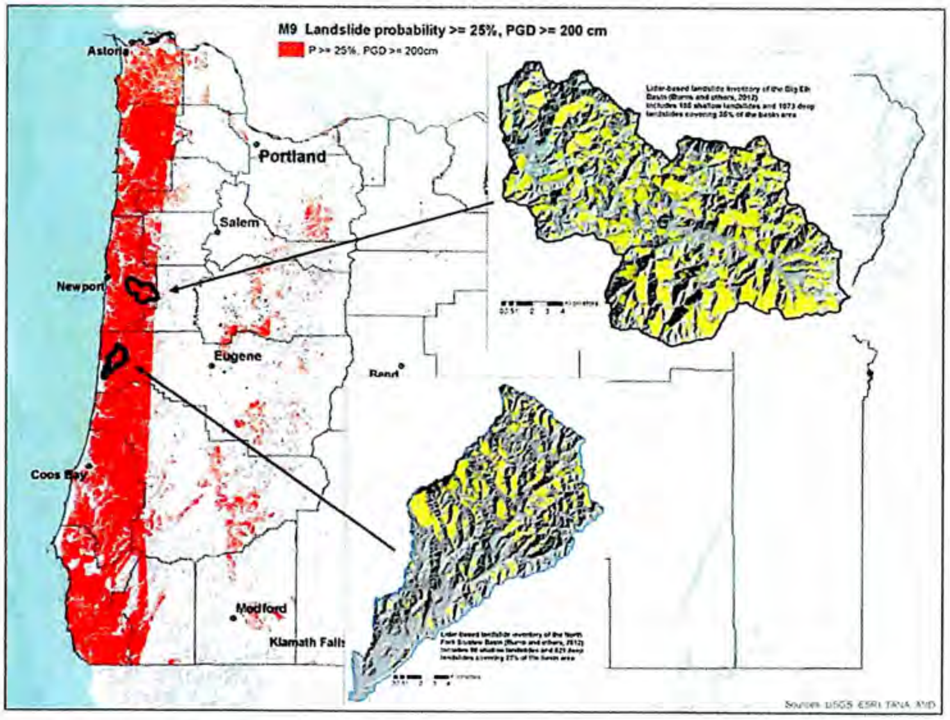


Figure 26. Map showing landslide probability ≥ 25% and permanent ground deformation (PGD) ≥ 200 cm for the M 9.0 scenario earthquake (red areas). Insets show recent lidar-based landslide inventory maps of the North Fork Siuslaw River (bottom inset) and Big Elk Creek (top inset) basins (Burns and others, 2012). Both basins are in the area of high modeled landslide probability and PGD. The inventories show that 35% of the Big Elk Creek basin and 23% of the North Fork Siuslaw River basin are covered by landslides.

5 OTHER HAZARD MAPS

In addition to the maps described above, we produced several other hazard maps for the use of the resilience plan workgroups. None required new analysis or modeling, so they are described only briefly here and are provided as plates in the appendix: tsunami inundation maps (Plates 14–38), coseismic subsidence maps (Plates 8–13), and earthquake damage potential map (Plate 7).

5.1 Tsunami inundation maps

In order to help the ORP workgroups assess the impact of the likely tsunami that would accompany the scenario M 9.0 earthquake, we prepared inundation maps for selected coastal communities. To define the tsunami inundation zone, we used a digital approximation of Oregon's official tsunami regulatory maps (Priest, 1995; Oregon Revised Statutes 455.466 Construction of certain facilities and structures in tsunami inundation zone prohibited). These maps are often called "SB 379" maps for the legislation that enacted the tsunami regulations. More up-to-date and sophisticated tsunami inundation models and maps were available for part of the Oregon coast at the time of the ORP process. These maps are being systematically produced by DOGAMI with the methodology described by Priest and others (2009) and Witter and others (2011), and complete coverage of the Oregon coast with the new maps is expected by summer 2013. The new maps model five different sizes of Cascadia tsunami. The medium size event for the new maps is based on a M 9.0 earthquake and is fairly similar to the "SB 379" line where modeling is complete. Therefore we chose the "SB 379" inundation line because it simulates an M 9.0 earthquake and is consistent along the coast. It should be noted that where the new maps are available, the worst case inundation model (~M 9.1) extends to a considerably greater elevation than the "SB 379" line used here.

The maps were made by layering a transparent orthophoto image over a lidar-based "slopeshade" image (i.e., a slope map with a grayscale shading: high values dark, low values white) to provide a base map, then a polygon based on the "SB 379" line was overlaid as a semi-transparent blue tint. To help evaluate the impact of the inundation, the maps include critical facilities and schools derived from the DOGAMI statewide seismic needs assessment (Lewis, 2007). Maps were prepared for 25 communities; however, we recommend that users obtain the most current tsunami inundation maps produced by DOGAMI by visiting http://www.oregongeology.org/tsuclearinghouse/pubs-inumaps.htm:

• Astoria-Warrenton	(Plate 14)
• Bandon	(Plate 15)
• Brookings	(Plate 16)
• Cannon Beach	(Plate 17)
• Coos Bay East	(Plate 18)
• Coos Bay West	(Plate 19)
• Depoe Bay	(Plate 20)
• Florence	(Plate 21)
• Garibaldi-Bay City	(Plate 22)
• Gold Beach	(Plate 23)
• Lincoln City North	(Plate 24)
• Lincoln City South	(Plate 25)
• Manzanita	(Plate 26)
• Neskowin	(Plate 27)
• Netarts	(Plate 28)
• Newport North	(Plate 29)
• Newport South	(Plate 30)
• Pacific City	(Plate 31)
• Port Orford	(Plate 32)
• Reedsport	(Plate 33)
• Rockaway	(Plate 34)
• Seaside	(Plate 35)
• Tillamook	(Plate 36)
• Waldport	(Plate 37)
• Yachats	(Plate 38)

Note also that the maps provided here are not authoritative representations of the regulatory tsunami line, nor should they be used as evacuation maps. Current evacuation maps based on most recent tsunami modeling can be found at http://www.oregongeology.org/tsuclearinghouse/pubs-evacbro.htm.

5.2 Coseismic subsidence map

In addition to the immediate but transitory coastal inundation caused by the tsunami accompanying the scenario M 9.0 earthquake, there is an additional impact along the coast due to permanent coseismic subsidence. The extent of subsidence is an important factor in assessing the likely recovery times for coastal communities, so we provided maps showing modeled subsidence due to the M 9.0 scenario event. We used data from the elastic dislocation models used by Witter and others (2011) to drive DOGAMI's new tsunami models for the Oregon coast. Witter and others modeled five differently sized earthquakes, each of which used different values of dislocation, proportional to the size of the earthquake. The "medium" size model is the best fit for our M 9.0 shaking model, so we used those data from Witter and others (2011). The data were provided as ASCII xyz files. We converted the data into a point shapefile in ArcMap, gridded the data at 30-m cells, and overlaid the data on an Esri map service base map to produce a subsidence map for each coastal county. The maps are provided in the appendix:

• Clatsop County	(Plate 8)
• Coos County	(Plate 9)
• Curry County	(Plate 10)
• Lane and Douglas Counties	(Plate 11)
• Lincoln County	(Plate 12)
• Tillamook County	(Plate 13)

5.3 Damage potential map

Many of the ORP workgroup participants were not familiar with the technical aspects of earthquake ground motions, so we provided a simplified damage potential map to help those users understand the relative impacts of the M 9.0 scenario earthquake across the state. We used the site PGV map (section 3.2) to create a map of Mercalli Intensity, using the same relationships as USGS ShakeMap products (Wald and others, 2006). To more accurately capture the impact of the tsunami, the tsunami inundation zone (section 5.1) was stamped on to the PGV-based map with a value of intensity X, which is described as "poorly built structures destroyed with their foundations; bridges and well-built wooden structures heavily damaged and in need of replacement" (http://quake.abag.ca.gov/shaking/mmi/), which seems an appropriate description of likely tsunami damage.

The map, which covers the western half of Oregon (because modeled damage for most of Oregon east of Bend is Mercalli V or less, i.e., very light damage or less) is provided as Plate 7 in the appendix.

ACKNOWLEDGMENTS

We thank the other members of the Oregon Resilience Plan Cascadia Scenario workgroup—Art Frankel, Ivan Wong, Dr. Matthey Mabey, Chris Goldfinger, George Priest, and Yumei Wang—for their assistance and input in the development of the scenario maps. The project would not have been possible without the generous assistance of Art Frankel, who provided numerous custom ground motion simulations and detailed technical advice. The paper benefitted from detailed review by Michael Olsen (Oregon State University), Tim Walsh (Washington Department of Natural Resources), and Vicki McConnell (DOGAMI). We would also like to thank Kent Yu (Degenlkolb Engineers) and Jay Wilson, chair and vice chair of OSSPAC, respectively, for their leadership on the Oregon Resilience Plan and support for our efforts.

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Ian P. Madin, Chief Scientist

Map of Peak Ground Acceleration for a Simulated Magnitude 9 Cascadia Earthquake

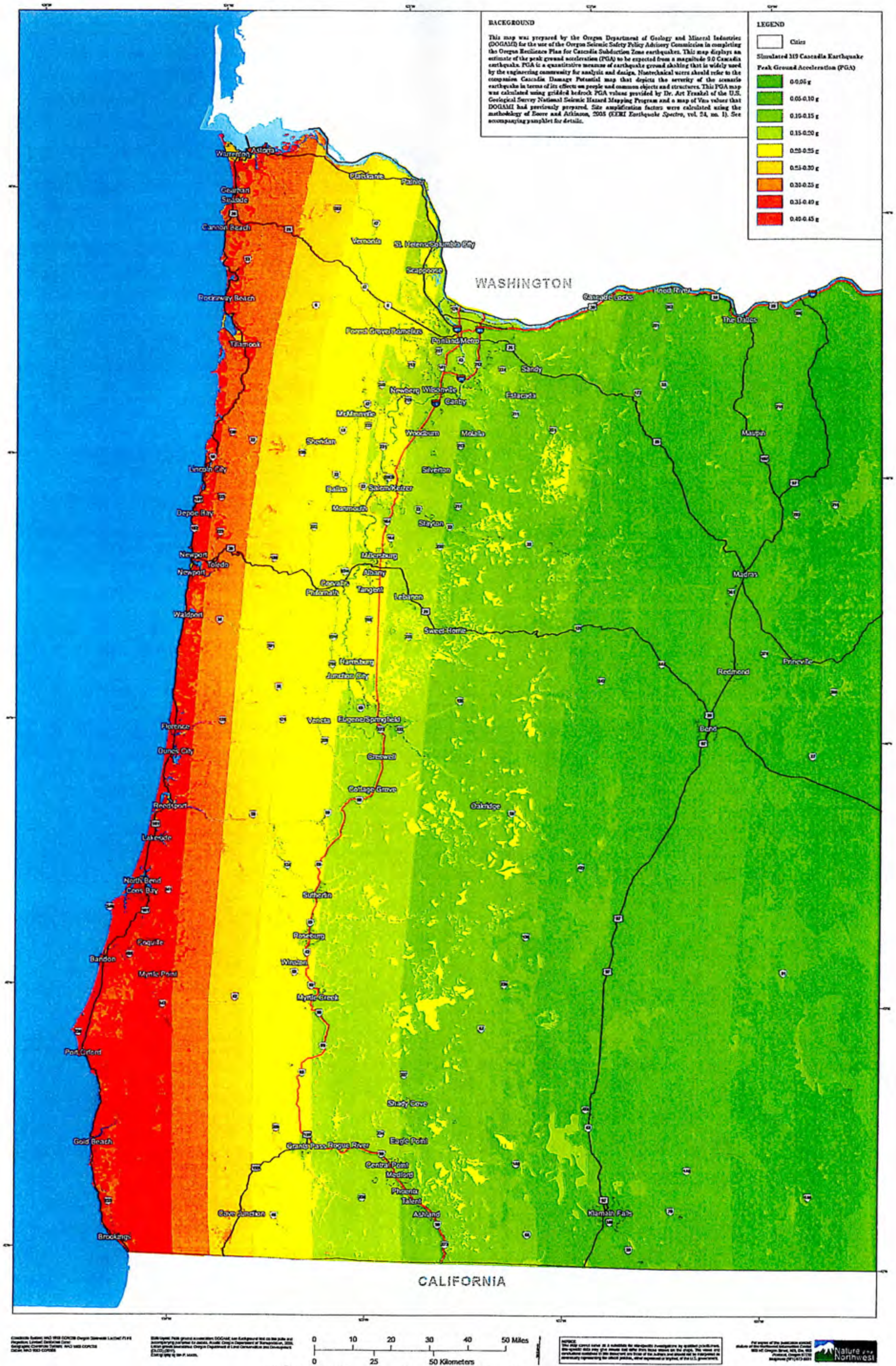
2013

OPEN-FILE REPORT O-13-06

Ground Motion and Ground Deformation Data and Maps for the 2012 Oregon Resilience Plan for Cascadia Subduction Zone Earthquakes

by Ian P. Madin and William J. Burns

PLATE 1



BACKGROUND

This map was prepared by the Oregon Department of Geology and Mineral Industries (DOGAMI) for the use of the Oregon Seismic Safety Policy Advisory Commission in completing the Oregon Resilience Plan for Cascadia Subduction Zone earthquakes. This map displays an estimate of the peak ground acceleration (PGA) to be expected from a magnitude 9.0 Cascadia earthquake. PGA is a quantitative measure of earthquake ground shaking that is widely used by the engineering community for analysis and design. Nontechnical users should refer to the companion Cascadia Damage Potential map that depicts the severity of the scenario earthquake in terms of its effects on people and common objects and structures. This PGA map was calculated using gridded bedrock PGA values provided by Dr. Art Frankel of the U.S. Geological Survey National Seismic Hazard Mapping Program and a map of Vs30 values that DOGAMI had previously prepared. Site amplification factors were calculated using the methodology of Boore and Atkinson, 2008 (EERI *Earthquake Spectra*, vol. 24, no. 1). See accompanying pamphlet for details.

LEGEND

☐ Cities

Simulated M9 Cascadia Earthquake

Peak Ground Acceleration (PGA)

- 🟩 0-0.05 g
- 🟩 0.05-0.10 g
- 🟩 0.10-0.15 g
- 🟩 0.15-0.20 g
- 🟨 0.20-0.25 g
- 🟨 0.25-0.30 g
- 🟧 0.30-0.35 g
- 🟥 0.35-0.40 g
- 🟥 0.40-0.45 g

Map of Peak Ground Velocity for a Simulated Magnitude 9 Cascadia Earthquake

2013

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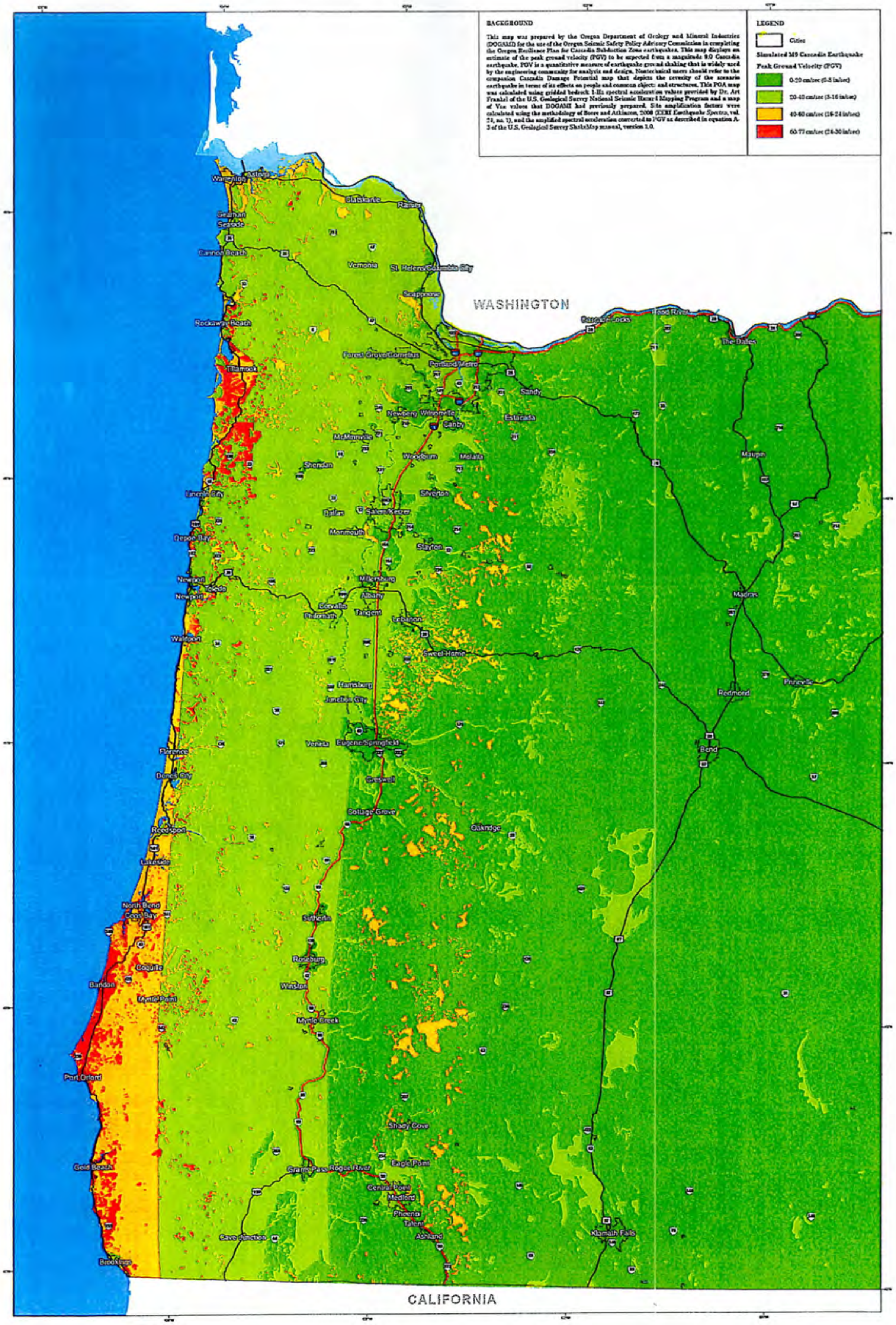
Ground Motion and Ground Deformation Data and Maps for the 2012 Oregon Resilience Plan for Cascadia Subduction Zone Earthquakes

by Ian P. Madin and William J. Burns

PLATE 2



BACKGROUND

This map was prepared by the Oregon Department of Geology and Mineral Industries (DOGAMI) for the use of the Oregon Seismic Safety Policy Advisory Commission in completing the Oregon Resilience Plan for Cascadia Subduction Zone earthquakes. This map displays an estimate of the peak ground velocity (PGV) to be expected from a magnitude 9.0 Cascadia earthquake. PGV is a quantitative measure of earthquake ground shaking that is widely used by the engineering community for analysis and design. Nontechnical users should refer to the companion Cascadia Damage Potential map that depicts the severity of the scenario earthquake in terms of its effects on people and common objects and structures. This PGA map was calculated using gridded bedrock 1-Hz spectral acceleration values provided by Dr. Art Frankel of the U.S. Geological Survey National Seismic Hazard Mapping Program and a map of Vs30 values that DOGAMI had previously prepared. Site amplification factors were calculated using the methodology of Boore and Atkinson, 2008 (EERI *Earthquake Spectra*, vol. 24, no. 1), and the amplified spectral acceleration converted to PGV as described in equation A-3 of the U.S. Geological Survey ShakeMap manual, version 1.0.

LEGEND

- ☐ Cities

Simulated M9 Cascadia Earthquake

Peak Ground Velocity (PGV)

- 🟩 0-20 cm/sec (0-8 in/sec)
- 🟩 20-40 cm/sec (8-16 in/sec)
- 🟨 40-60 cm/sec (16-24 in/sec)
- 🟥 60-77 cm/sec (24-30 in/sec)

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Map of Probability of Liquefaction for a Simulated Magnitude 9 Cascadia Earthquake

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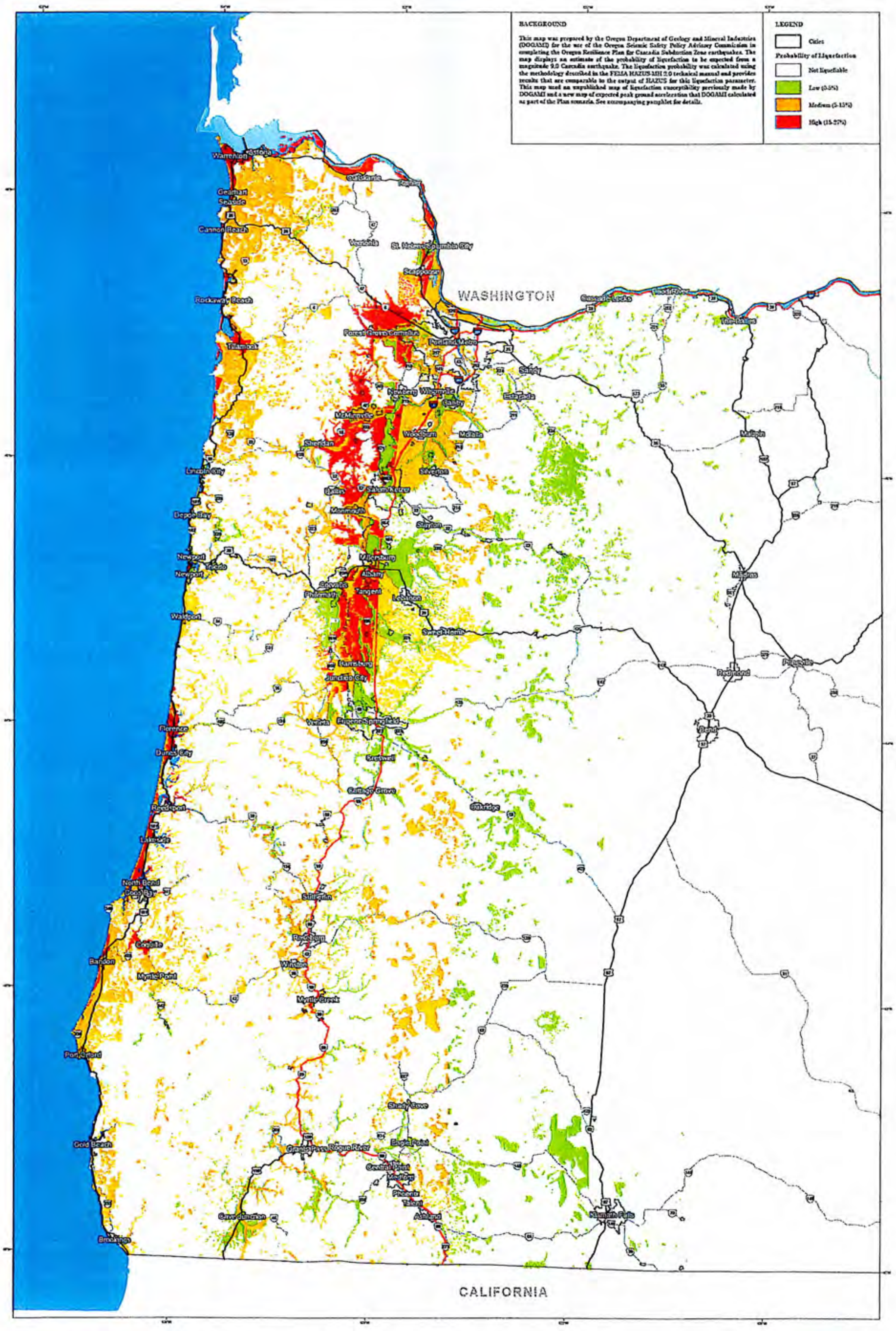
by Ian P. Madin and William J. Burns

PLATE 3



BACKGROUND

This map was prepared by the Oregon Department of Geology and Mineral Industries (DOGAMI) for the use of the Oregon Seismic Safety Policy Advisory Commission in completing the Oregon Resilience Plan for Cascadia Subduction Zone earthquakes. The map displays an estimate of the probability of liquefaction to be expected from a magnitude 9.0 Cascadia earthquake. The liquefaction probability was calculated using the methodology described in the FEMA HAZUS-MH 2.0 technical manual and provides results that are comparable to the output of HAZUS for this liquefaction parameter. This map used an unpublished map of liquefaction susceptibility previously made by DOGAMI and a new map of expected peak ground acceleration that DOGAMI calculated as part of the Plan scenario. See accompanying pamphlet for details.

LEGEND

☐ Cities

Probability of Liquefaction

☐ Not liquefiable

🟩 Low (0-5%)

🟧 Medium (5-15%)

🟥 High (15-27%)

Map of Permanent Ground Deformation Due to Liquefaction Lateral Spreading for a Simulated Magnitude 9 Cascadia Earthquake

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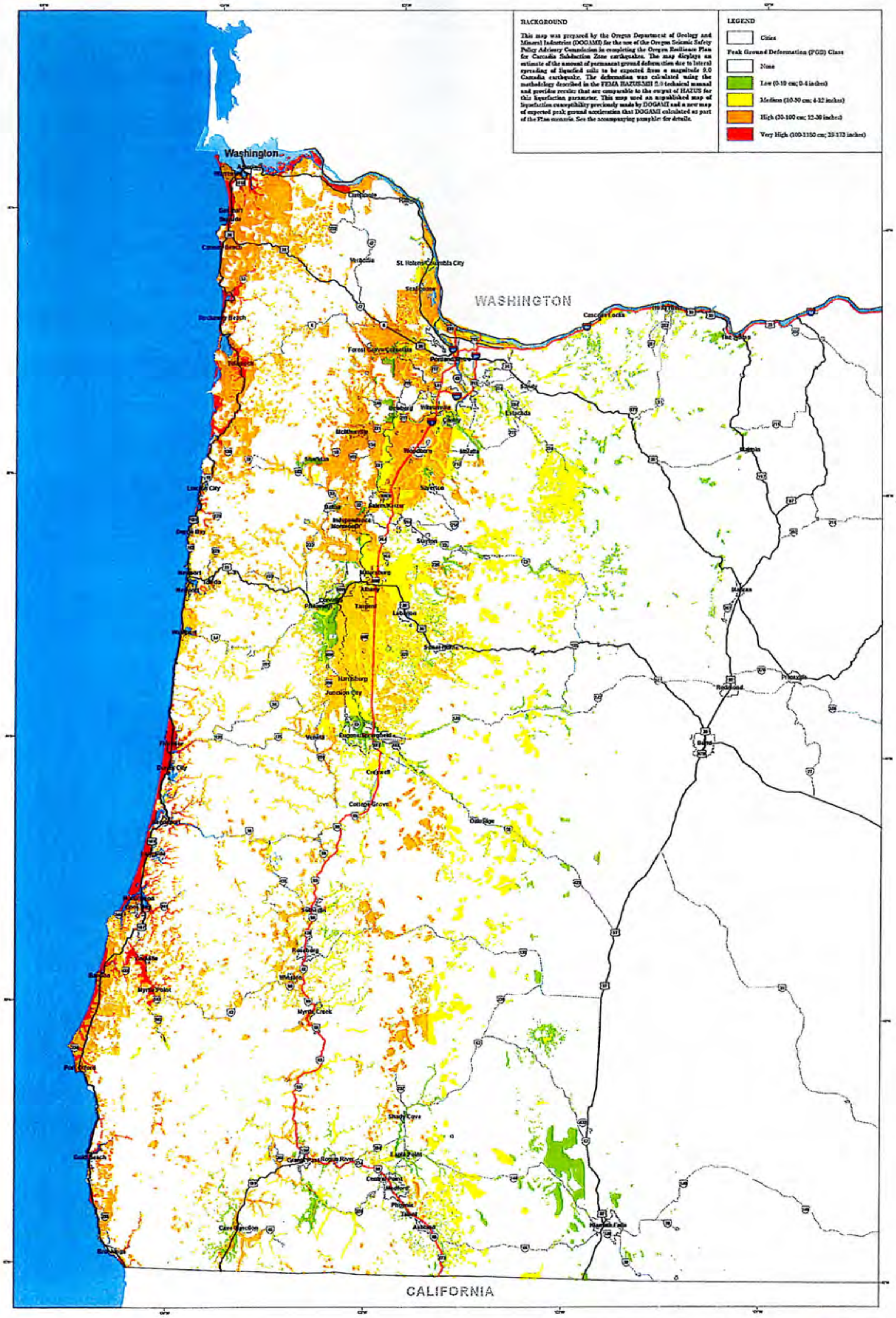
Ground Motion and Ground Deformation Data and Maps for the 2013 Oregon Resilience Plan for Cascadia Subduction Zone Earthquakes

by Ian P. Madin and William J. Burns

PLATE 4



BACKGROUND

This map was prepared by the Oregon Department of Geology and Mineral Industries (DOGAMI) for the use of the Oregon Seismic Safety Policy Advisory Commission in completing the Oregon Resilience Plan for Cascadia Subduction Zone earthquakes. The map displays an estimate of the amount of permanent ground deformation due to lateral spreading of liquefied soils to be expected from a magnitude 9.0 Cascadia earthquake. The deformation was calculated using the methodology described in the FEMA HAZUS-MH 2.0 technical manual and provides results that are comparable to the output of HAZUS for this liquefaction parameter. This map used an unpublished map of liquefaction susceptibility previously made by DOGAMI and a new map of expected peak ground acceleration that DOGAMI calculated as part of the Plan scenario. See the accompanying pamphlet for details.

LEGEND

☐ Cities

Peak Ground Deformation (PGD) Class

☐ None

🟩 Low (0-10 cm; 0-4 inches)

🟨 Medium (10-30 cm; 4-12 inches)

🟧 High (30-100 cm; 12-39 inches)

🟥 Very High (100-1150 cm; 39-173 inches)

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Map of Probability of Earthquake-Induced Landslides from a Simulated Magnitude 9 Cascadia Earthquake

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Ground Motion and Ground Deformation Data and Maps for the 2012 Oregon Resilience Plan for Cascadia Subduction Zone Earthquakes

by Ian P. Madin and William J. Burns

PLATE 5

BACKGROUND

This map was prepared by the Oregon Department of Geology and Mineral Industries (DOGAMI) for the use of the Oregon Seismic Safety Policy Advisory Commission in completing the Oregon Resilience Plan for Cascadia Subduction Zone earthquakes. This map displays an estimate of the probability of earthquake-induced landsliding to be expected from a magnitude 9.0 Cascadia earthquake.

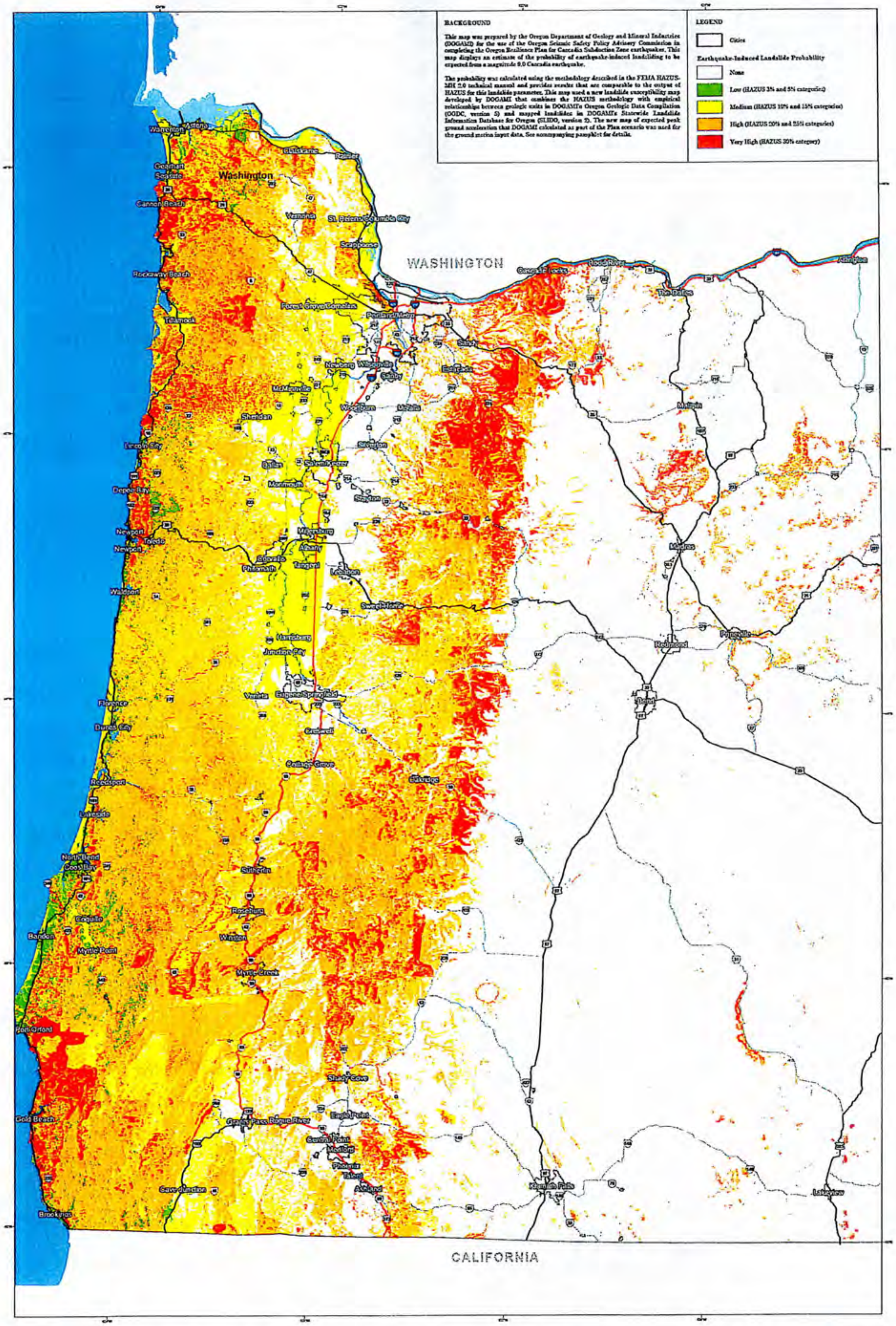
The probability was calculated using the methodology described in the FEMA HAZUS-MH 2.0 technical manual and provides results that are comparable to the output of HAZUS for this landslide parameter. This map used a new landslide susceptibility map developed by DOGAMI that combines the HAZUS methodology with empirical relationships between geologic units in DOGAMI's Oregon Geologic Data Compilation (OGDC, version 5) and mapped landslides in DOGAMI's *Statewide Landslide Information Database for Oregon* (SLIDO, version 2). The new map of expected peak ground acceleration that DOGAMI calculated as part of the Plan scenario was used for the ground motion input data. See accompanying pamphlet for details.

LEGEND

- ☐ Cities

Earthquake-Induced Landslide Probability

- ☐ None
- 🟩 Low (HAZUS 3% and 5% categories)
- 🟨 Medium (HAZUS 10% and 15% categories)
- 🟧 High (HAZUS 20% and 25% categories)
- 🟥 Very High (HAZUS 30% category)



Map of Permanent Ground Deformation Due to Landslides for a Simulated Magnitude 9 Cascadia Earthquake

2013

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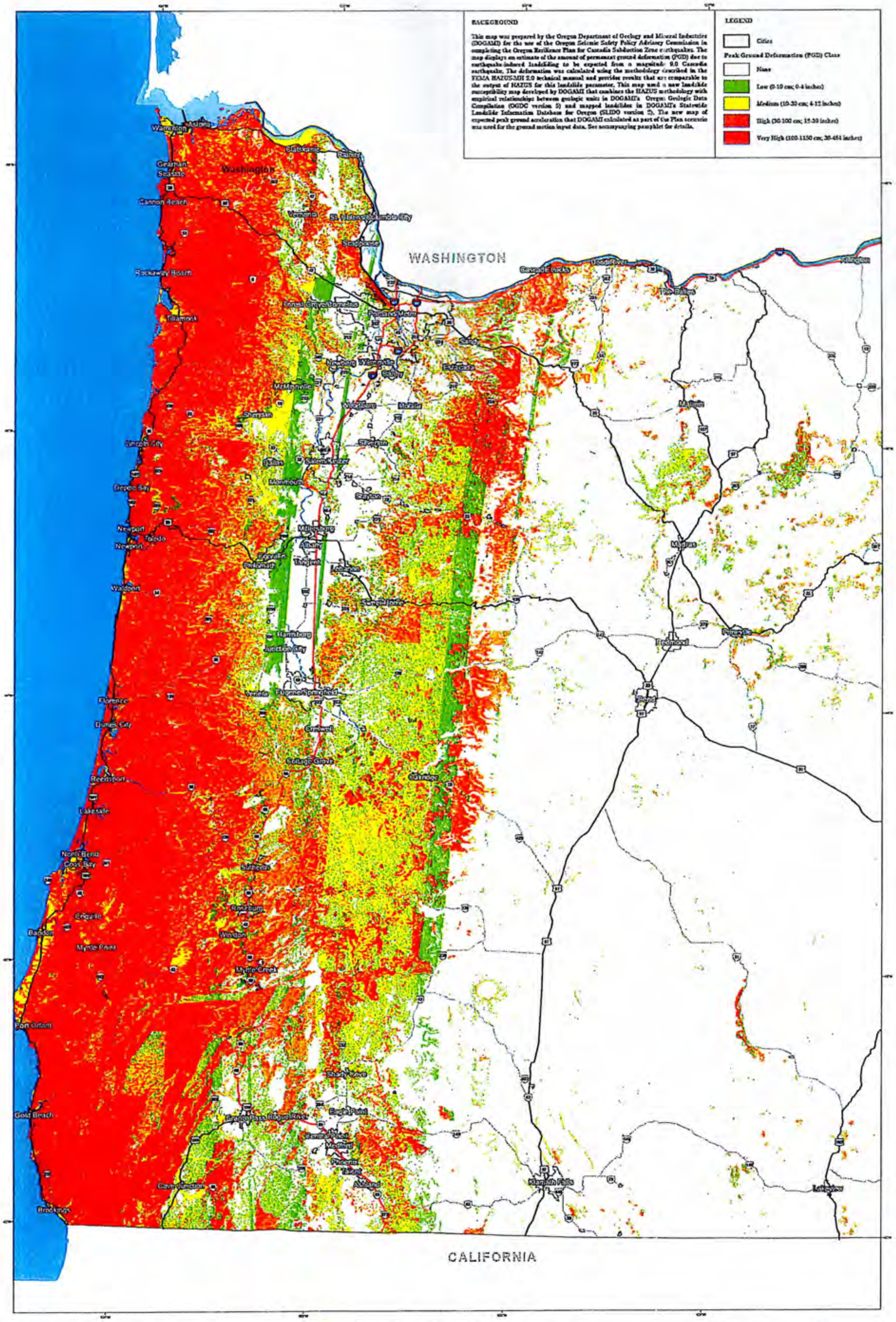
Ground Motion and Ground Deformation Data and Maps for the 2013 Oregon Resilience Plan for Cascadia Subduction Zone Earthquakes

by Ian P. Madin and William J. Burns

PLATE 6



BACKGROUND

This map was prepared by the Oregon Department of Geology and Mineral Industries (DOGAMI) for the use of the Oregon Seismic Safety Policy Advisory Commission in completing the Oregon Resilience Plan for Cascadia Subduction Zone earthquakes. The map displays an estimate of the amount of permanent ground deformation (PGD) due to earthquake-induced landsliding to be expected from a magnitude 9.0 Cascadia earthquake. The deformation was calculated using the methodology described in the FEMA HAZUS-MH 2.0 technical manual and provides results that are comparable to the output of HAZUS for this landslide parameter. This map used a new landslide susceptibility map developed by DOGAMI that combines the HAZUS methodology with empirical relationships between geologic units in DOGAMI's Oregon Geologic Data Compilation (OGDC version 5) and mapped landslides in DOGAMI's Statewide Landslide Information Database for Oregon (SLIDO version 2). The new map of expected peak ground acceleration that DOGAMI calculated as part of the Plan scenario was used for the ground motion input data. See accompanying pamphlet for details.

LEGEND

☐ Cities

Peak Ground Deformation (PGD) Class

☐ None

🟩 Low (0-10 cm; 0-4 inches)

🟨 Medium (10-30 cm; 4-12 inches)

🟥 High (30-100 cm; 12-39 inches)

🟥 Very High (100-1150 cm; 39-454 inches)

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Ian P. Madin, Chief Scientist

Map of Earthquake and Tsunami Damage Potential for a Simulated Magnitude 9 Cascadia Earthquake

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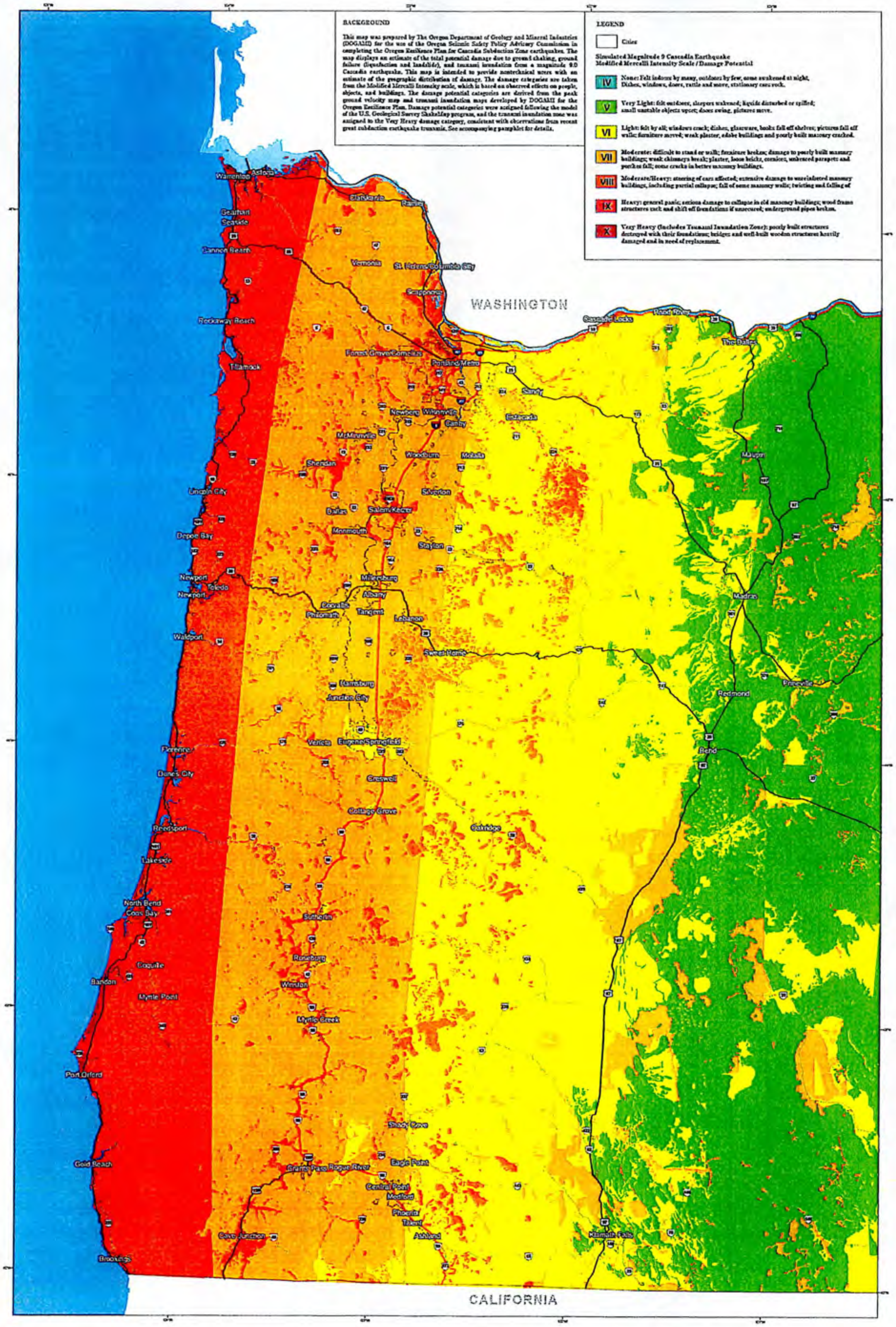
Ground Motion and Ground Deformation Data and Maps for the 2013 Oregon Resilience Plan for Cascadia Subduction Zone Earthquakes

by Ian P. Madin and William J. Burns

PLATE 7



BACKGROUND

This map was prepared by The Oregon Department of Geology and Mineral Industries (DOGAMI) for the use of the Oregon Seismic Safety Policy Advisory Commission in completing the Oregon Resilience Plan for Cascadia Subduction Zone earthquakes. The map displays an estimate of the total potential damage due to ground shaking, ground failure (liquefaction and landslide), and tsunami inundation from a magnitude 9.0 Cascadia earthquake. This map is intended to provide nontechnical users with an estimate of the geographic distribution of damage. The damage categories are taken from the Modified Mercalli Intensity scale, which is based on observed effects on people, objects, and buildings. The damage potential categories are derived from the peak ground velocity map and tsunami inundation maps developed by DOGAMI for the Oregon Resilience Plan. Damage potential categories were assigned following the model of the U.S. Geological Survey ShakeMap program, and the tsunami inundation zone was assigned to the Very Heavy damage category, consistent with observations from recent great subduction earthquake tsunamis. See accompanying pamphlet for details.

LEGEND

☐ Cities

Simulated Magnitude 9 Cascadia Earthquake
Modified Mercalli Intensity Scale / Damage Potential

IV	None: Felt indoors by many, outdoors by few, some awakened at night, Dishes, windows, doors, rattle and move, stationary cars rock.
V	Very Light: felt outdoors, sleepers wakened; liquids disturbed or spilled; small unstable objects upset; doors swing, pictures move.
VI	Light: felt by all; windows crack; dishes, glassware, books fall off shelves; pictures fall off walls; furniture moved; weak plaster, adobe buildings and poorly built masonry cracked.
VII	Moderate: difficult to stand or walk; furniture broken; damage to poorly built masonry buildings; weak chimneys break; plaster, loose bricks, cornices, unbraced parapets and porches fall; some cracks in better masonry buildings.
VIII	Moderate/Heavy: steering of cars affected; extensive damage to unreinforced masonry buildings, including partial collapse; fall of some masonry walls; twisting and falling of
IX	Heavy: general panic; serious damage to collapse in old masonry buildings; wood frame structures rack and shift off foundations if unsecured; underground pipes broken.
X	Very Heavy (Includes Tsunami Inundation Zone): poorly built structures destroyed with their foundations; bridges and well-built wooden structures heavily damaged and in need of replacement.

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Coseismic Subsidence Map for Simulated Magnitude 9 Cascadia Earthquake: Coos County, Oregon

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Ground Motion and Ground Deformation Data and Maps for the 2012 Oregon Resilience Plan for Cascadia Subduction Zone Earthquakes

by Ian P. Madin and William J. Burns

PLATE 9

BACKGROUND

This map was prepared by the Oregon Department of Geology and Mineral Industries (DOGAMI) for the use of the Oregon Seismic Safety Policy Advisory Commission in completing the Oregon Resilience Plan for Cascadia Subduction Zone earthquakes. This map displays an estimate of the amount of permanent subsidence (lowering of the land level) to be expected during the Scenario magnitude 9.0 earthquake (see accompanying pamphlet). DOGAMI is currently preparing a new set of tsunami inundation maps for the entire Oregon coast that depict inundation from five different sizes of tsunami: small, medium, large, extra large, and extra extra large. This subsidence map is based on the data used to model the medium (Witter and others, 2011) event, which is considered the most likely, and which corresponds roughly to the inundation maps prepared for the Oregon Resilience Plan. Coastal and riverine flooding will worsen in areas with significant subsidence after an earthquake.

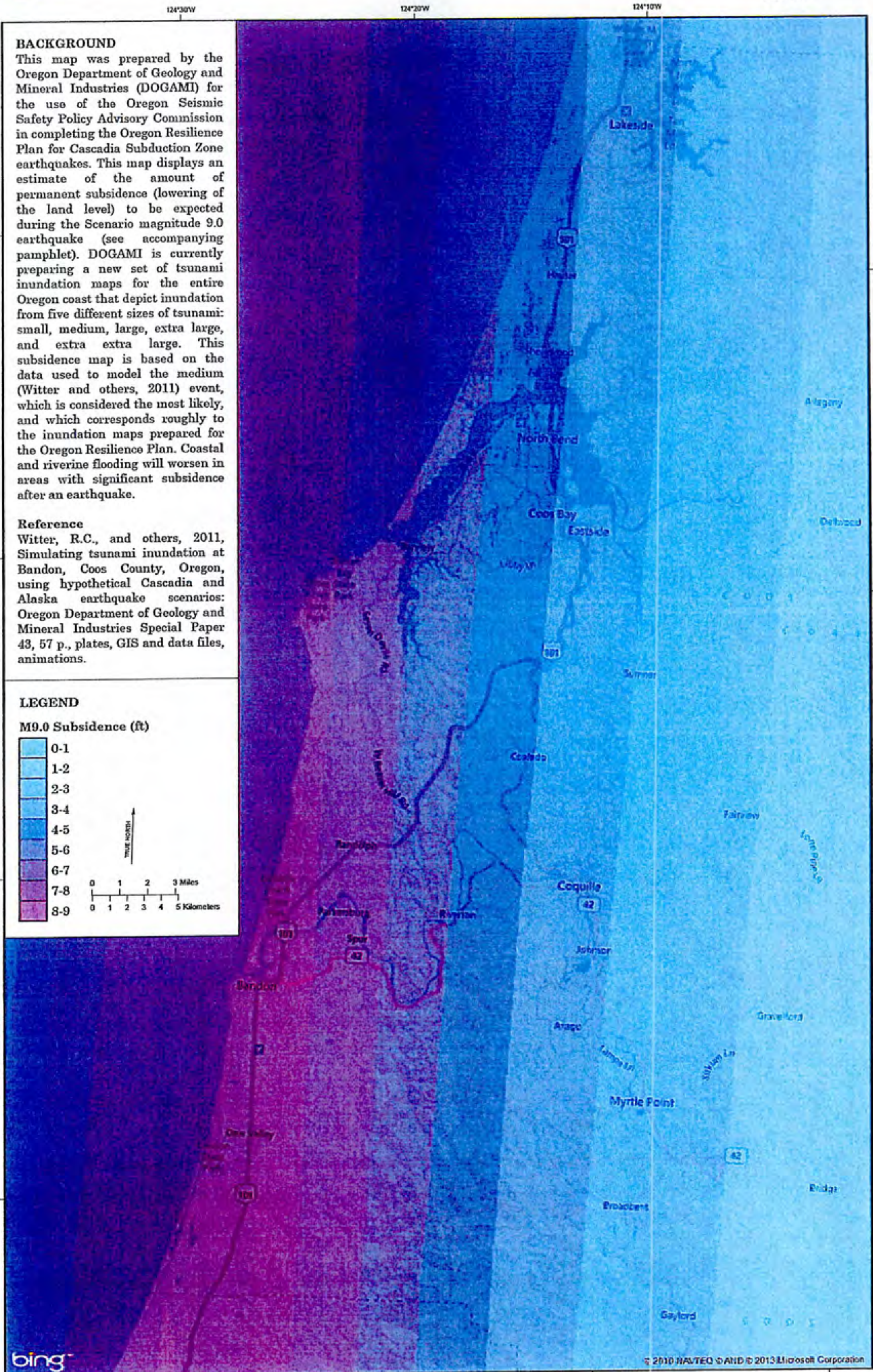
Reference

Witter, R.C., and others, 2011, Simulating tsunami inundation at Bandon, Coos County, Oregon, using hypothetical Cascadia and Alaska earthquake scenarios: Oregon Department of Geology and Mineral Industries Special Paper 43, 57 p., plates, GIS and data files, animations.

LEGEND

M9.0 Subsidence (ft)

- ▨ 0-1
- ▨ 1-2
- ▨ 2-3
- ▨ 3-4
- ▨ 4-5
- ▨ 5-6
- ▨ 6-7
- ▨ 7-8
- ▨ 8-9



Coordinate System: NAD 1983 HARN Lambert Conformal Conic
Projection: Lambert Conformal Conic
Geographic Coordinate System: North American 1983 HARN
Datum: North American 1983 HARN

Base map: Microsoft® Bing™ Road Map via Esri® map service.
M9 Cascadia earthquake coseismic subsidence data: DOGAMI, 2011; see accompanying pamphlet for details.
Cartography by Ian P. Madin.

NOTICE: This map cannot serve as a substitute for site-specific investigations by qualified practitioners. Site-specific data may give results that differ from those shown on the maps. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. government.

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Tsunami Inundation Map for a Simulated Magnitude 9 Cascadia Earthquake
Coos Bay East, Coos County, Oregon

2013

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Ground Motion and Ground Deformation Data and Maps for the 2013 Oregon Resilience Plan for Cascadia Subduction Zone Earthquakes

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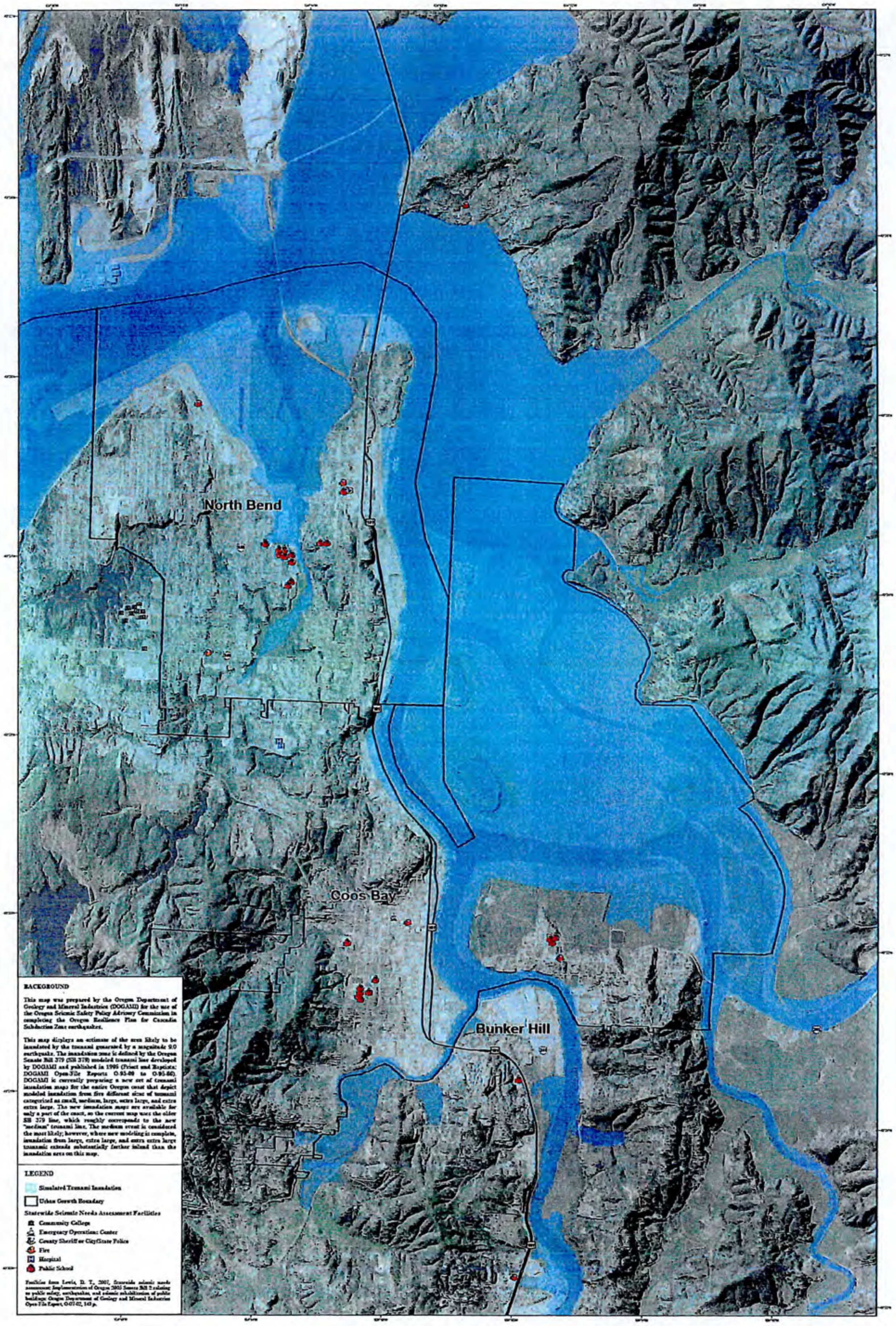
PLATE 18



BACKGROUND

This map was prepared by the Oregon Department of Geology and Mineral Industries (DOGAMI) for the use of the Oregon Seismic Safety Policy Advisory Commission in completing the Oregon Resilience Plan for Cascadia Subduction Zone earthquakes.

This map displays an estimate of the area likely to be inundated by the tsunami generated by a magnitude 9.0 earthquake. The inundation zone is defined by the Oregon Senate Bill 379 (SB 379) modeled tsunami line developed by DOGAMI and published in 1995 (Priest and Baptista; DOGAMI Open-File Reports O-95-09 to O-95-66). DOGAMI is currently preparing a new set of tsunami inundation maps for the entire Oregon coast that depict modeled inundation from five different sizes of tsunami categorized as small, medium, large, extra large, and extra extra large. The new inundation maps are available for only a part of the coast, so the current map uses the older SB 379 line, which roughly corresponds to the new "medium" tsunami line. The medium event is considered the most likely; however, where new modeling is complete, inundation from large, extra large, and extra extra large tsunamis extends substantially farther inland than the inundation area on this map.

LEGEND

- Simulated Tsunami Inundation
- ☐ Urban Growth Boundary

Statewide Seismic Needs Assessment Facilities

- Community College
- Emergency Operations Center
- County Sheriff or City/State Police
- Fire
- Hospital
- Public School

Facilities from Lewis, D. T., 2007, Statewide seismic needs assessment: Implementation of Oregon 2005 Senate Bill 2 relating to public safety, earthquakes, and seismic rehabilitation of public buildings: Oregon Department of Geology and Mineral Industries Open-File Report, O-07-02, 140 p.

0 0.2 0.4 0.6 0.8 1 Mile
0 0.2 0.4 0.6 0.8 1 Kilometer

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Tsunami Inundation Map for a Simulated Magnitude 9 Cascadia Earthquake
Coos Bay West, Coos County, Oregon

2013

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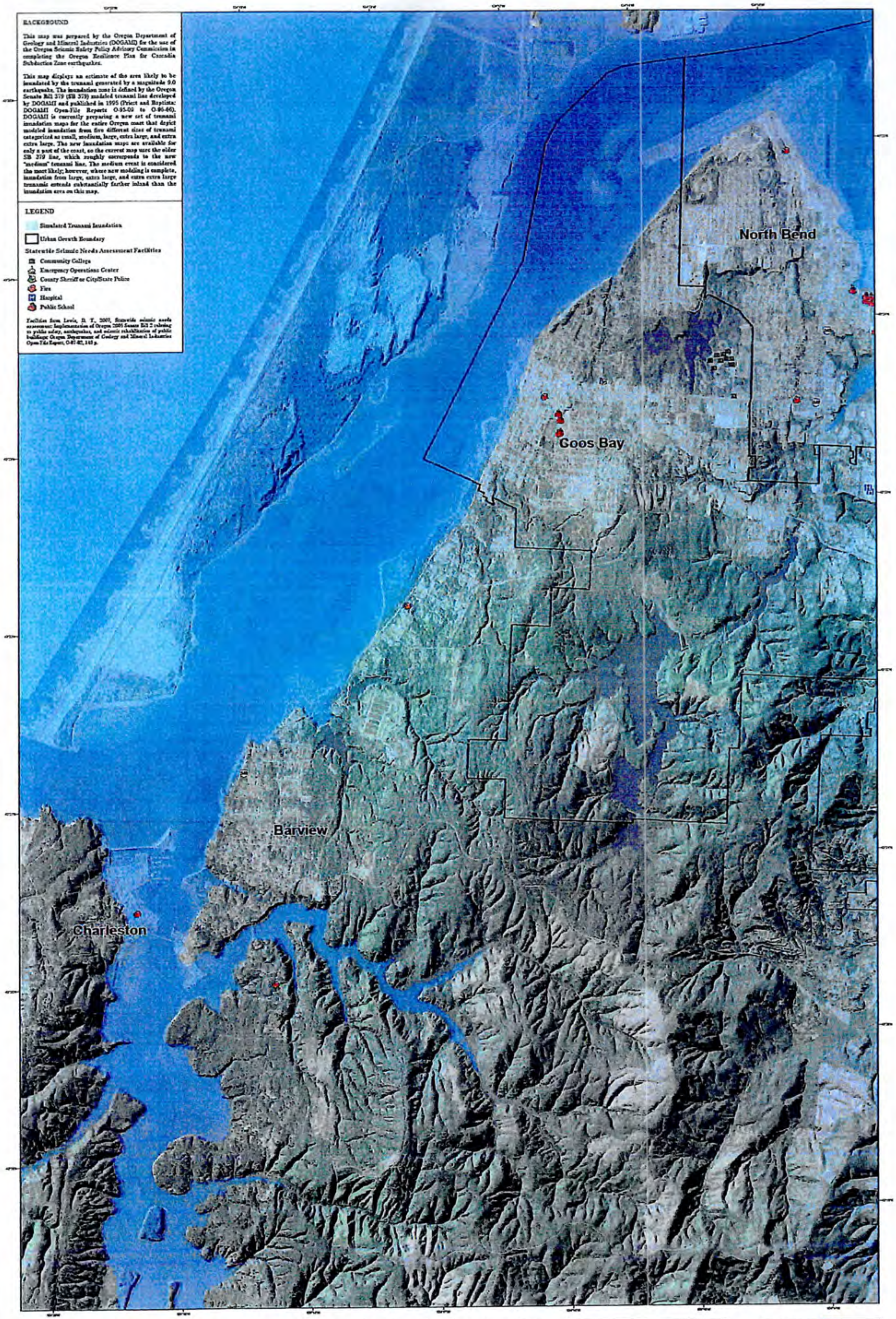
Ground Motion and Ground Deformation Data and Maps for the [illegible] Oregon Resilience Plan for Cascadia Subduction Zone Earthquakes

by Ian P. Madin and William J. Burns

PLATE 19



BACKGROUND

This map was prepared by the Oregon Department of Geology and Mineral Industries (DOGAMI) for the use of the Oregon Seismic Safety Policy Advisory Commission in completing the Oregon Resilience Plan for Cascadia Subduction Zone earthquakes.

This map displays an estimate of the area likely to be inundated by the tsunami generated by a magnitude 9.0 earthquake. The inundation zone is defined by the Oregon Senate Bill 379 (SB 379) modeled tsunami line developed by DOGAMI and published in 1995 (Priest and Baptista: DOGAMI Open-File Reports O-95-09 to O-95-66). DOGAMI is currently preparing a new set of tsunami inundation maps for the entire Oregon coast that depict modeled inundation from five different sizes of tsunami categorized as small, medium, large, extra large, and extra extra large. The new inundation maps are available for only a part of the coast, so the current map uses the older SB 379 line, which roughly corresponds to the new "medium" tsunami line. The medium event is considered the most likely; however, where new modeling is complete, inundation from large, extra large, and extra extra large tsunamis extends substantially farther inland than the inundation area on this map.

LEGEND

▨ Simulated Tsunami Inundation

☐ Urban Growth Boundary

Statewide Seismic Needs Assessment Facilities

- Community College
- Emergency Operations Center
- County Sheriff or City/State Police
- Fire
- Hospital
- Public School

Facilities from Lewis, D. T., 2007, Statewide seismic needs assessment: Implementation of Oregon 2005 Senate Bill 2 relating to public safety, earthquakes, and seismic rehabilitation of public buildings: Oregon Department of Geology and Mineral Industries Open-File Report, O-07-02, 140 p.

0 0.2 0.4 0.6 0.8 1 Mile

Tsunami Inundation Map for a Simulated Magnitude 9 Cascadia Earthquake
Bandon, Coos County, Oregon

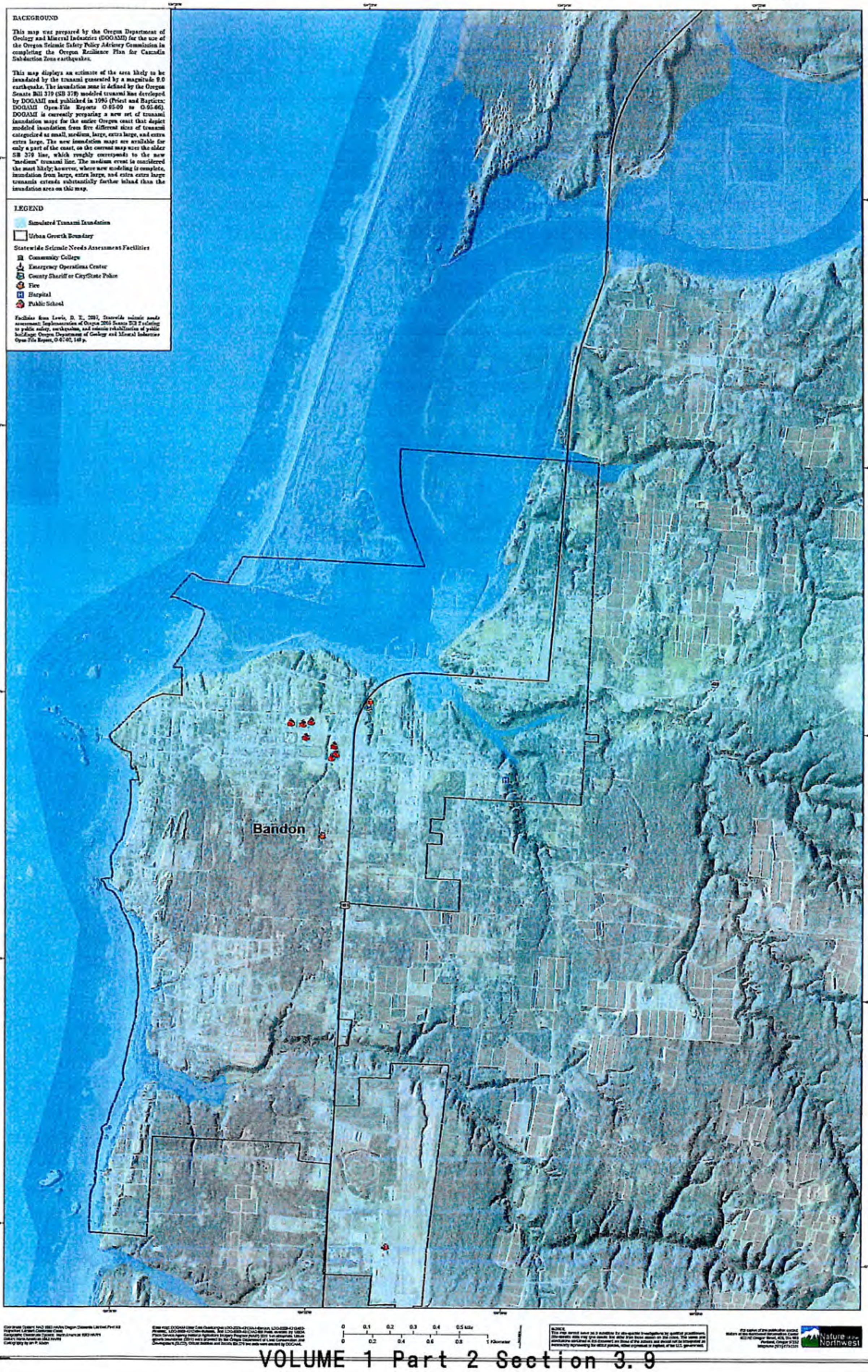
2013

OPEN-FILE REPORT O-13-06

Ground Motion and Ground Deformation Data and Maps for the 2013 Oregon Resilience Plan for Cascadia Subduction Zone Earthquakes

by Ian P. Madin and William J. Burns

PLATE 17



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LEGEND

- Simulated Tsunami Inundation
- ☐ Urban Growth Boundary

Statewide Seismic Needs Assessment Facilities

- Community College
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- Hospital
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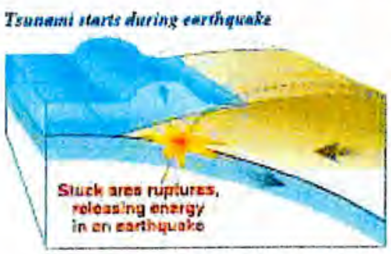
Facilities from Lewis, D. T., 2007, Statewide seismic needs assessment: Implementation of Oregon 2005 Senate Bill 2 relating to public safety, earthquakes, and seismic rehabilitation of public buildings: Oregon Department of Geology and Mineral Industries Open-File Report, O-07-02, 140 p.

SECTION 3.9.300 TSUNAMIS

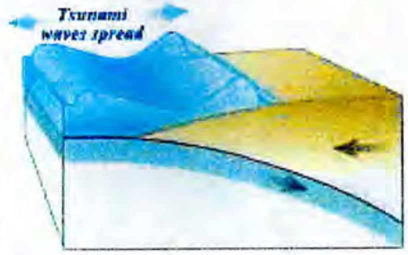
A tsunami is a series of ocean waves most often generated by disturbances of the sea floor during shallow, undersea earthquakes. Less commonly, landslides and volcanic eruptions can also trigger these wave events. Although infrequent in occurrence, tsunamis are the most dangerous natural hazard affecting the Oregon Coast. In the deep water of the open ocean, tsunami waves can travel at speeds up to 800 km (500 miles) per hour and are imperceptible to ships because the wave height is typically less than a few feet.

However, as a tsunami approaches the coast it slows dramatically and its height may multiply by a factor of 10 or more, having catastrophic consequences to people living at the coast. As a result, people on the beach, in low-lying areas of the coast, and near estuary mouths or tidal flats face the greatest danger from tsunamis.



During an Earthquake

An earthquake along a subduction zone happens when the leading edge of the overriding plate breaks free and springs seaward, raising the sea floor and the water above it. This uplift starts a tsunami. Meanwhile, the bulge behind the leading edge collapses, thinning the plate and lowering coastal areas.



Minutes Later

Part of the tsunami races toward nearby land, growing taller as it comes in to shore. Another part heads across the ocean toward distant shores.

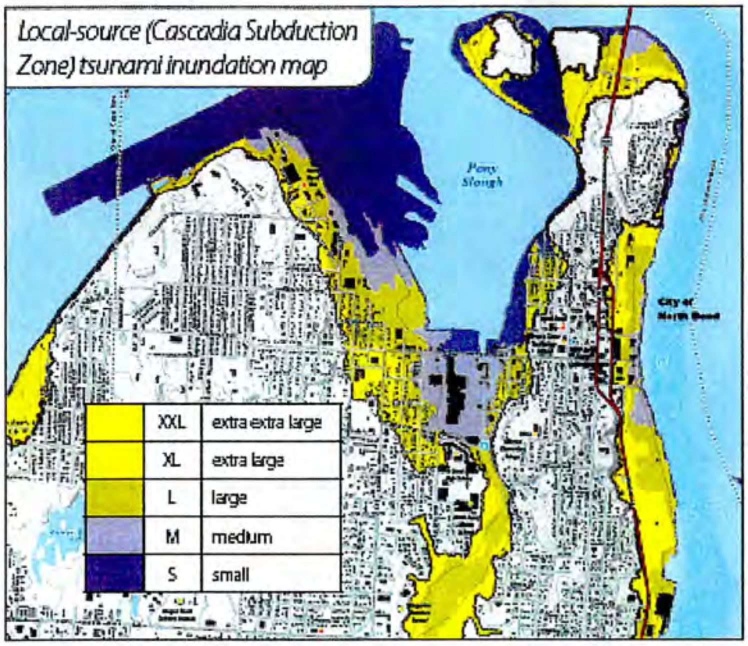
The Oregon coast is a part of the tectonically active Pacific Ring of Fire, posing the risk for both locally and distantly generated tsunamis. The close proximity of the Cascadia Subduction Zone, a 960-km-long (600 mile) earthquake fault zone that sits off the Pacific Northwest coast has the potential to generate earthquakes of magnitude 9.0 or greater. Following the earthquake will be a destructive tsunami, which will reach the coast in 10-20 minutes making the local event the most dangerous type of tsunami for Oregon.

A distant tsunami produced by an earthquake far from Oregon will take 4 or more hours to travel cross the Pacific Ocean, usually allowing time for an official warning and evacuation, if necessary. A distant tsunami will be smaller in size and much less destructive, but it can still be very dangerous.

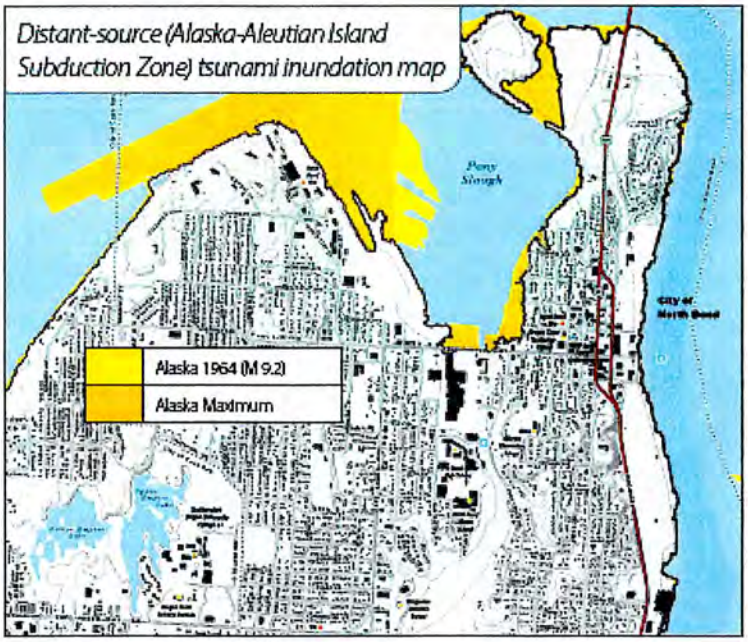
The Oregon Department of Geology and Mineral Industries (DOGAMI) has been identifying and mapping the tsunami inundation hazard along the Oregon coast since 1994. In Oregon, DOGAMI manages the National Tsunami Hazard Mitigation Program, which has been administered by the National Oceanic and Atmospheric Administration (NOAA) since 1995. DOGAMI's work is designed to help cities, counties, and other sites in coastal areas reduce the potential for disastrous tsunami-related consequences by understanding and mitigating this geologic hazard. Using federal funding awarded by NOAA, DOGAMI has developed a new generation of tsunami inundation maps to help residents and visitors along the entire Oregon coast prepare for the next Cascadia Subduction Zone (CSZ) earthquake and tsunami.

TIM series inundation maps incorporate all the best tsunami science that is available today, including recent publications by colleagues studying the Cascadia Subduction Zone, updated computer simulation models using high-resolution lidar topographic data, and knowledge gained from the 2004 Sumatra, 2010 Chile, and 2011 Tōhoku earthquakes and tsunamis.

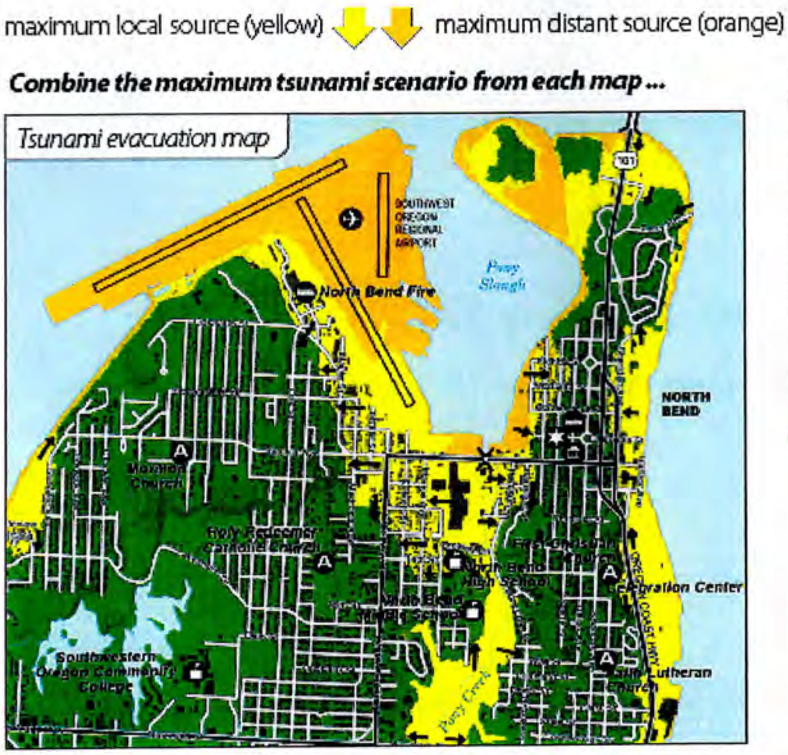
Each publication includes two plates: one showing local-source (Cascadia Subduction Zone) and one showing distant-source (Alaska-Aleutian Subduction Zone) tsunami inundation scenarios.



TIM Plate 1 displays five scenarios, labeled as "T-shirt sizes" (S, M, L, XL, and XXL), of the impact of Cascadia Subduction Zone tsunamis that reflect the full range of what was experienced in the past and will be encountered in the future. The geologic record shows that the amount of time that has passed since the last great Cascadia earthquake (312 years since January 26, 1700) is not a reliable indicator of the size of the next one, so the size ranges are intended to fully bracket what might happen next.



TIM Plate 2 shows tsunami inundation scenarios for two distant-source tsunamis that were modeled and originate in Alaska. These distant tsunamis are not nearly as dangerous as the local ones, as Oregonians will have several hours instead of only minutes to evacuate and the tsunamis themselves are much smaller. For these reasons DOGAMI's focus is on the big Cascadia events. If the ground shakes for an extended period of time, don't wait for more warning, evacuate to high ground as fast as possible.



Combine the maximum tsunami scenario from each map ...

After the inundation maps have been created, the tsunami inundation zones derived from the Cascadia XXL tsunami scenario (yellow area, top figure, left) and the hypothetical maximum Alaska tsunami (orange area, middle figure, left) are put together on one map to create a **tsunami evacuation map**. Green on the evacuation map shows typically higher elevation areas that lie outside the zones prone to tsunami hazard. The purpose of the evacuation map is to help people identify safe evacuation routes, as developed by local emergency authorities.

All tsunami evacuation maps

TIM maps include a wealth of information, including projected tsunami wave height time series charts and a measurement of the exposure each community has to the various tsunami scenarios: we count the number of buildings that are inundated by each scenario.

The public, planners, emergency managers and first responders, elected officials, and other local decision makers can use these detailed and innovative map products to mitigate risk and to reduce the loss of life and property.

Coos County has continued to work to reduce the risk in the tsunami areas. This effort has been done through zoning ordinance and developing an evacuation facilities plan. The other effort has been through the Coos County Hazard Mitigation Plan that Emergency Management updates and implements. Coos County Planning will continue to participate and consult with the Coos County office of Emergency Management to ensure the risks are reduced.

Tsunami Evacuation Facilities Improvement Plan (TEFIP)

For the coastal unincorporated communities of Coos County, Oregon

September 2019

TSUNAMI EVACUATION FACILITIES IMPROVEMENT PLAN (TEFIP) FOR THE COASTAL UNINCORPORATED COMMUNITIES OF COOS COUNTY, OREGON

First Edition, September 2019

Plan Development

This plan was developed by the Coos County Planning Department with help from the Coos County Emergency Management Division and the Oregon Department of Land Conservation and Development. Input was received from the Port of Coos Bay, Coos County Roads Department, Oregon Department of Transportation, Oregon Parks and Recreation Department, the Confederated Tribes of the Coos, Lower Umpqua, and Siuslaw, the Coquille Indian Tribe, South Slough Estuarine Research Reserve, and the Charleston Fire Department.

Funding

Financial assistance for this plan was provided in part by the Coastal Zone Management Act of 1972, as amended, administered by the Office for Coastal Management, National Oceanic and Atmospheric Administration, and the Oregon Coastal Management Program, Department of Land Conservation and Development. Federal Grant No. NA15NOS4190118. Financial assistance was also provided in part by a grant from the Federal Emergency Management Agency RiskMAP Program, no. EMS-2016-CA-2008.

Figures

All figures in this document were created by the Oregon Department of Geology and Mineral Industries (DOGAMI). Open-File Report O-19-07, Tsunami evacuation analysis of communities surrounding the Coos Bay Estuary: Building community resilience on the Oregon coast, by Laura L. S. Gabel, Fletcher E. O'Brien, John M. Bauer, and Jonathan C. Allan; 60 p. report.
Additional information can be found at www.oregontsunami.org. For more information about the tsunami evacuation analysis completed by DOGAMI, please contact their Coastal Field Office:
Oregon Department of Geology and Mineral Industries
Newport (Coastal) Field Office
P.O. Box 1033, 313 SW 2nd, Suite D
Newport, OR 97365
Phone: 541-574-6658
Hours: Monday-Friday, 8 a.m. – 5 p.m.
Please call before visiting to check staff availability.

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1. INTRODUCTION

1.1 General

Coastal unincorporated areas of Coos County, OR are vulnerable to the effects of a local Cascadia Subduction Zone (CSZ) earthquake and tsunami event. In addition to the potentially catastrophic damage caused by the earthquake event itself, the resultant tsunami will inundate portions of the community and a risk-based and community-specific approach to evacuation will be critical to save lives. This Tsunami Evacuation Facilities Improvement Plan (TEFIP) is a comprehensive look at existing and potential evacuation routes and needed improvements for these coastal communities, and includes identified facility and infrastructure improvement projects and potential financing strategies. **This TEFIP is essential to the implementation of evacuation route development and improvement in conjunction with the land use review and approval process, established through Coos County's Tsunami Hazard Overlay Zone (*Article 4.11.260-270*).** The cities of Coos Bay and North Bend also have tsunami risk but are not included in this plan because they are not within the jurisdiction of the Coos County Planning Department.

The Oregon Department of Geology and Mineral Industries (DOGAMI) has been identifying and mapping the tsunami inundation hazard along the Oregon coast since 1994. DOGAMI developed a series of tsunami inundation maps in 2013 to help residents and visitors along the entire Oregon coast prepare for the next CSZ earthquake and tsunami, called the Tsunami Inundation Maps (TIMs). The TIMs display five scenarios, labeled as "T-shirt sizes" (S, M, L, XL, and XXL), showing the impact of Cascadia Subduction Zone tsunamis that reflect the full range of possible inundation. The geologic record shows that the amount of time that has passed since the last great Cascadia earthquake (in January 26, 1700) is not a reliable indicator of the size of the next one, so the size ranges are intended to be inclusive of the range of scenarios that a community might expect during a CSZ event.

1.2 Limitations and Constraints

Because life safety risk is present in all areas potentially subject to inundation during a tsunami event, the XXL tsunami scenario is used for evacuation facility planning, so that all areas with the **XXL scenario** can be effectively evacuated. This local tsunami is generated by a high magnitude earthquake just off the Oregon Coast and thus the inundation area is much larger than for a distant tsunami event. Also, unlike a distant tsunami that can be predicted several hours prior to its arrival (4 or more hours), this local CSZ tsunami can strike the coast within 15 – 20 minutes after the earthquake.

For the purposes of this plan, tsunami evacuation means the immediate movement of people from the tsunami inundation zone to high ground or safety following a CSZ earthquake. Comprehensive disaster planning for a CSZ earthquake and tsunami event requires a phased and scalable approach to planning and coordination; immediate evacuation for the purposes of life safety is only one (albeit a very important) phase. This TEFIP does not include planning for earthquake shaking damage mitigation or post-event disaster response and recovery. Other entities at the local, state, and federal level continue to prepare for those additional phases.

1.3 Definitions

Horizontal evacuation is the preferred response for tsunami evacuation, which is the movement of people to high ground and/or inland away from tsunami waters. In some locations, high ground may not exist, or tsunamis triggered by a local event may not allow sufficient time for communities to evacuate low-lying areas. Where horizontal evacuation out of the tsunami inundation zone is neither possible nor practical, a potential solution is **vertical evacuation**[1] into the upper levels of structures designed to resist the effects of an earthquake as well as a tsunami. A **vertical evacuation structure** is a building or earthen mound that has sufficient height to elevate evacuees above the level of tsunami inundation, and is designed and constructed with the strength and resiliency needed to resist the expected earthquake shaking and the loading due to tsunami waves.

This TEFIP identifies and discusses **tsunami evacuation facilities**, which are defined as places, amenities, infrastructure, or equipment that can be used to assist in tsunami evacuation (horizontally or vertically). Tsunami evacuation facilities generally include (but are not limited to): roads, trails, wayfinding elements (signs, kiosks, trail markers), supply caches, assembly areas, bridges, and vertical evacuation structures. Evacuation improvements for a community may also include education and outreach activities.

1.4 Whole Community

Every person who lives, works, or visits Coos County (including access and functional needs populations) shares responsibility for minimizing tsunami risks and vulnerabilities. These individual responsibilities include tsunami awareness, knowledge of appropriate protective actions, and preparations for personal and family safety. Knowledgeable residents and visitors who are prepared to take care of themselves and their families and to assist neighbors in the early phases of a tsunami event can make a significant contribution towards survival and community resiliency.

The development of this TEFIP involved a range of stakeholders including the public, scientific community, local government, and community-based organizations.

1.5 Coordination with the Tsunami Hazard Overlay Zone (Article 4.11.260-270)

Coos County has adopted land use regulations addressing tsunami risk for certain types of new development and substantial improvements. These regulations are implemented through the Tsunami Hazard Overlay Zone, Article 4.11.260-270 of the Balance of County. Except single family dwellings on existing lots and parcels, all new development, substantial improvements and land divisions in the Tsunami Hazard Overlay Zone (everything within the XXL tsunami scenario) are required to incorporate evacuation measures and improvements which are consistent with and conform to this adopted Tsunami Evacuation Facilities Improvement Plan.

For purposes of compliance with this TEFIP and the THOZ, applicants should review the entire plan, particularly the following sections as they relate to the proposed development and related evacuation improvements:

---

[1] Applied Technology Council. April 2012. FEMA Guidelines for Design of Structures for Vertical Evacuation from Tsunamis, Second Edition. Federal Emergency Management Agency, National Oceanic and Atmospheric Administration.

- **Section 3: Evacuation Facility Assessments and Recommendations** – this section is organized into four discrete geographic areas. Review the subsection applicable to the proposed project location for evacuation routes and identified improvement projects.
- **Section 4: Implementation Resources for Evacuation Projects** – this section describes resources related to different types of evacuation improvements. In particular, the *Oregon Tsunami Evacuation Wayfinding Guidance* (Version 05-13-2019) developed by the Oregon Office of Emergency Management and the Department of Geology and Mineral Industries should be reviewed for compliance with evacuation signage standards.
- **Section 5: Education, Outreach, and Training** – this section describes resources related to education, outreach, and training materials and activities for tsunami evacuation. If an applicant is proposing evacuation improvements related to this topic, this section should be consulted for consistency.
- **Appendices A-D as needed.**

2. TSUNAMI RISK AND VULNERABILITY ASSESSMENT

2.1 Hazard Identification

The hazard being addressed by this TEFIP is a tsunami event that results in the need for community evacuation. A tsunami impacting the County would be the result of an earthquake from one of two categories:

- **Local Tsunami:** Generated by an earthquake immediately offshore of the Oregon Coast (e.g. a Cascadia Subduction Zone earthquake) and would result in a tsunami to come onshore within 15-20 minutes following the earthquake.
- **Distant Tsunami:** Generated by a distant earthquake (e.g. large event occurring off a distant coastline such as Japan or Alaska) and would result in a tsunami to come onshore 4 hours or more following an earthquake on another continent.

A local earthquake resulting in a tsunami is likely to generate additional hazards that may further hinder an individual's ability to evacuate and may increase the time needed to evacuate. Such examples include:

- **Damage to buildings:** Severe shaking, especially in areas of poor soils, will damage buildings, making it difficult to evacuate. Homes built before 1974 may not be tied to foundations and can shift off foundations. Unreinforced masonry buildings and under-reinforced concrete buildings will be severely damaged or collapse. Furnishings and equipment not securely fastened can cause injuries.
- **Damage to infrastructure:** Severe shaking and areas of poor soils will result in infrastructure failures. Infrastructure systems that may cause barriers to evacuation are water, wastewater, and stormwater facilities, liquid fuel and natural gas tanks and lines, electrical systems, bridges, embankments and roads. Shaking damage may result in fallen electrical lines, damaged gas lines, tank and pipeline failures and leaks, bridge failures, as well as physical interruptions in the surface transportation system due to slope failures and ground failures.
- **Landslides:** Landslides and ground movement may present added barriers to evacuation resulting in blocked roads, bridges, and walking trails.
- **Fires:** Fires from damaged electrical lines or propane may result in injuries that hinder an individual's ability to evacuate.
- **Liquefaction:** Similar to landslides, liquefied soils may result in unstable, damaged roads, bridges, and walking trails that present added barriers to an individual's ability to evacuate, especially those who experience access and functional needs.
- **Vehicular accidents and traffic jams:** Individuals may attempt to evacuate in personal vehicles en masse and push their vehicles to cover unusual terrain either due to damaged infrastructure or an attempt to bypass typical infrastructure to save time. This may result in accidents and traffic jams that prevent individuals from reaching higher ground.
  ****NOTE: Vehicle evacuation is NOT recommended following a local CSZ event!*****

2.2 Mapping

Mapping produced by the Oregon Department of Geology and Mineral Industries (DOGAMI) is the primary source of information for the identification of areas subject to tsunami inundation. DOGAMI has produced a number of map products depicting tsunami inundation for the county, including the Tsunami Inundation Maps (TIMs), Tsunami Evacuation Brochures, and more recently, the "Beat the Wave" (BTW) maps. These map products are referenced throughout this plan and identify areas within Coos County that are subject to potential life safety risk and that need to be evacuated during a local CSZ tsunami event.

2.2.1 Tsunami Inundation Maps

The TIM series depicts the projected tsunami inundation zone from five different magnitude seismic and tsunami events: small, medium, large, extra-large, or extra extra-large (S, M, L, XL, XXL). These different modeled events are associated with differing levels of risk in terms of the relative likelihood of tsunami inundation (Appendix A). These maps are referenced in Chapter IV Balance of County Zones, Overlays & Special Consideration Section 4.11.260 Tsunami Hazard Overlay Zone. The purple zones on these maps show the small and medium earthquake and tsunami events, while the three shades of yellow indicate the large through extra extra-large events.

See http://www.oregongeology.org/tsuclearinghouse/pubs-inumaps.htm for more information.

2.2.2 Tsunami Evacuation Brochures

The Tsunami Evacuation Brochures are public products designed to direct visitors and residents away from low-lying areas in the event of a tsunami. They depict three color zones: orange for the largest expected distant tsunami; yellow for the largest expected local tsunami; and green for safety (or high ground).

See http://nvs.nanoos.org/TsunamiEvac and www.oregontsunami.org for more information.

2.2.3 Beat the Wave Maps

DOGAMI has also completed BTW tsunami evacuation modeling for the unincorporated areas of Charleston, Barview, and the North Spit, which provides additional detail on estimated evacuation clearance times and evacuation needs. The results of this mapping have been used in this plan to identify evacuation deficiencies, as well as potential evacuation improvements. These maps will be discussed in greater detail in Section 3. See Appendix B for examples of the Beat the Wave map products referenced in this plan. *The final report, once published, will be available on www.oregontsunami.org as an Open File Report.*

2.3 Populations at Risk

The purpose of this section is to determine the overall numbers of people and identify, to the extent possible, access and functional needs populations that are within the tsunami inundation zone areas and thus in harm's way. The goal is to estimate how many people will need to be evacuated, and to identify the characteristics and locations of populations that may have specific additional needs or requirements for evacuation.

Overall, the coastal unincorporated communities of Coos County have a low vulnerability to tsunami risk. There are few critical and essential facilities in the tsunami inundation zone and most areas within the zone have nearby access to high ground. However, there are access and functional needs populations within the tsunami zones that are addressed in this plan, in order to better support their evacuation success.

2.3.1 Demographics

According to Portland State University's Population Research Center, 25,000 people live in unincorporated Coos County (which also includes non-coastal areas)[2]. These areas are forecasted to stay around the same population or decrease over the next fifty years.

A report developed by the Department of Human Services (2017)[3] compiled information on the characteristics and economic and health indicators of each county in Oregon. The following information was compiled for Coos County and may have relevance when considering tsunami evacuation improvements (NOTE: data is for the whole county):

- Poverty rate: 17.8% (statewide rate of 16.2%)
- Unemployment rate: 9.2% (statewide rate of 7.0%)
- Rate of homeownership: 56% (excludes renters)
- Persons with a self-reported disability: 22.9%
- Persons in poverty: 18.3%; Persons under age 18 in poverty: 25.2%
- Households with retirement income: 28.4%
- Households with social security income: 46.4%
- Major employment sectors: Trade, transportation, utilities, education, health, and government

In addition, the Charleston/Barview area is considered a poverty hotspot (geographic concentration of poor residents). The poverty rate for this area is 31% (encompassing approximately 2,654 people and 1,165 households). Approximately 25% of the population in Charleston and Barview has a disability.

2.3.2 Population Estimates

Tsunami evacuation is of greatest concern to populations residing or working within the inundation zone. The following table illustrates the estimated populations and facilities within the LARGE and XXL inundation zone[4]. While some of these numbers are based on the LARGE tsunami event, **everyone within the XXL tsunami hazard zone should evacuate after an earthquake for life safety purposes.**

---

[2] PSU Oregon Population Forecast Program. 2018. Preliminary Coordinated Forecasts for Coos County, its Urban Growth Boundaries (UGBs), and the Area Outside UGBs.

[3] Office of Business Intelligence & the Office of Forecasting, Research, and Analysis (DHS/OHA). 2017. DHS County Quick Facts. URL: www.oregon.gov/DHS/ABOUTDHS/DataDocuments/County-QuickFacts-2017.pdf.

[4] Wood, NJ, Jones, J, Spielman, S, and Schmidtlein, MC. 2015. Community clusters of tsunami vulnerability in the US Pacific Northwest. Proceedings of the National Academy of Sciences of the United States of America: 112 (17): 5354–5359.

Population or Asset	#'s in the L tsunami zone	#'s in XXL tsunami zone[5]
Residents	1,605	3,385
Residents 65 and older	395	861
Employees	152	1,309
Employers	No data	116
Public Venues	3	No data
Dependent-Care Facilities	1	No data
Community Businesses	8	No data

Because population estimates are based on census data, only resident populations are reflected and not transient populations.

2.3.3 Access and Functional Needs Populations

Access and Functional Needs populations (also referred to as vulnerable populations and special needs populations) are members of the community who experience physical, mental, or medical care needs and who may require assistance before, during, and after an emergency incident after exhausting their usual resources and support network. In the case of evacuations, examples of individuals who have access and functional needs that may make evacuation challenging include, but are not limited to:

- Individuals who experience mobility challenges (e.g. physical disabilities, elderly, children)
- Individuals who are blind or have low vision
- Individuals with limited-English proficiency
- Individuals who are deaf or hard of hearing
- Individuals who have been injured during the earthquake

Tsunami evacuation requires the ability to move from the inundation zone to high ground (or safety) in a timely matter. Due to this short onset time, individuals who experience access and functional needs may lack the resources to travel such distances.

2.3.4 Using Key Locations as a Proxy

Specific information about where or how many access and functional needs individuals would need assistance in an evacuation is not available; however, by identifying key locations that can be used as a proxy for access and functional needs, we can extrapolate where those individuals may be in a CSZ event. In the event of an update more information needs to be obtained regarding tourist facilities, childcare facilities, youth organizations and other meeting facilities that have the ability to high volumes of population to gather.

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[5] Gabel, LS, Bauer, JB, O'Brien, FE, Bauer, JM, and Allan, JC. 2019. OFR O-19-07, *Tsunami evacuation analysis of communities surrounding the Coos Bay Estuary: Building community resilience on the Oregon coast.*

2.3.5 Housing

According to the 2015 Oregon Natural Hazard Mitigation Plan[6], 78.5% of the housing stock in Coos County was built pre-1990, before seismic building standards were put into place. This could have implications for sheltering needs after a Cascadia earthquake and tsunami event, meaning more people could be displaced following an event beyond those in the tsunami inundation zone due to extensive earthquake damage in the community.

2.3.6 Community Sheltering

The following facilities are outside of the XXL tsunami inundation zone and may be used for community sheltering after a CSZ event:

Table 3: Potential Community Shelters

Several facilities were named during the process (Future Coos Head Conference Center, Coquille Tribes Maintenance Building and Former Charleston School Site but the capacity and other factors were not completed through this study and should be considered in an updated revision.

2.4 Conclusions

Tsunami vulnerability for Coos County is relatively low. The coastal areas of the county have: a) relatively low numbers of residents, employees, and customer-heavy businesses in the tsunami hazard zone; and b) those that occupy the zone will likely have enough time to reach high ground before the first tsunami wave (see Section 3 for more information). However, of those people that are in the tsunami hazard zone, there is a relatively high percentage of residents over 65 years old, persons in poverty, and persons with mobility challenges. Additionally, the coastal areas of Coos County experience high numbers of visitors and tourists, who are unfamiliar with the landscape and tsunami hazards. These groups may need additional assistance in evacuating effectively.

Additionally, successful evacuations are not guaranteed in these communities, because individuals still need to understand the threat, recognize signs of imminent waves, and take self-protective action. Education efforts that recognize demographic differences (e.g. age, living situation, and resident vs. tourist) may be the best course of action for these communities. Specifically, evacuation improvement efforts focused on communicating to and supporting visitors and populations over 65 years would be the most beneficial strategies for these communities.

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[6] State Interagency Hazard Mitigation Team. 2015. Oregon Natural Hazards Mitigation Plan.

3. EVACUATION FACILITY ASSESSMENTS AND RECOMMENDATIONS

The process of evaluating existing evacuation facilities and identifying prioritized improvement recommendations involved three phases:

- **Existing Facility Assessments:** The planning team engaged in a desktop analysis of existing evacuation routes and facilities to determine gaps. This was followed up by a review by the relevant experts from the communities to ensure all existing facilities had been accounted for.
- **Identification of needed improvements:** A meeting with community stakeholders served to assess gaps in existing facilities to determine locations requiring improvements. This meeting, informed by DOGAMI's Beat the Wave modeling results, led to an initial list of potential improvement projects that underwent comparison and scrutiny to ensure project need and feasibility.
- **Prioritization of needed improvements:** Following the identification of needed improvements, the planning team reviewed the list of proposed projects and prioritized them (high, medium, low) based upon the project's perceived effectiveness and feasibility (measured by capacity, administrative control, and political considerations). This resulted in the prioritized project alternatives identified in the following sections.

Considering Co-Benefits

The most cost-effective and successful projects generate benefits outside of their intended purpose. For example, a tsunami evacuation route sign provides lifesaving guidance following an earthquake, but it also increases overall hazard awareness and personal preparedness before an earthquake. The sections that follow highlight recommended evacuation improvement projects throughout the coastal areas of the County. In addition, the recommendations also identify co-benefits created through the implementation of each project, which may support the identification of additional partners and funding opportunities. The co-benefits identified in this plan are as follows:

- Hazard Awareness and Education
- Personal Preparedness
- Health and Wellness
- Transportation Effectiveness
- Asset Protection
- Economic Development
- Environmental Protection

3.1 North Spit

3.1.1 Community Overview

For this plan, the North Spit is defined as the area from the northern edge of Horsfall Lake south to the southern-most tip of the spit at the north jetty of the Coos Bay estuary. It is bounded on the east by the Coos Bay estuary and on the west by the Pacific Ocean. The area consists mostly of open sand dunes, forested islands, wetlands, and a few developed areas. There are only a few access roads across the spit and the area is primarily used (and zoned) for recreation or industry.

Recreational Uses:
A significant portion of land on the North Spit is federally owned and managed (Bureau of Land Management and the Siuslaw National Forest) and open to recreational uses, including: hiking, horseback riding, sand driving, boating, and fishing. There are three campgrounds along Horsfall Beach Road (two public and one private), and a few Off-Highway Vehicle (OHV) staging areas and day-use parking lots.

Industrial Uses:
Several areas along the eastern shoreline of the North Spit are owned and managed by the International Port of Coos Bay and are utilized as industrial sites by private companies. Currently, there are about 170 employees on the North Spit, working at a few different industrial sites.

3.1.2 Existing Evacuation Facilities Analysis

Tsunami Wave Arrival Time
The first tsunami wave arrives at the western edge of the North Spit between 14 and 16 minutes. The wave crosses the North Spit fairly uniformly, coming across the spit as one wave. It gets to the eastern shore of the southern portion of the spit (near DB Western and Southport Lumber) between 20 and 24 minutes. Bluebill campground gets inundated by 20 to 24 minutes; Roseburg Forest Products is inundated by 24 to 26 minutes; and the eastern edge of the northern portion of the spit is completely inundated by 26 to 30 minutes.

See Appendix B for wave arrival time maps.

Existing Evacuations Routes
Main evacuation routes in the area have been determined for the following locations (see Appendix C):

- For the Horsfall Beach area, the main evacuation route is along Horsfall Beach Road east towards the high dunes near Horsfall Campground.
- The high dunes along the central portion of Trans Pacific Lane serve as the nearest high ground for the industrial sites along Coos Bay estuary and the southern portions of the spit.

Evacuation Speeds
For locations within the central and eastern portions of the North Spit, walking speeds range from a slow walk to a fast walk. Areas along the beach and western portion of the spit reach much higher pedestrian speeds (jog, run, and sprint) because of their distance from high ground. The southern

end of the spit is especially challenging to evacuate with walking speeds of sprint (7-10 mph) and unlikely to survive (>10 mph) near South Dike Lane, DB Western, and Southport Lumber. There is a high dune near DB Western that is safe in a LARGE (L) tsunami scenario but would be overtopped by XL and XXL.

Critical Facilities

The North Spit area is primarily used recreationally and for industry. There are four companies with operations on the spit currently, with potential for growth in the future. While there are no critical facilities on the spit, there are potentially hazardous materials housed within the industrial complexes that will likely be damaged by an earthquake and tsunami event. Additionally, there could be substantial large debris created from the lumber yard. There is one main bridge (via Trans Pacific Lane) east across Coos Bay estuary connecting to Highway 101 (which is also a bridge) that will likely fail or incur significant damage after the earthquake and tsunami, leaving those on the North Spit isolated from other communities.

Conclusions

The people working or recreating in this area could become very isolated in a local earthquake and tsunami event. Additionally, evacuation speeds are quite high in some areas, especially further south on the spit or out on the open sandy beach areas. There is limited high ground and evacuation success could be severely limited under current evacuation conditions. If people have access to their ATV's when evacuation is necessary, they will be able to use those vehicles to more quickly access high ground over potentially challenging terrain. However, anyone on foot will have a much more difficult time evacuating on loose sand. Current signage for tsunami evacuation on the North Spit is sparse. There are currently no designated assembly areas. There is also potential for growth in the industrial sector of the North Spit and so evacuation facilities should anticipate the potential for increased numbers of workers and tourists for this area. Vertical evacuation structures, increased signage and education, and emergency caches are recommended for evacuation facility improvements to this area.

3.1.3 Evacuation Improvements Project Identification

WAYFINDING & EDUCATION

Project Name	Priority	Potential Project Partners	Potential Funding Sources	Project Beneficiaries
Evacuation route markers from beach access	High	BLM, County Emergency Management, Campground Managers, Public Works, Road Department	NTHMP (OEM/DOGAMI), FEMA HMA, BLM	Visitors/tourists
Entering/Leaving Signs	High	BLM, County Emergency Management, Campground Managers, Public Works, Road Department	NTHMP (OEM/DOGAMI), FEMA HMA, BLM	Visitors/tourists
Evacuation Training for	High	Industrial facilities, Port of Coos Bay, County	NTHMP, County Emergency	Employers and employees of

Employees		Emergency Management	Management, Industrial Facilities	industrial sites
Informational Kiosks	High	BLM, US Forest Service, Oregon State Parks, County Emergency Management, Campground Managers	NTHMP (OEM/DOGAMI), FEMA HMA, BLM	Visitors/tourists

Problem Statement: Limited existing signage and educational materials may present difficulty to residents and visitors in evacuating from the inundation zone.
Project Descriptions:

1. **Evacuation route markers along major tsunami evacuation routes starting from beach access points**: Individuals on the beach and other recreational sites on North Spit are challenged to get to high ground during a tsunami event, due to difficult terrain (loose sand) and unclear evacuation routes. There are existing numbered beach access point signs (large neon yellow signs) that could be tied into the tsunami evacuation system. From major beach access points on the North Spit, mark every quarter mile along major evacuation routes to lead people to high ground (safety destination). Major evacuation routes are Horsfall Beach Road and Trans Pacific Lane. Route markers could be small, blue, reflective signs (similar to hiking trail markers) leading the way to high ground. Once trail markers are installed, their description should be tied into the informational kiosks described above and other education efforts so that visitors know what the markings mean and what to do in an earthquake and tsunami event. Evacuation communities (Appendix C) show the flow of people on existing roads to high ground (safety destinations). This concept should be followed when installing tsunami evacuation route markers.

2. **Entering/leaving tsunami zone signs at high ground intersections along major evacuation routes:** Signs indicating the extent of the XXL tsunami inundation zone should be placed at high dune areas along Horsfall Beach Road and Trans Pacific Lane. See Appendix C (Beat the Wave maps) for locations of the intersection of tsunami zones and high ground (green dots). Entering signs should be placed on the side of the road where travel is moving into the tsunami zone. Leaving signs should be placed on the side of the road where travel is moving out of the tsunami zone. These signs help both to educate people of these zones before an event and to let them know when they've reached safety during an evacuation event.

3. **Evacuation training for all workers located on the North Spit**: Provide all employers and employees located on the North Spit with tsunami evacuation education and training to ensure everyone knows when and how to evacuate in the event of a local CSZ tsunami event. The County Emergency Management Division does presentations about preparing for a Cascadia subduction zone earthquake and tsunami to various audiences around the County regularly and should be able to provide this training for North Spit employees.

4. **Information kiosks at every major parking lot and campground entrance on the North Spit**: Create a centralized tsunami information platform for visitors. Develop informational kiosks at the following populated locations:

a. Parking lots at Horsfall Beach
b. Old Bark Road OHV Staging Area
c. Campgrounds: Bluebill, Horsfall, and Box Car Hill

Kiosk messaging should focus on tsunami education and evacuation for visitors and ATV riders. Include information that says "you are *x* number of minutes from high ground" and maps the route visitors should follow in the event of needed evacuation. Work with the property owner or manager of each site on the best design for a kiosk or to integrate with existing educational information.

CONSTRUCTION

Project Name	Priority	Potential Project Partners	Potential Funding Sources	Project Beneficiaries
Vertical Evacuation Structures for (2) Industrial Sites	Medium	Industrial Facilities, Port Of Coos Bay, County Emergency Management	FEMA HMA, Municipal Financing	Industry Employees, Visitors
Long Term Emergency Cache	High	Industrial Facilities, Port Of Coos Bay, County Emergency Management, Local Food Banks	FEMA HMA, Municipal Financing, Port of Coos Bay, Private Financing	Industry Employees, Visitors

Problem Statement: Two industrial sites on the North Spit are currently very far from high ground, presenting the potential for unsuccessful evacuation prior to the tsunami's arrival.

Project Descriptions:

1. **Vertical evacuation structure and emergency caches to serve DB Western and southern portion of North Spit:** Because of the high evacuation clearance times required for employees and visitors of the southern end of the North Spit to evacuate in a local tsunami event, a vertical evacuation structure constructed near DB Western would greatly enhance the evacuation success of this area (Appendix C). There is a high dune to the west of DB Western where such a structure could be constructed, since that dune is already of sufficient height to place people above the LARGE tsunami event. A vertical evacuation structure built here would be designed to place evacuees above the XXL tsunami event and would be potentially less intensive to build because of the advantage of the height of the high dune. No other tsunami evacuation improvements have been identified that could improve evacuation success for these communities. A trail or road to access the structure would also have to be designed and built as part of this project. Lastly, the vertical evacuation structure should contain an emergency cache as part of the overall project and design to aid the evacuees once they've reached safety.

2. **Vertical evacuation structure and emergency caches to serve Southport Lumber and surrounding area:** Because of the high evacuation clearance times required for employees and visitors of the southern end of the North Spit to evacuate in a local tsunami event, a vertical evacuation structure constructed near Southport Lumber would greatly enhance the evacuation success of this area (Appendix C). A vertical evacuation structure built here would be designed to place evacuees above the XXL tsunami event. No other tsunami evacuation improvements

have been identified that could improve evacuation success for these communities. A trail or road to access the structure would also have to be designed and built as part of this project. Lastly, the vertical evacuation structure should contain an emergency cache as part of the overall project and design to aid the evacuees once they've reached safety.

Considerations: A vertical evacuation refuge from tsunamis is a building or earthen mound that has sufficient height to elevate evacuees above the level of tsunami inundation, and is designed and constructed with the strength and resiliency needed to resist the effects of tsunami waves. Vertical evacuation refuges can be stand-alone or part of a larger facility. They can be single-purpose refuge-only facilities, or multi-purpose facilities in regular use when not serving as a refuge. In concept, these options are applicable to new or existing structures, but it is generally more difficult to retrofit an existing structure than to build a new tsunami-resistant structure[7]. Loading and other criteria for the design of vertical evacuation structures are provided in Section 4.

NOTE: While building one vertical evacuation refuge would be more efficient and cost-effective than having to build two (one for each industrial facility), the stretch of landscape between Southport Lumber and DB Western is long, low in elevation, and of loose sandy material. A mid-way point would likely cost too much in terms of engineering and construction compared to locating such structures elsewhere (e.g. closer to one or the other industrial site). A more detailed geotechnical investigation would be required to make an ideal location determination for such a structure.

3. **Long term cache near Roseburg Forest Products:** A community cache would contain supplies to assist the population on the North Spit in surviving immediately after a CSZ tsunami event because this community is likely to be isolated from other communities in Coos County (due to bridge failures and geography). This emergency supply cache would be located in the high dunes near the industrial sites of Roseburg Forest Products and others, and provide shelter and supplies to anyone isolated on the North Spit for at least two weeks (Appendix C).
   Considerations: Emergency caches are complex stores of emergency supplies. A community must think about: where to locate the cache; how many people it should serve and for how long; who are the potential users; what and how much of: food, water, shelter, first aid, sanitation, communication, mental health support; access to (and security of) the cache; incident command procedures; camp layout; ownership of the supplies; and a maintenance plan.

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[7] Applied Technology Council. April 2012. FEMA Guidelines for Design of Structures for Vertical Evacuation from Tsunamis, Second Edition.

3.2 Barview

3.2.1 Community Overview

For this plan, Barview is defined as the area from Wisconsin Ave (border of Coos Bay City Limits) south to Giddings Boat Works and the bridge over South Slough. It is bounded on the west by the Coos Bay estuary. The area consists mostly of residential and small commercial development. While much of the residential areas are within the XXL tsunami inundation zone, high ground is immediately nearby as described below.

3.2.2 Existing Evacuation Facilities Analysis

Tsunami Wave Arrival Time

The first wave reaches the southern end of Barview in about 18 minutes. It reaches Cape Arago Highway in about 20 minutes and reaches the extent of inundation by about 26 minutes (up to 30 minutes in the Joe Ney Slough area).

See Appendix B for wave arrival time maps.

Existing Evacuations Routes & Speeds

Most evacuation routes in the area are west to east on existing streets. Evacuation speeds for the community range between a slow walk (0-1.4 mph) and fast walk (2.7-4.1 mph). See Appendix C for Beat the Wave pedestrian speed maps and evacuation communities.

Considerations: There are two reservoirs (4th Creek and Tarheel) in the tsunami inundation area and the reservoir dams may be prone to failure during an earthquake. Dam failure is unlikely to have negative impacts on evacuation success because those areas can be avoided by going on eastbound streets to the south or north of the respective dam. Also, the bridges over South Slough and Joe Ney Slough have not been earthquake retrofitted and will likely fail during an earthquake. The inability to use the bridges as an evacuation route does not impact evacuation speeds for the community in Barview because there is high ground on both sides of the bridges. However, the bridges are important for community connectivity (movement of people and supplies) post-event.

Critical Facilities

The majority of the structures in the tsunami inundation zone consist of residential development or small businesses, as well as some of the Coquille Indian Tribe reservation lands. Charleston Fire District does have one fire station in the Barview tsunami inundation zone. The Coquille Indian Tribal Police Department and the Charleston wastewater treatment facility are also in the inundation zone. No other critical or essential facilities are in the inundation zone.

Future development: A 200-lot RV park is under development in Barview, in the inundation zone. This area may be challenging to evacuate due to its proximity to the river; however, high ground is nearby (to the east) and accessible by foot.

Conclusions

While much of this community is within the XXL tsunami inundation zone, no evacuation routes identified through BTW prevent evacuation clearance, assuming a slow or fast walking speed.

However, additional demographic data indicates that a high percentage of this population is older and mobility-limited, which may make successful evacuation more challenging, especially if road conditions post-earthquake are not accessible to wheelchairs or other walking aid devices (e.g. scooters). Additionally, routes are not currently marked or lit for escape during the night or in poor weather conditions. Current signage for tsunami evacuation in Barview is sparse. There is one Assembly Area at the Baseball Field off Libby Lane. Adding additional assembly areas and signage is suggested.

3.2.3 Evacuation Improvements Project Identification

WAYFINDING & EDUCATION

Project Name	Priority	Potential Project Partners	Potential Funding Sources	Project Beneficiaries
Directional Evacuation Highway Signs	High	Oregon Department Of Transportation, County Roads Department, Public Works	NTHMP (OEM/DOGAMI), FEMA HMA	Residents and Visitors
Entering/Leaving Signs	High	Oregon Department Of Transportation, County Roads Department, Public Works	NTHMP (OEM/DOGAMI), FEMA HMA	Residents and Visitors
Assembly Area Designations	Medium	School Districts, Private Landowners, Coquille Indian Tribe, Confederated Tribes Of Coos, Lower Umpqua, And Siuslaw	County (in-kind)	Residents
Outreach with Schools	High	School districts, County Emergency Management	School Districts, County Emergency Management (In-Kind), OEM	Residents
Community-wide Evacuation Drills	High	School Districts, County Emergency Management, Police And Fire Districts, Public Health Organizations, CERT Or Other Emergency Response Volunteer Groups	County (in-kind)	Residents
Flood Insurance Outreach	Medium	County Emergency Management, DLCD, FEMA, insurance agents	FEMA HMA, OEM, DLCD grants	Residents

Problem Statement: Limited existing signage may present difficulty to residents and visitors in evacuating from the inundation zone.

Project Descriptions:

1. **Directional evacuation highway signs off Cape Arago Highway towards high ground:** Tsunami evacuation signs with a directional arrow should be placed along Cape Arago Highway in Barview at the intersections of east/west streets that continue to high ground. In Barview, much of the residential community is in the tsunami zone, but most of the east/west streets continue to high ground, making evacuation fairly straightforward. Signage will help to reinforce this evacuation flow to residents on a daily basis, as well as act as a wayfinding aid during tsunami evacuation. Evacuation communities (see Appendix C) show the flow of people on existing roads to high ground (safety destinations). This concept should be followed when installing new road signs.
2. **Entering/leaving tsunami zone signs at high ground intersections along major evacuation routes:** Signs indicating the extent of the XXL tsunami inundation zone should be placed along major evacuation routes in Barview. See maps in Appendix C for locations of the intersection of tsunami zones and high ground (green dots). Entering signs should be placed on the side of the road where travel is moving into the tsunami zone. Leaving signs should be placed on the side of the road where travel is moving out of the tsunami zone. These signs help both to educate people before an event and to let them know when they've reached safety during an evacuation event. Blue lines could be used in addition to or instead of signs, but must be easily visible and include public outreach and education about what they mean. OEM has more information about tsunami blue lines.
3. **Additional assembly area designations:** An assembly point is a location that has been designated by local authorities for residents and visitors to gather AFTER safely reaching their nearest high ground outside the tsunami zone. A person's nearest safety destination (high ground) may not be at an assembly area. Assembly areas are temporary meeting points to meet-up with others during the immediate aftermath of a disaster (12-24 hours later). Currently, there is one assembly area designated at the baseball field off Libby Lane. Additional assembly areas would allow residents to more readily access an area nearby. Identify appropriate sites for a temporary assembly area based on property ownership and accessibility.
4. **Outreach with area schools:** While no schools are in the tsunami zone, students may live in a tsunami zone. Outreach should be done at all the nearby schools to talk about tsunami hazards, evacuation routes, and the role of schools after a disaster (as assembly areas or long-term shelter facilities).
5. **Conduct community-wide evacuation drills:** It is important for residents who live in or near tsunami hazard zones to practice evacuating to high ground regularly so they are prepared for an actual evacuation event. The Oregon Office for Emergency Management (OEM) published a "Tsunami Evacuation Drill Guidebook" as a reference for planning community-wide tsunami evacuation drills, which can serve as a starting point for staging such drills in both Barview and Charleston, and any residential area in Coos County that is within the tsunami hazard zone. A neighborhood-by-neighborhood effort to instigate and carry-out evacuation drills might also be an effective tactic, where a smaller geographic area is targeted and works together to think about evacuation and post-event recovery. CERT (Community Emergency Response Teams) might be a good resource to tap for this kind of event.

6. **Flood insurance outreach for tsunami damage protection:** The National Flood Insurance Program (NFIP) flood insurance covers losses due to flooding, including after a tsunami. Conduct outreach efforts with property owners to encourage the purchase of flood insurance for properties within the tsunami hazard area (but outside of the special flood hazard area outlined in NFIP Flood Insurance Rate Maps). This insurance is offered at a much discounted rate compared to mandatory flood insurance and covers losses from tsunami damage. Contact FEMA NFIP staff for further information. This type of outreach can be done in every residential community in a tsunami hazard area.

CONSTRUCTION

Project Name	Priority	Potential Project Partners	Potential Funding Sources	Project Beneficiaries
Elevated Scooter Trail	High	County Emergency Management, Oregon Department Of Transportation, County Roads Department, Public Works	FEMA HMA, Municipal Financing, Port of Coos Bay, Private Financing	Industry Employees, Visitors
Supply Caches	Medium	County Emergency Management, School Districts, Local Food Banks	FEMA HMA, Municipal Financing, Private financing	Residents, Visitors

<u>Problem Statement:</u> A high percentage of residents in Barview are mobility-challenged and may have difficulty evacuating in a local tsunami event. Additionally, because of the high numbers of homes in the XXL tsunami scenario, many residents will be displaced after a tsunami event and will need supplies and shelter.

<u>Project Descriptions:</u>

1. **Elevated scooter trail (or similar improvement):** Although evacuation speeds for the Barview area range between a slow and fast walk, mobility is an issue for about a quarter of the population living there. Residents may need a centralized infrastructure improvement to withstand earthquake shaking and allow for scooter/wheelchair passage to high ground. This would be a major engineering project and require considerable capital investment. An engineering geologic report would have to be completed to locate the best road to build this improvement on or near, and an engineer to design a concept that might meet the need.

2. **Supply caches for Barview residents and visitors:** A community cache would contain supplies to assist the population in Barview in surviving immediately after a CSZ tsunami event. This community may initially be somewhat isolated from other communities in Coos County (due to transportation network failures). These emergency supply caches would be located in the eastern part of the community above the XXL tsunami zone, at designated areas. Two locations are suggested: at the baseball field off Libby Lane and at the end of Spaw Lane. <u>Considerations</u>: Emergency caches are complex stores of emergency supplies. A community must think about: where to locate the cache; how many people should it serve and for how long;

who are the potential users; what and how much of: food, water, shelter, first aid, sanitation, communication, mental health support; access to (and security of) the cache; incident command procedures; camp layout; ownership of the supplies; and a maintenance plan (rotation of supplies). It might be beneficial to coordinate with local food banks who could benefit from supplies when they need to be rotated, so nothing goes to waste. Additionally, when siting caches, public property would provide be the most ideal location, especially at an existing office building or heavily used area, so that the supplies could be monitored more easily by the relevant local, state, or federal authorities.

3.3 Charleston

3.3.1 Community Overview

For this plan, Charleston is defined as the area from the mouth of the Coos Bay estuary to Roosevelt Road. It is bounded on the east by the Coos Bay estuary. The area consists of the Oregon Institute for Marine Biology campus, the Charleston Marine Life Center, the Charleston Marina complex, US Coast Guard facilities, and several other small businesses and restaurants. While much of this community is within the XXL tsunami inundation zone, high ground is immediately nearby as described below.

3.3.2 Existing Evacuation Facilities Analysis

Tsunami Wave Arrival Time

The first wave reaches the northern part of Charleston in 16 to 18 minutes and reaches the Oregon Institute for Marine Biology campus by about 20 minutes. The extent of inundation of the first tsunami wave occurs by 24 to 26 minutes.

Existing Evacuations Routes and Speeds

Coos Head Loop is the main evacuation route for the northern part of the community and Cape Arago Highway is the main route for the southern part of the community (Kingfisher Road is the approximate split between evacuation communities). Coos Head Loop is a steep road; however, landslide risk appears to be low in this area. Evacuation speeds for this community range between a slow walk (0-1.4 mph) and fast walk (2.7-4.1 mph). See Appendix C for pedestrian evacuation speeds and evacuation communities.

Critical Facilities

Charleston Fire District has a fire station in the inundation zone (although it only houses equipment, no personnel). The Oregon Institute for Marine Biology campus, the Charleston Marina complex, and the Coast Guard Station are also in the inundation zone. The remaining structures are generally small businesses and light industrial facilities (including a boat fueling facility). The bridge over South Slough has not been earthquake retrofitted and will likely fail during an earthquake. The inability to use the bridge as an evacuation route does not impact evacuation speeds for the community in Charleston, but will impact community connectivity post-event.

Conclusions

While much of this community is within the XXL tsunami inundation zone, no evacuation routes identified through the BTW analysis prevent evacuation clearance, assuming a slow or fast walking speed. However, there is a high percentage of tourists and visitors in this area during certain times of the year, who may not be familiar with the tsunami hazard and evacuation routes. Also, routes are not currently well marked or lit for escape during the night or in poor weather conditions. Evacuation improvements targeted to tourist groups are recommended. Current signage for tsunami evacuation in Charleston is sparse. There are two designated Assembly Areas at Seven Devils Rd and Cape Arago Highway. Adding additional assembly areas (such as at the former Charleston school site) and evacuation signage may be warranted.

3.2.3 Evacuation Improvements Project Identification

WAYFINDING & EDUCATION

Project Name	**Priority**	**Potential Project Partners**	**Potential Funding Sources**	**Project Beneficiaries**
Directional Evacuation Route Signs	High	Oregon Department Of Transportation, County Roads Department, Public Works	NTHMP (OEM/DOGAMI), FEMA HMA	Residents and Visitors
Entering/Leaving Signs	High	Oregon Department Of Transportation, County Roads Department, Public Works	NTHMP (OEM/DOGAMI), FEMA HMA	Residents and Visitors
Visitor Education	Medium	School Districts, Private Landowners, Coquille Indian Tribe, Confederated Tribes Of Coos, Lower Umpqua, And Siuslaw	County (in-kind)	Residents
Community Outreach 5K	Medium	School districts, County Emergency Management	School Districts, County Emergency Management (In-Kind), OEM	Residents

Problem Statement: Limited existing signage may present difficulty to residents and visitors in evacuating from the inundation zone.

Project Descriptions:

1. **Directional evacuation highway signs off Cape Arago Highway and Boat Basin Road, towards high ground:** There are two major evacuation routes in Charleston: 1) Cape Arago Highway towards Seven Devils Road, and 2) Coos Head Loop. Tsunami evacuation signs with a directional arrow should be placed along Boat Basin Road and Cape Arago Highway, pointing in the direction of these two main evacuation routes. Increased signage in this area will help to reinforce the evacuation flow to residents, visitors, and businesses on a daily basis, as well as act as a wayfinding aid during tsunami evacuation. Evacuation communities (Appendix C) show the flow of people on existing roads to high ground (safety destinations). This concept should be followed when installing new road signs.
2. **Entering/leaving tsunami zone signs at high ground intersections along major evacuation routes:** Signs indicating the extent of the XXL tsunami inundation zone should be placed along the two major evacuation routes in Charleston. See Figure 17 for locations of the intersection of tsunami zones and high ground (green dots). Entering signs should be placed on the side of the road where travel is moving into the tsunami zone. Leaving signs should be placed on the side of the road where travel is moving out of the tsunami zone. These signs help

both to educate people of these zones on a daily basis and to let them know when they've reached safety during an evacuation event. Blue lines could be used in addition to or instead of signs, but must be easily visible and include public outreach and education about what they mean. OEM has more information and guidance about tsunami blue lines.

3. **Visitor Education:** Provide educational and evacuation information at the Charleston Marine Life Center and Charleston Welcome Center. This could include evacuation brochures and route maps, background information on the CSZ earthquake and tsunami hazard, and tips for becoming prepared (as a resident or as a visitor). Some of this information could be developed as an interpretive sign or informational kiosk, as well as to be handed out to visitors as brochures.
4. **Community Outreach Event – "Race the Wave 5k":** Similar to what has been done in Cannon Beach, the community could host a run/walk event that has participants race a tsunami evacuation route as a fun awareness event. An emergency preparedness fair could be incorporated at the event finish to answer questions and give tips on personal preparedness to participants in a fun learning environment. *See maps in Appendix C for potential race routes.*

CONSTRUCTION

Project Name	Priority	Potential Project Partners	Potential Funding Sources	Project Beneficiaries
Bridge Retrofit Over South Slough	Low	ODOT, County Public Works, Confederated Tribes Of The Coos, Lower Umpqua, And Siuslaw	FEMA HMA, Municipal Financing, ODOT, Federal Highway	Residents, Employees, Visitors
Pedestrian Bridge Construction	Low	ODOT, County Public Works, Confederated Tribes Of The Coos, Lower Umpqua, And Siuslaw	FEMA HMA, Municipal Financing, ODOT, Federal Highway	Residents, Employees, Visitors
Trail Improvements for Coos Head	Medium	County Public Works, Confederated Tribes Of The Coos, Lower Umpqua, And Siuslaw, Oregon State Parks	ODOT, Recreational Trail Grants	Residents, Employees, Visitors

<u>Problem Statement:</u> The highway bridge over South Slough is not earthquake or tsunami retrofitted and will likely fail in a CSZ event. While this bridge is not necessary for pedestrian evacuation according to the Beat the Wave analysis, it does serve an important purpose to the community for connectivity post-event.

<u>Project Descriptions:</u>

1. **Bridge retrofit of Cape Arago Highway Bridge over South Slough:** If this bridge needs improvements in the future, it may be beneficial to incorporate earthquake and tsunami retrofits into the bridge at that time. For example, it would be good to include the estimated wave height of tsunami waves at that location in order to ensure the bridge is high enough to survive the tsunami and be functional after a CSZ event. This project would be a major undertaking.

2. **Pedestrian/recreational bridge across South Slough**: Retrofitting a vehicle bridge may be too costly, but constructing a new pedestrian or multi-use pathway bridge may be more feasible and provide additional community benefits. Such a pathway could be developed alongside the existing bridge and be used as a walking/cycling pathway on a day-to-day basis to relieve congestion and provide safety for bikers and pedestrians. It can be incorporated into the County's Transportation System Plan and ongoing traffic planning for the Coos Head area. Construction of this type of bridge should incorporate both earthquake and tsunami design principles to be able to withstand both events. Additionally, the bridge would need to accommodate maritime traffic entering and leaving the slough (e.g. a draw bridge).
3. **Trail improvements along Coos Head Loop**: There is an existing pedestrian trail off Coos Head Loop. This trail could be improved for tsunami evacuation purposes. This could include adding lighting, signage, trail hardening, and vegetation maintenance. This pathway would serve to provide additional evacuation access from the Charleston area to high ground. Additionally, it could provide added community benefits by providing a recreational hiking trail and scenic overlook on a daily basis.

3.4 Outer Coast (South of Coos Bay Estuary)

3.3.1 Community Overview

For this plan, the Outer Coast is defined as the area from the south jetty of the Coos Bay estuary to Shore Acres State Park and includes Bastendorff Beach and Sunset Bay State Park and Campground. Cape Arago State Park was also included in the BTW modeling for this area, but is outside of the tsunami inundation zone so was left out of this analysis for evacuation purposes. This area includes two state parks, one county park, a campground, a golf course, an RV resort, and a few residential areas.

3.3.2 Existing Evacuation Facilities Analysis

Tsunami Wave Arrival Time

The first wave reaches the beaches here around 16 minutes. This whole outer coast area gets completely inundated quickly – in 18 to 20 minutes. The extent of inundation (to areas southwest of Cape Arago Highway) occurs by 22 to 24 minutes.

Existing Evacuations Routes and Speeds

The evacuation routes for this area vary. There are no critical or essential facilities in the inundation zone here. Evacuation speeds for these predominantly beach areas range between a slow walk (0-1.4 mph; near developed areas) to a sprint (6.8-10 mph; out on beaches) and even to "unlikely to survive" categories (>10 mph; in isolated areas). See Appendix C for pedestrian evacuation speeds and evacuation communities.

Challenging areas to evacuate include the beach at the south jetty; Bastendorff beach; the beach between Yoakam Point and Gregory Point; and some areas near Sunset Bay and Sunset Bay campground.

Critical Facilities

There are no critical facilities in this area.

Conclusions

Areas out on the beach and away from existing development or facilities will be hard to evacuate on foot and may prevent evacuation clearance. New or improved pedestrian evacuation trails may help some of these more remote areas evacuate more easily. Additionally, evacuation signs and route markers would help direct pedestrians in the right direction, as evacuation routes may not be intuitive and this area experiences high volumes of visitors. Current signage for tsunami evacuation along the Outer Coast is inadequate. There are no designated assembly areas. Adding assembly areas and signs is suggested.

3.2.3 Evacuation Improvements Project Identification

WAYFINDING & EDUCATION

Project Name	Priority	Potential Project Partners	Potential Funding Sources	Project Beneficiaries

Directional Evacuation Route Signs	High	County Emergency Management, Oregon Department Of Transportation, County Roads Department, Public Works, Oregon State Parks	NTHMP (OEM/DOGAMI), FEMA HMA, Recreational Funds	Tourists/Visitors
Entering/Leaving Signs	High	County Emergency Management, Oregon Department Of Transportation, County Roads Department, Public Works, Oregon State Parks	NTHMP (OEM/DOGAMI), FEMA HMA, Recreational Funds	Tourists/Visitors
Visitor Education	Medium	Chamber of Commerce, Travel Oregon (Oregon Coast Visitor's Association), Oregon Sea Grant, Oregon State Parks, Coos County Parks	Oregon State Parks, Coos County Parks, FEMA HMA	Tourists/Visitors

Problem Statement: Limited existing signage may present difficulty to residents and visitors in evacuating from the inundation zone.

Project Descriptions:

1. **Directional evacuation highway signs off Cape Arago Highway, towards high ground:** Tsunami evacuation signs with a directional arrow should be placed along Cape Arago Highway at intersections with major evacuation routes that continue to high ground. For areas south of the Coos Bay estuary south jetty, these intersections include: Ocean View Road, Coos Head Loop, Bastendorff Beach Road, Cottell Lane, and an unnamed road to a wastewater treatment facility off Cape Arago Highway. Signage will help to reinforce what roads go to high ground to residents, tourists, and visitors on a daily basis, as well as act as a wayfinding aid during tsunami evacuation. (NOTE: "You are Here" tsunami evacuation signs already exist at the main beach access points at Bastendorff Beach.)
2. **Entering/leaving tsunami zone signs at high ground intersections along major evacuation routes:** Signs indicating the extent of the XXL tsunami inundation zone should be placed along the major evacuation routes off Cape Arago Highway as noted above. See maps in Appendix C for locations of the intersection of tsunami zones and high ground (green dots). Entering signs should be placed on the side of the road where travel is moving into the tsunami zone. Leaving signs should be placed on the side of the road where travel is moving out of the tsunami zone. These signs help both to educate people of these zones on a daily basis and to let them know when they've reached safety during an evacuation event. Blue lines could be used in addition to or instead of signs, but must be easily visible and include public outreach and education about what they mean. OEM has more information about tsunami blue lines.
3. **Visitor Education:** Provide educational and evacuation information at every state and county park in this area: Bastendorff Beach, Sunset Bay State Park, Shore Acres State Park, and Cape

Arago State Park. This could include evacuation brochures and route maps, background information on the CSZ earthquake and tsunami hazard, and tips for becoming prepared (as a resident or as a visitor). Some of this information could be developed as an interpretive sign or informational kiosk, as well as to be handed out to visitors as brochures. Interpretive walks along tsunami evacuation routes could be integrated in ongoing park educational activities.

CONSTRUCTION

Project Name	Priority	Potential Project Partners	Potential Funding Sources	Project Beneficiaries
Pedestrian Trail Improvements	Medium	County Public Works, Confederated Tribes Of The Coos, Lower Umpqua, And Siuslaw, Oregon State Parks	ODOT, Recreational Trail Grants	Residents, Employees, Visitors

Problem Statement: Evacuation from the beach is very difficult in this area.
Project Descriptions:

1. **Pedestrian trail improvements:** Evacuation on the beach areas between Bastendorff Beach and Cape Arago Lighthouse is difficult. Adding additional pedestrian evacuation trails off Cape Arago Highway in key places could significantly help decrease pedestrian walking speeds for these areas (Appendix C.8). While locations have been suggested, an investigation into land ownership and easements would have to be conducted, as well as an engineering geologic review of sites to find the best locations to put new pedestrian trails. Additionally, the existing trail located behind Sunset Bay Campground could be more clearly signed and hardened as an official tsunami evacuation route.

4. IMPLEMENTATION RESOURCES AND EVACUATION PROJECTS

4.1 Design and Construction Standards

Below is a list of resources related to Evacuation Facility Design and Construction Standards, applicable for a variety of projects suggested in the sections above:

- Bicycle and Pedestrian Design:
    - Oregon Department of Transportation. 2011. Oregon Bicycle and Pedestrian Design Guide, 3rd Edition. Oregon Highway Design Manual Appendix L.
- Design requirements and ideas for wayfinding signage:
    - PUARL (Portland Urban Architecture Research Lab). 2014. "Up and Out" Oregon Tsunami Wayfinding Research Project: Final Project Report and Guidance Document.
    - PUARL (Portland Urban Architecture Research Lab). 2015. "Up and Out 2" Oregon Tsunami Wayfinding Research Project: A Study in Seaside and Warrenton.
    - DOGAMI. 2003. OFR-03-06 Tsunami Sign Placement Guidelines.
    - OEM & DOGAMI. Version 05-13-2019. Oregon Tsunami Evacuation Wayfinding Guidance.
- Vertical evacuation structures:
    - Applied Technology Council. April 2012. FEMA Guidelines for Design of Structures for Vertical Evacuation from Tsunamis, Second Edition. Federal Emergency Management Agency, National Oceanic and Atmospheric Administration.
    - Chock, G. 2016. Design for Tsunami Loads and Effects in the ASCE 7-16 Standard. Journal of Structural Engineering: 142 (11). (International Building Code standards)
    - Applied Technology Council. June 2009. Vertical Evacuation from Tsunamis: A Guide for Community Officials. Federal Emergency Management Agency, National Oceanic and Atmospheric Administration.

4.2 Tsunami Evacuation Wayfinding Signage

Any proposed tsunami evacuation wayfinding signage proposed for the unincorporated coastal areas of Coos County should conform to the publication: OEM & DOGAMI. Version 05-13-2019. *Oregon Tsunami Evacuation Wayfinding Guidance.*

A tsunami evacuation wayfinding system informs people what to do and when to do it. The system is designed to make the process clear and efficient before, during, and after a tsunami. Prime elements to include in wayfinding improvements:

- Awareness kiosks
- Tsunami hazard zone signs
- Tsunami evacuation route signs
- Zone thresholds (entering/leaving)
- Assembly areas

For different populations, such as people with disabilities and the many unprepared tourists during the summer season, special escape sequences and patterns provide innovative wayfinding solutions for tsunami evacuation. These populations include elderly, disabled, children, visitors in hotels, RV park visitors, etc. The wayfinding system should include techniques to find safe ground in a limited period of time, potentially at night or in difficult weather conditions.

4.2.1 Sign Type Selection

Signage can be two-dimensional, but also can include technological/sensory signals (e.g. sound, light) – an important concept when considering access and functional needs populations. When selecting a sign as a part of a signage system, the following elements should be considered:

- Basic function of sign
- Signage technology applied
- Position in space, method of fixing
- Size in relation to reading distance
- Illumination
- Requirements for impaired users
- Level of vandal resistance

4.3 Financing Strategies

Cost estimates have not been developed for the tsunami evacuation improvement projects identified in this plan. Resources to help develop facility improvement cost estimates can be found at the following:

- American Association of Cost Engineers – requires membership or payment (https://web.aacei.org/resources)
- Whole Building Design Guide – Cost Estimating (http://www.wbdg.org/design/dd_costest.php)
- American Association of State Highway and Transportation Officials (AASHTO) – Practical Guide to Cost Estimating, requires membership or payment (https://bookstore.transportation.org/collection_detail.aspx?ID=122)
- FEMA Cost Estimating Format (https://www.fema.gov/public-assistance-cost-estimating-format-standard-operating-procedure)
- See **Appendix C** for municipal financing mechanisms, state and federal funding programs, and other grant and financing mechanisms to consider.

4.3.1 Questions to Ask

In identifying projects to move forward with, it's important to bear in mind the following questions:

- Do citizens consider this to be an important public issue that requires a public remedy?
- Who directly benefits from the design, construction, and operation of these assets?
- Who indirectly benefits from the presence of these assets when not needed for an emergency?
- Do citizens have a preference among the various options available to finance the infrastructure investment?
- Is the scale of the need within the means of the community to finance or is outside assistance necessary?
- Should different strategies be used to elicit funding from seasonal vs. year-round residents?

- Is needed infrastructure within the jurisdiction/control of the community, or is there a need to engage other units or levels of government?

The following tools are mostly likely to succeed for enhancing a community's evacuation route system[8]:

    - Using existing right-of-ways,
    - Negotiating/purchasing easements, and
    - Purchasing new right-of-ways.

In addition, the construction of evacuation facilities should consider the following:

- Determining the most effective location,
- Determining co-benefits to access additional funding streams, and
- Determining design and construction standards applicable to specific project.

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[8] DLCD. 2018. Tsunami Land Use Guide, Chapter 5, Tip. URL: https://www.oregon.gov/LCD/OCMP/docs/Publications/TsunamiLandUseGuide_FINAL_062718.pdf

5. EDUCATION, OUTREACH, AND TRAINING

In tsunami areas, it is crucial to support an ongoing sustained tsunami public education program in order to ensure effective evacuation and save lives. This section presents guidance for creating pre-disaster education and outreach activities to educate the public about appropriate actions to take when natural signs (i.e. ground shaking) indicate a tsunami is imminent or when a tsunami warning message has been issued.

Residents, homeowners, business owners, and tourists alike benefit from educational activities that increase their awareness of local hazards. These educational activities can and should be combined with other, existing hazard education programs, such as earthquake preparedness, when possible.

5.1 News and Social Media

Traditional local media outlets (TV, radio, newspaper, etc.), public social media accounts, and other local websites (e.g. the Chamber of Commerce) should be utilized as appropriate to announce community training events and provide public service announcements (PSAs) regarding tsunami evacuation.

5.1.1 News Organizations

Developing a working relationship with local newspapers and radio is an effective mode of communicating with the public.

Recommended Action

- Work with local newspapers and radio stations to announce tsunami awareness events and provide community education information and resources. Local service providers include:
    - All local TV stations (KEZI, KCBY, KDCQ and any other stations available)
    - All Newspapers (The World newspaper, Bandon Western World newspaper, Coquille Valley Sentinel Newspaper, Myrtle Point Herald Newspaper and any other Newspaper that is available in the area)
    - All local radio Stations (KOOZ, K-Light-K-Dock,KYTT-FM, KSHR, BICOASTAL MEDIA and any other stations available in area).

Resources

- Tsunami Emergency Guidebook for Oregon Mass Media, Oregon Emergency Management, September 2007:
  http://www.oregongeology.org/tsuclearinghouse/resources/pdfs/OregonTsunamiMediaBinder_final_6_20_07.pdf

5.1.2 Social Media

Social media's role in emergency communication has grown over the past several years, not only as a major channel for broadcasting emergency information but also as a means of engaging and conversing with the public during all emergency mission phases (protection, preparedness, mitigate, response, and recovery).

Recommended Action

- Consistently incorporate tsunami education information into social media accounts, including the graphics used on tsunami evacuation signs. Social media accounts should be monitored to manage misinformation and rumor control.
- Develop working relationships with local bloggers and businesses to utilize their social media presence to retweet or copy posts so they reach a larger audience.

Resources

- FEMA Social Media and Emergency Preparedness Press Release - https://www.fema.gov/news-release/2018/04/16/social-media-and-emergency-preparedness
- FEMA Social Media in Emergency Management Training - https://training.fema.gov/is/courseoverview.aspx?code=IS-42
- The Department of Homeland Security's Innovative Uses of Social Media in Emergency Management: https://www.dhs.gov/sites/default/files/publications/Social-Media-EM_0913-508_0.pdf

5.1.3 Websites

Websites continue to play a large role in providing information and outreach activities to residents and tourists.

Recommended Action

- Include tsunami awareness information on County websites in a prominent location, and use the websites to announce tsunami-related community activities. Consider linking to relevant webpages from DOGAMI, DLCD, NOAA, etc., rather than recreating the information.
- Develop working relationships with local businesses and organizations to include a link back to the County's tsunami information to increase the website's reach.

5.2 Community Activities

Community activities are a vital part of public education and outreach. Below are some examples of community activities held by other coastal communities.

Recommended Action

- Hold at least one community-wide outreach or education activity annually.
- Provide educational and evacuation information at every state and county park.
- Develop community outreach materials such as the following to be distributed at community events:
    - Brochures containing zone and route information
    - Refrigerator magnets with preparedness information
    - Maps to be printed in phonebooks

5.2.1 Door-to-Door Education and Community-wide Evacuation Drills

The National Tsunami Hazard Mitigation Program studied which educational strategies work best for tsunami awareness in Seaside, Oregon (Connor 2005). Door-to-door outreach and evacuation drills were the most effective techniques according to polls for this study.

Recommended Action

- Develop Volunteer Educators who can go door-to-door to discuss tsunami awareness and safety with residents. These volunteers would be trained by the County and given brochures to hand out to residents.
- Conduct a community-wide tsunami evacuation drill.

Resources

- The Oregon Office for Emergency Management's Tsunami Evacuation Drill Guidebook: https://www.oregon.gov/oem/Documents/Tsunami_Evacuation_Drill_Guidebook.pdf

5.2.2 Run/Walk Event

Events like the Cannon Beach Race the Wave provide an opportunity to build awareness of tsunami routes. Participants in the annual 5K and 10K Race the Wave fun run/walk/roll start on the beach, follow a scenic tsunami evacuation route through the County, and reach the finish-line out of the tsunami inundation zone. A preparedness fair is held near the finish-line for all participants and includes food, games, and giveaways.

Recommended Action

- Host a run/walk event that has participants race a tsunami evacuation route as a fun awareness event.
- Hold a preparedness fair at the end of the race. See Section 6.2.3 for additional information on Preparedness Fairs.

Resources

- An example press release for the Cannon Beach event: https://www.fema.gov/news-release/2015/09/08/know-your-tsunami-evacuation-routes-race-wave-cannon-beach-or-sept-13
- Up and Out Oregon Tsunami Wayfinding Research Project Final Project Report & Guidance Document: https://www.oregon.gov/oem/Documents/Up_And_Out_Phase1.pdf

5.2.3 Preparedness Fairs/Booth

An emergency preparedness fair or a tsunami preparedness-focused booth at a community event can help educate community members and visitors about tsunami evacuation. A preparedness fair can feature many booths and activities. It can be held separately or combined with another event, such as a 5K run/walk.

Recommended Action

- Set up a booth about tsunami preparedness at local community events such as:

    - Coos County Fair
    - Local Festivals (Such as: Gay 90's, Harvest Festivals, Gorse Blossom Festival, Cranberry Festival, Blackberry Festival, Seafood Festival and Fun Festival)
    - Home & Gardening Shows

Resources

- The American Red Cross and California Emergency Management Agency's Disaster Preparedness Event Toolkit: https://www.redcross.org/content/dam/redcross/atg/Chapters/Division_2_-_Media/Bay_Area/Bay_Area_-_PDFs/Preparedness_Event_Toolkit.pdf

5.2.4 Tsunami Quests

A Tsunami Quest is an educational activity for families and children to learn about tsunamis and tsunami evacuation routes in a clue-directed hunt format. The Oregon Sea Grant is already using Tsunami Quests in Clatsop, Lincoln, and Coos Counties to help residents and visitors prepare for a major earthquake and tsunami. The "hunt" culminates in discovery of a box that holds a guest book so participants can record their achievement at completing the Quest. The goal is to encourage people to explore these routes for fun, so that they will be familiar with them in the event of a tsunami.

Recommended Action

- Invite the Oregon Sea Grants Quest Coordinator to hold a workshop.
- Develop a map and a series of educational clues that, when followed, lead the walkers to higher ground.
- Engage elementary or middle school students to develop the clues as a class exercise.
- Consider incorporating geocaches with preparedness information.

Resources

- The 2017-18 Oregon Coast Quests Book: https://seagrant.oregonstate.edu/sgpubs/2017-18-oregon-coast-quests-book
- A video that describes the quest concept and how quests are used to teach coastal visitors and locals what to do in the event of a tsunami: https://youtu.be/TQvgSMiby7k.

5.3 Schools and Childcare Facilities

Empowering children with knowledge about tsunami hazards and evacuation routes can be an excellent motivator for families to become more aware and prepared. Tsunami education efforts can be incorporated into existing emergency exercises and trainings.

5.3.1 Child-Appropriate Trainings

Many materials are available online for teachers to use in educating children about tsunamis. The Tommy Tsunami Coloring Book from the National Tsunami Warning Center is one example.

Recommended Action

- Work with teachers to develop tsunami curriculum that is age appropriate.

Resources

- The Washington Military Department, Emergency Management Division's booklet "How the Smart Family Survived a Tsunami" for elementary children (K-6): https://www.mil.wa.gov/uploads/pdf/Publications/HowtheSmartFamilySurvivedaTsunami.pdf
- The Tommy Tsunami Coloring Book from the National Tsunami Warning Center: https://www.tsunami.noaa.gov/pdfs/tommy_tsunami_coloring_book.pdf
- San Diego County used an animated short film to educate kids about tsunamis: https://www.youtube.com/watch?v=UzR0Rt3i4kc
- NOAA's Tsunami Education website: https://www.tsunami.noaa.gov/education.html#kids

5.3.2 Parent/Guardian Trainings and Workshops

Children are not the only audience that can be reached through school activities—parents and guardians attend many events at schools, providing ample opportunities to reach them with the tsunami preparedness message.

Recommended Action

- Encourage schools to incorporate tsunami information into their Back-to-School nights or other gatherings where parents/guardians are present.

5.3.3 Evacuation Drills

Evacuation drills are effective in training students and children on what to do in the event of a tsunami.

Recommended Action

- Encourage schools and childcare facilities to conduct evacuation drills, in conjunction with their earthquake drills, in the mapped tsunami evacuation zone.

Resources

- The Oregon Office for Emergency Management's Tsunami Evacuation Drill Guidebook: https://www.oregon.gov/oem/Documents/Tsunami_Evacuation_Drill_Guidebook.pdf

5.4 Businesses

5.4.1 Business Workshops

Businesses in the hazard zones may be owned, staffed, or frequented by customers who, like visitors, live elsewhere and may not have been reached by the local outreach activities. Therefore, employers and their employees need tsunami evacuation education and training to ensure everyone knows when and how to evacuate in the event of a local earthquake and tsunami.

Recommended Action

- Work with the Chamber of Commerce to host regular training sessions for business owners, sharing information with them, so they, in turn, could return to their businesses and host in-house training.
- Develop Volunteer Educators to conduct in-house trainings at local businesses for staff.

Resources

- How to Prepare Your Business for the Next Tsunami (Hawaii specific, but useful information): http://tsunami.org/1about/pdfs/how_to_prepare_your_business_for_the_next_tsunami.pdf

5.4.2 Tsunami Quests for Businesses

Tsunami Quest activities are not just for families and children, they can be used by businesses to educate their employees about tsunami preparedness.

Recommended Action

- Encourage local businesses to utilize the Tsunami Quest activity (described above) as a "wellness event" for their employees. The activity may need to be adapted to be more appropriate for businesses.

Resources

- 2017-18 Oregon Coast Quests Book: https://seagrant.oregonstate.edu/sgpubs/2017-18-oregon-coast-quests-book
- A video that describes the quest concept and how quests are used to teach coastal visitors and locals what to do in the event of a tsunami: https://youtu.be/TQvgSMiby7k.
- Effective Emergency Preparedness Planning: Addressing the Needs of Employees with Disabilities: https://www.dol.gov/odep/pubs/fact/effective.htm

5.5 Visitors/Recreationists

Visitors and recreationists may spend a limited amount of time in tsunami prone communities, but they are still at risk. There are many ways to provide these temporary residents with some education about the possibility of a tsunami and what to do if one happens.

5.5.1 Education Materials

The brochures and other hand-outs developed for community activities can be used to educate visitors about what to do and why.

Recommended Action

- Place materials at the following locations:
    - Visitor centers
    - Information kiosks
    - Trail markers
    - Signs on beaches (particularly areas that are hard to evacuate from or in which the direction you need to evacuate to is not obvious)

Resources

- The Disaster Response Guidebook for Hotels and Motels on Washington's Coast, published by the Washington Military Department Emergency Management Division, includes information about a variety of disasters, including tsunamis: https://www.mil.wa.gov/uploads/pdf/emergency-management/haz_hotelmotel_guidebook.pdf
- FEMA Website tsunami page with information about recognizing the signs: https://www.ready.gov/tsunamis

If printing materials on this scale is prohibitive, consider developing a catchy phrase and website link that individuals can go to in order to download the files.

5.5.2 Hotels, Motels, and Bed and Breakfasts

Visitors staying overnight for the weekend or on an extended vacation may be unfamiliar with tsunamis. The hand-outs used for preparedness fairs and other events hold valuable information about tsunami evacuation that can be shared with temporary residents.

Recommended Action

- Provide tsunami evacuation literature to local hospitality businesses. Request that they be permanently displayed in the lobby or hotel rooms, informing tourists of evacuation routes and general earthquake/tsunami awareness.

Resources

- A glossy brochure is available in many languages from UNESCO, at: http://itic.ioc-unesco.org/index.php?option=com_content&view=article&id=1169&Itemid=2017
- Disaster Response Guidebook for Hotels and Motels on Washington's Coast: https://www.mil.wa.gov/uploads/pdf/emergency-management/haz_hotelmotel_guidebook.pdf

5.6 Access and Functional Needs

You will need unique means of warning your community's non-English speaking and deaf populations, and people with health or mobility issues may need to be transported out of the hazard area in a far-field event.

5.6.1 Mobility Challenges

Within mobility disabilities, there are several subcategories that should be taken into account when planning for tsunami evacuations including: wheelchair users, ambulatory mobility disabilities, respiratory issues, and young children.

Recommended Action

- Encourage residents to get to know their neighbors and whether they will need assistance evacuating.
- Encourage hospitals, doctors, and clinics to provide tsunami evacuation materials to their patients.
- Incorporate evacuation planning into CERT training.

Resources

- To Define, Locate, and Reach Special, Vulnerable, and At-risk Populations in an Emergency: This CDC workbook is intended to provide public health and emergency preparedness planners with better ways to communicate health and emergency information to at-risk individuals with access and functional needs for all-hazards events through step-by-step instructions, resources guides and templates. https://emergency.cdc.gov/workbook/pdf/ph_workbookfinal.pdf
- This guidance will introduce and connect you to available resources and inclusive strategies for integrating the access and functional needs of at-risk individuals into emergency preparedness, response, and recovery planning at all jurisdictional levels. https://www.phe.gov/Preparedness/planning/abc/Pages/afn-guidance.aspx
- Preparing for Disaster for People with Disabilities and other Special Needs. https://www.fema.gov/media-library/assets/documents/897

5.6.2 Vision Impairment

Individuals who experience partial or total vision loss, including night vision challenges, rely on their sense of touch and hearing to perceive their environment. After a CSZ event, when physical obstructions such as debris, road or sidewalk damage, and liquefaction changes the lay of the land, those who experience vision impairment may find it difficult to navigate to a location outside the tsunami zone without assistance.

Recommended Action

- Incorporate lighting and reflective material on evacuation signs.
- Produce community information in larger text options.

Resources

- American Council for the Blind: http://www.acb.org/large-print-guidelines
- American Foundation for the Blind: http://www.afb.org/info/reading-and-writing/making-print-more-readable/35

5.6.3 Limited-English Proficiency

Key to an individual's ability to evacuate is access to information. Individuals with limited English proficiency may require additional guidance in their native language.

Recommended Action

- Incorporate communication education materials into community events and websites in their native language.

Resources

- The U.S. Department of Justice's 2016 Tips and Tools for Reaching Limited English Proficient Communities in Emergency Preparedness, Response, and Recovery: https://www.justice.gov/crt/file/885391/download
- https://www.hhs.gov/civil-rights/for-individuals/special-topics/emergency-preparedness/limited-english-proficiency/index.html

5.6.4 Deaf or Hard of Hearing

Individuals who are deaf or hard of hearing may not respond to verbal direction or hear warning sirens.

Recommended Action

- Work with organizations who provide services to those who are deaf or hard of hearing to recognize the signs of a possible Tsunami (ground shaking) and the necessity of evacuating immediately after the ground stop shaking.
- Encourage residents to get to know their neighbors and whether they will need non-verbal communication assistance.

Resources

- Emergency Preparedness for Individuals with Hearing Loss: A Family Guide, from the Vanderbilt Kennedy Center for Excellence in Developmental Disabilities: https://vkc.mc.vanderbilt.edu/assets/files/tipsheets/emprephearinglosstips.pdf
- The American Red Cross and NTID's Disaster Preparedness and the Deaf Community — For the Deaf, Hard of Hearing and Latened Deaf: http://www.cidrap.umn.edu/sites/default/files/public/php/332/332_brochure.pdf

5.7 Training and Exercises

Trainings and exercises are an excellent tool to help solidify provided educational materials into action.

Recommended Action

- Conduct yearly exercises with County staff to encourage awareness around their responsibilities during and after a Tsunami event.
- Conduct community exercises.
- Offer frequent trainings to local businesses and community organizations.

5.8 Measuring Success

Learning what the community's awareness is about tsunamis through community surveys is an informative way to help guide education efforts.

Recommended Action

- Distribute questionnaires bi-annually to measure the baseline of public awareness and preparedness and subsequent changes to determine program effectiveness and to revise efforts. Consider encouraging participation by utilizing a raffle prize related to emergency preparedness.

Resources

- A sample Community Tsunami Awareness Survey is available here: http://kejian1.cmatc.cn/vod/comet/emgmt/community/media/documents/survey.pdf.

5.9 Current Education & Outreach Efforts

Below is a short summary of current activities related to tsunami evacuation and preparedness happening in Coos County.

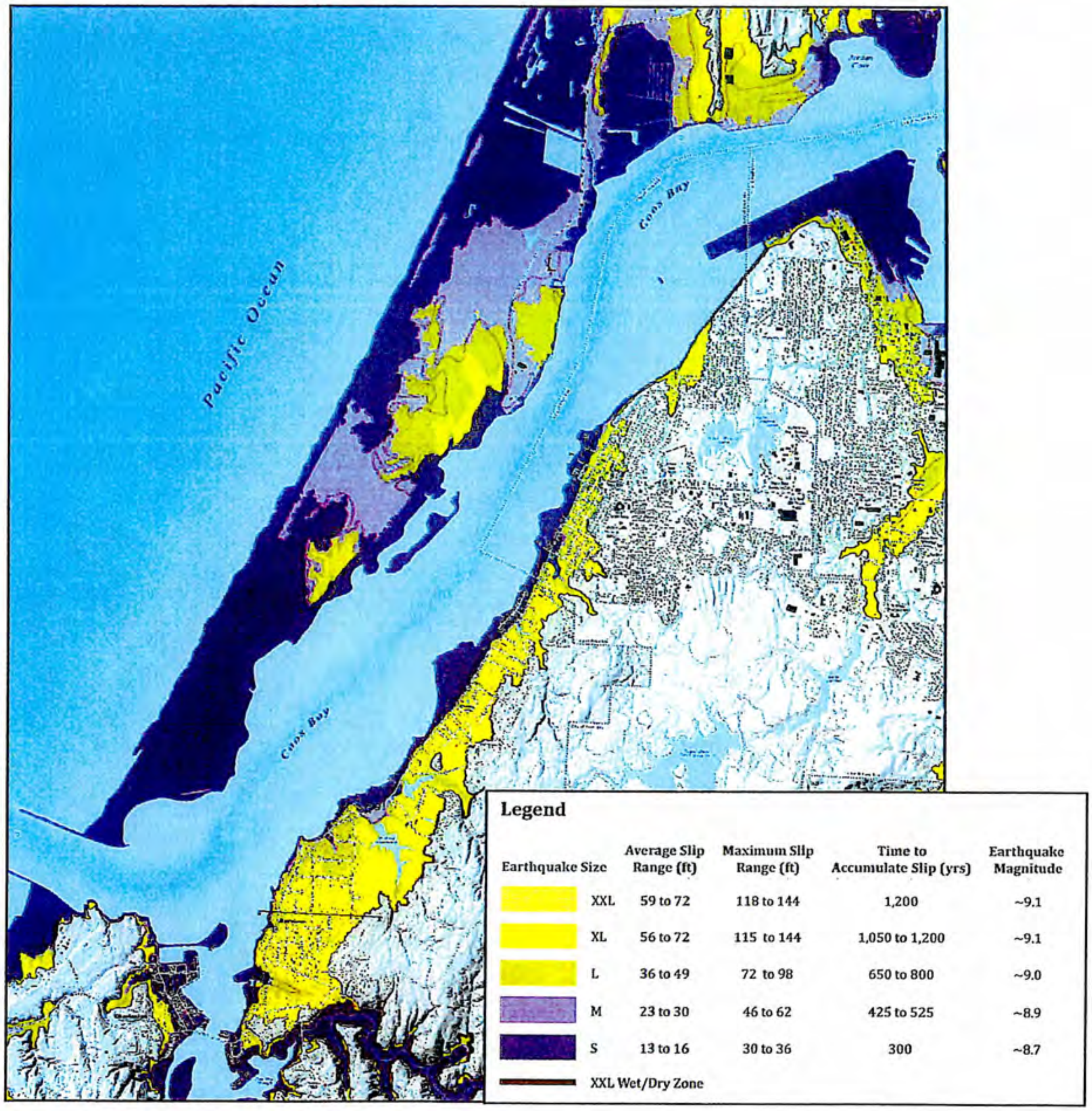
Port of Coos Bay – gives informational brochures to all boaters who come into the office. Does training with all their staff about tsunami hazards and evacuation routes. Has an emergency operations plan and updates/practices this regularly.

County Emergency Manager – gives outreach presentations about personal preparedness to any group that requests a presentation. This usually results in approximately 20 public events per year. The Emergency Manager is available to give presentations to schools groups, campgrounds, employees and businesses, and preparation fairs.

Appendix A: Tsunami Inundation Map

The Tsunami Inundation Map (TIM) series depicts the projected tsunami inundation zone from five different magnitude seismic and tsunami events: small, medium, large, extra-large, or extra extra-large (S, M, L, XL, XXL). These different modeled events are associated with differing levels of risk in terms of the relative likelihood of tsunami inundation (Appendix A). These maps are referenced in Chapter IV Balance of County Zones, Overlays & Special Consideration Section 4.11.260 Tsunami Hazard Overlay Zone.

Below is a portion of the Coos Bay estuary TIM. See www.oregongeology.org/tsuclearinghouse/pubs-inumaps.htm for the whole map and for more information.



Legend

Earthquake Size		Average Slip Range (ft)	Maximum Slip Range (ft)	Time to Accumulate Slip (yrs)	Earthquake Magnitude
🟨	XXL	59 to 72	118 to 144	1,200	~9.1
🟨	XL	56 to 72	115 to 144	1,050 to 1,200	~9.1
🟨	L	36 to 49	72 to 98	650 to 800	~9.0
🟪	M	23 to 30	46 to 62	425 to 525	~8.9
🟦	S	13 to 16	30 to 36	300	~8.7
▬	XXL Wet/Dry Zone				

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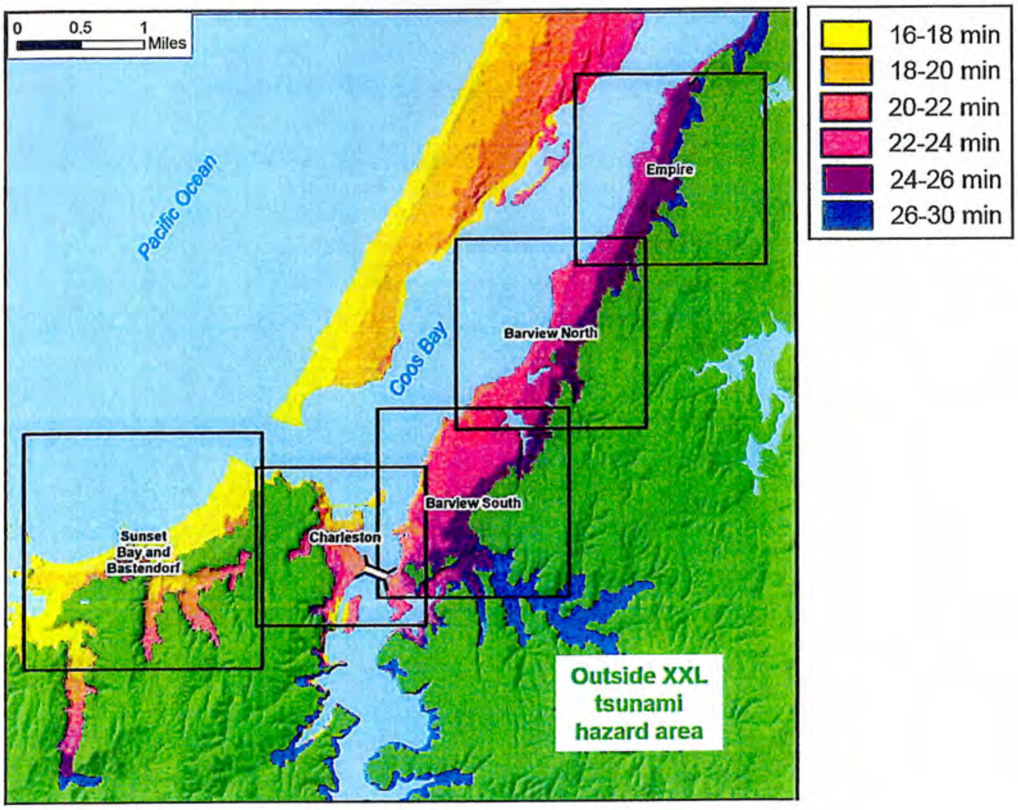
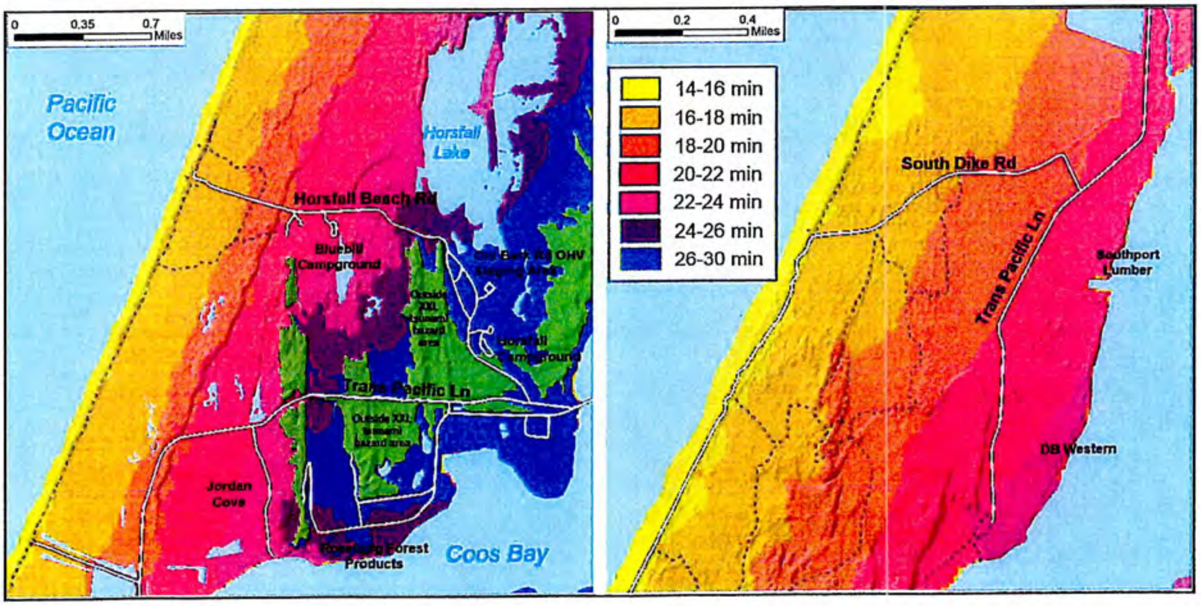
Appendix B: Wave Arrival Times

Map of XXL tsunami wave arrival times after a Cascadia subduction zone earthquake for the Coos Bay estuary.

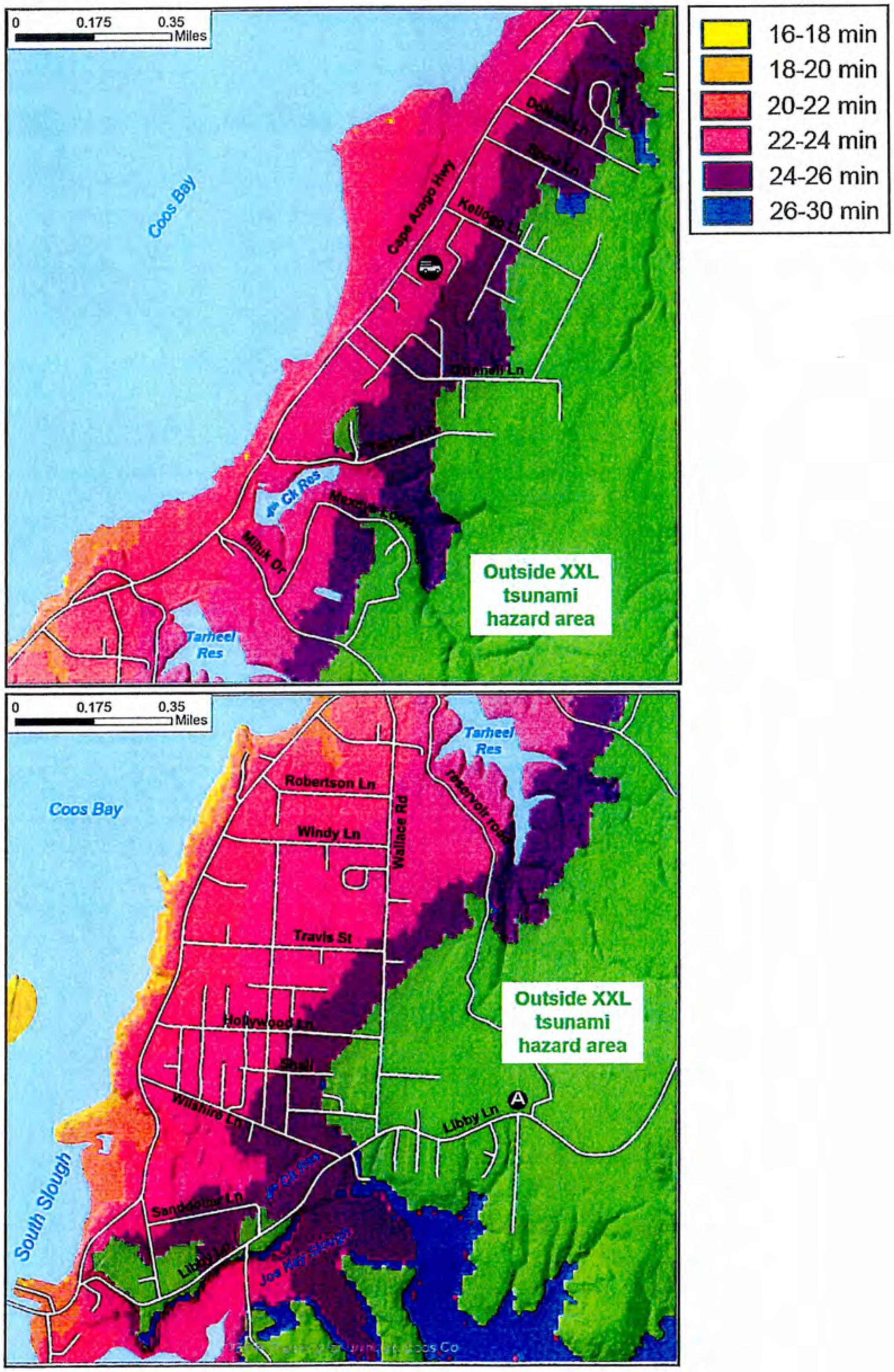


B.1 North Spit Wave Arrival Times:

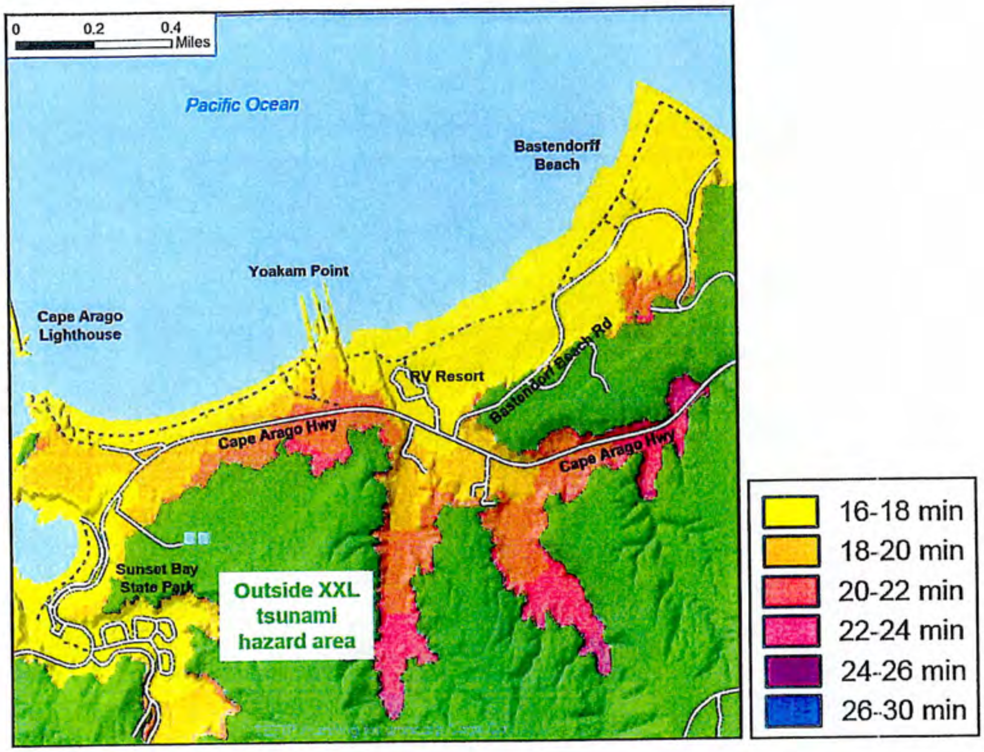


Open-File Report O-19-07, Tsunami evacuation analysis of communities surrounding the Coos Bay Estuary: Building community resilience on the Oregon coast, by Laura L. S. Gabel, Fletcher E. O'Brien, John M. Bauer, and Jonathan C. Allan; 60 p. report. www.oregongeology.org/pubs/ofr/p-O-19-07.htm. b

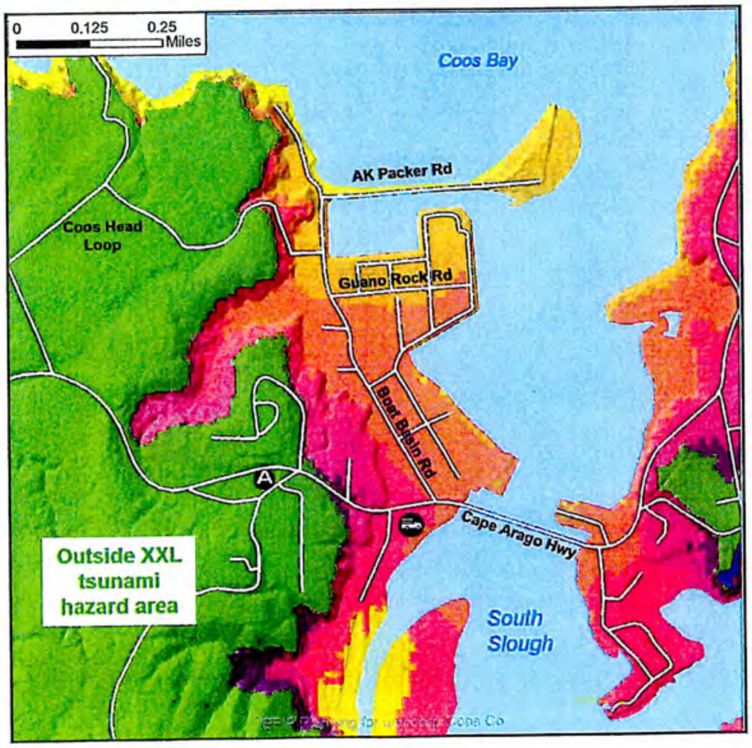
B.2 Barview Wave Arrival Times (north and south):



B.3 Charleston Wave Arrival Times:



B.4 Bastendorff Beach & Sunset Bay State Park Wave Arrival Times:



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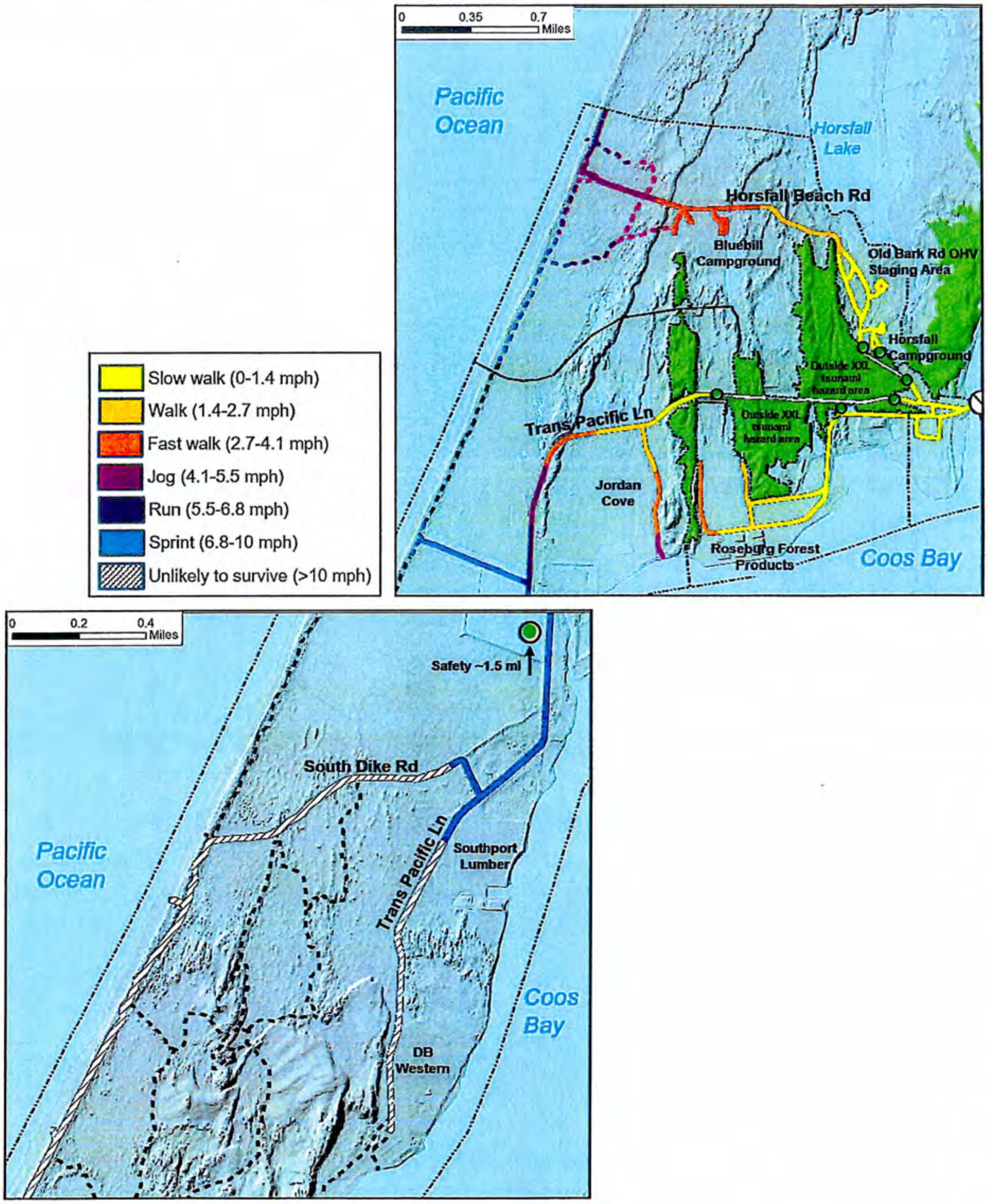
Appendix C: Beat the Wave Maps

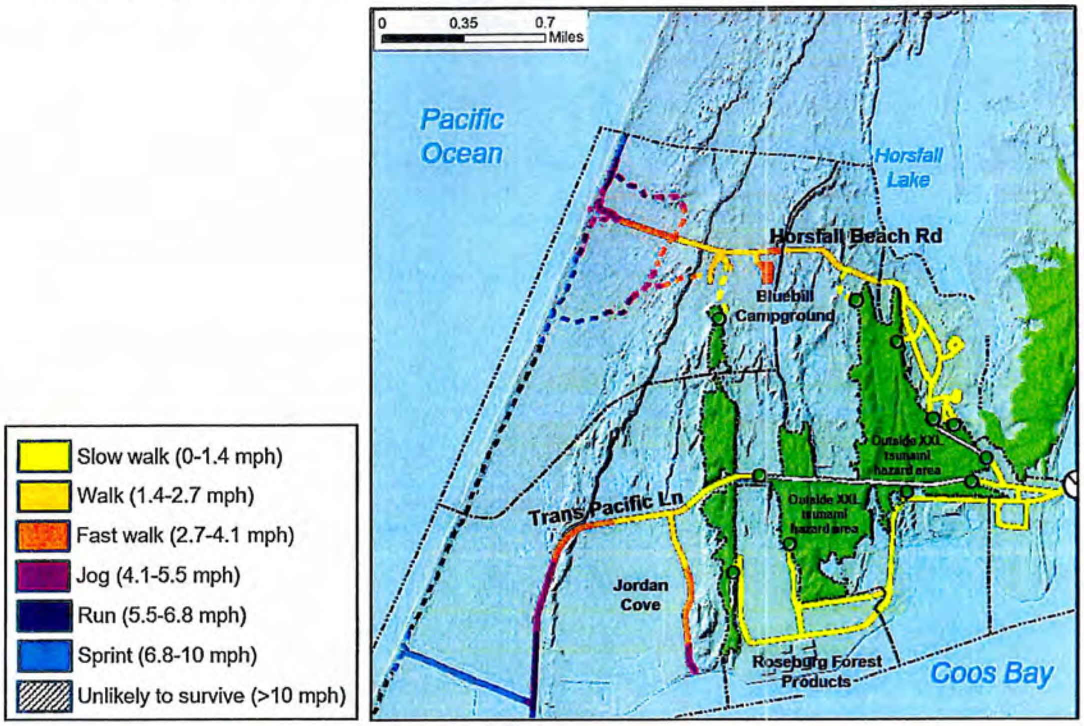
C.1 North Spit, north (top) and south (bottom) – existing conditions:

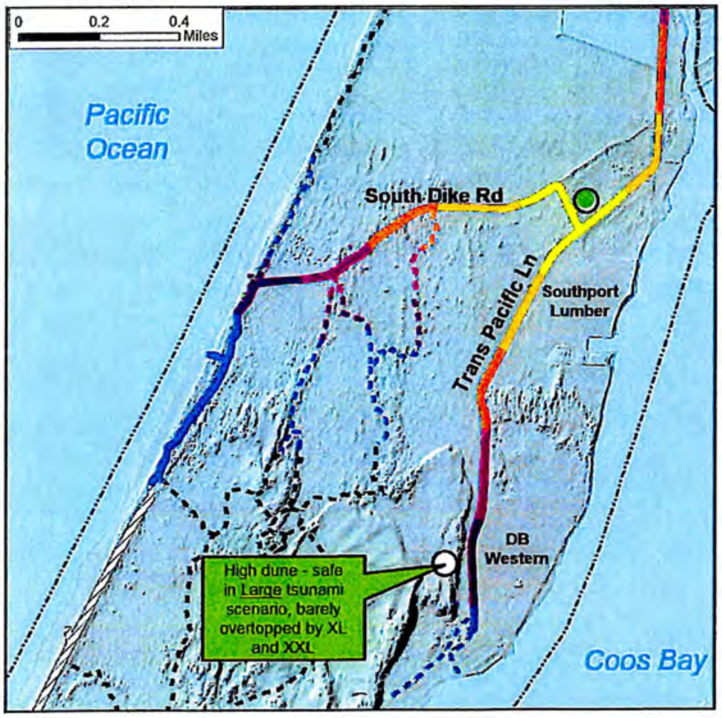
Beat the Wave pedestrian evacuation speeds are indicated by road color. Green dots indicate safety destinations and green shaded areas are outside of the XXL tsunami inundation zone.



C.2 North Spit, north (top) and south (bottom) with hypothetical mitigation options:

Beat the Wave pedestrian evacuation speeds are indicated by road color. On the north image, yellow dotted lines indicate hypothetical pedestrian trails off Horsfall Beach Rd. On the south image, the green dot near Southport Lumber indicates a hypothetical vertical evacuation structure. Green dots indicate safety destinations and green shaded areas are outside of the XXL tsunami inundation zone.





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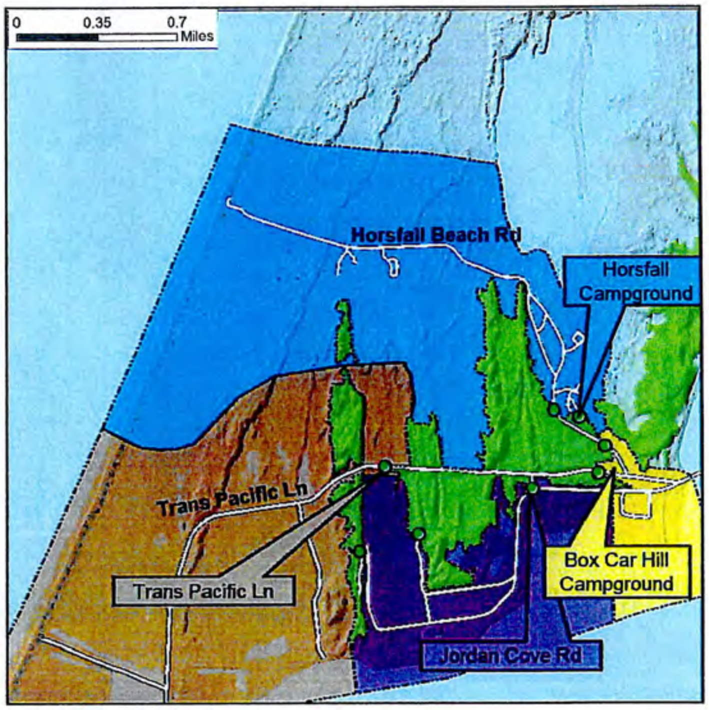
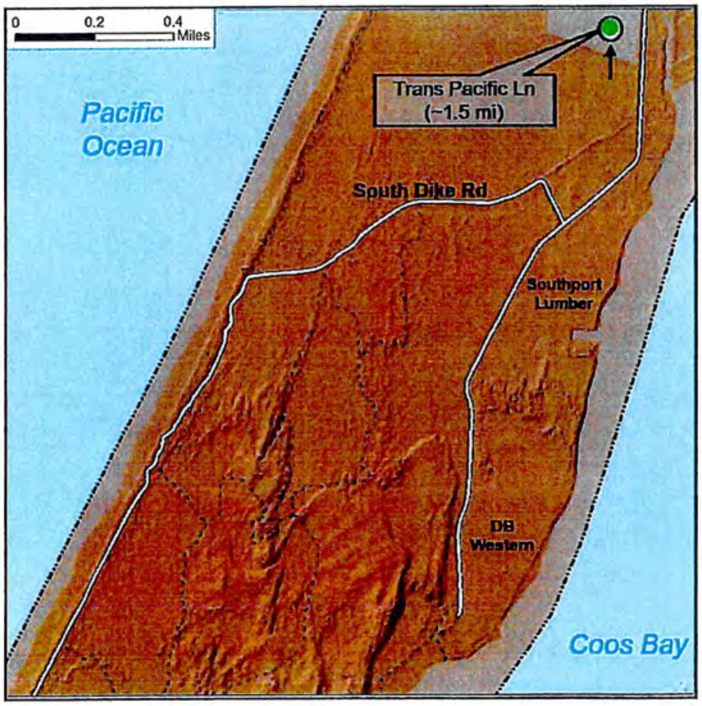
C.3 North Spit, north (top) and south (bottom) – evacuation communities:

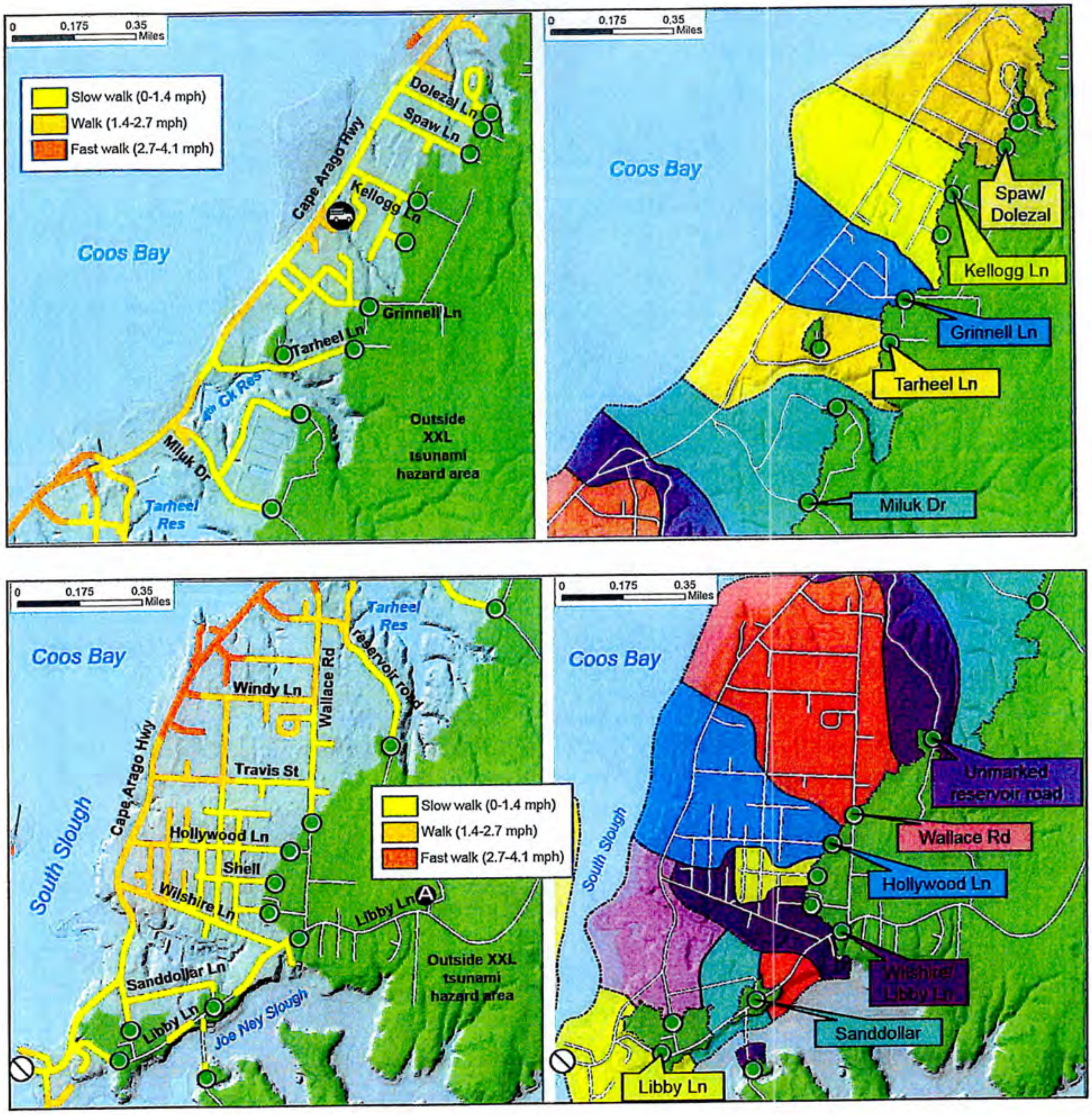
Colored areas bounded by black dotted lines indicate evacuation communities. People should evacuate to the green dot nearest them, which indicates high ground from the XXL tsunami event. On the southern part of the spit, the closest safety destination is on Trans Pacific Lane. Green shaded areas are outside of the XXL tsunami inundation zone.





C.4 Barview, north (top) and south (bottom) – pedestrian speeds & evacuation communities:

Beat the Wave pedestrian evacuation speeds are indicated by road color on the left. Evacuation communities (colored areas – on the right) define the area of evacuation and the associated nearest safety destination(s) indicated by the green dots. Green shaded areas are outside of the XXL tsunami inundation zone.



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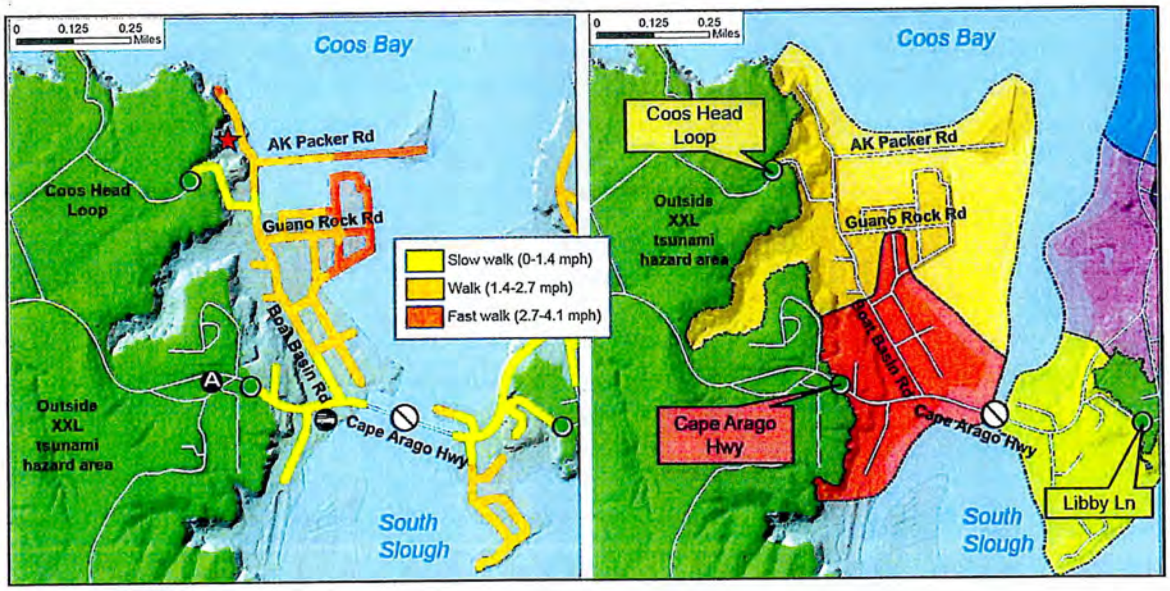
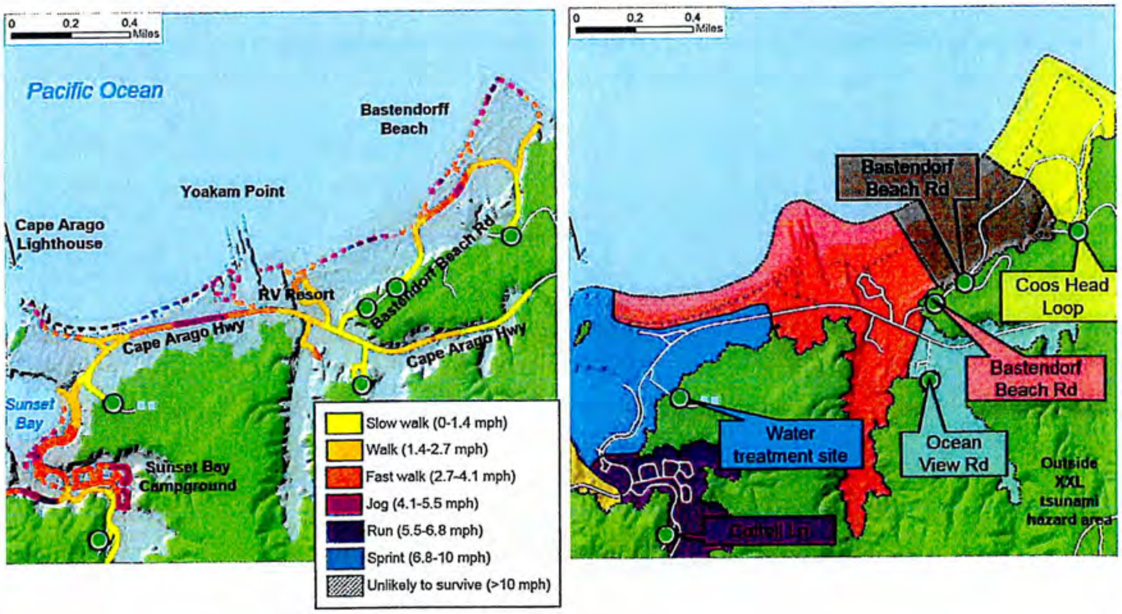
C.5 Charleston – pedestrian speeds & evacuation communities:

Beat the Wave pedestrian evacuation speeds are indicated by road color on the left. Evacuation communities (colored areas – on the right) define the area of evacuation and the associated nearest safety destination(s) indicated by the green dots. Green shaded areas are outside of the XXL tsunami inundation zone.



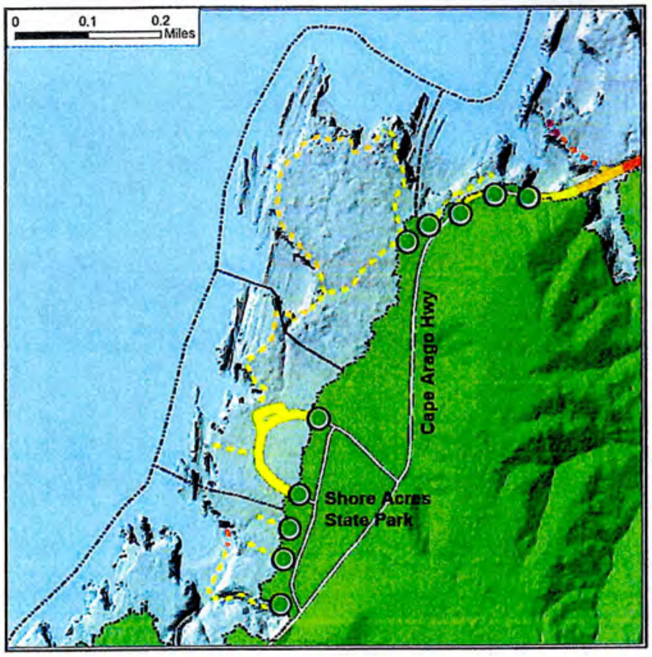
C.6 Outer Coast (south of Coos Bay Estuary) – pedestrian speeds & evacuation communities:

Beat the Wave pedestrian evacuation speeds are indicated by road color on the left. Evacuation communities (colored areas – on the right) define the area of evacuation and the associated nearest safety destination(s) indicated by the green dots. Green shaded areas are outside of the XXL tsunami inundation zone.



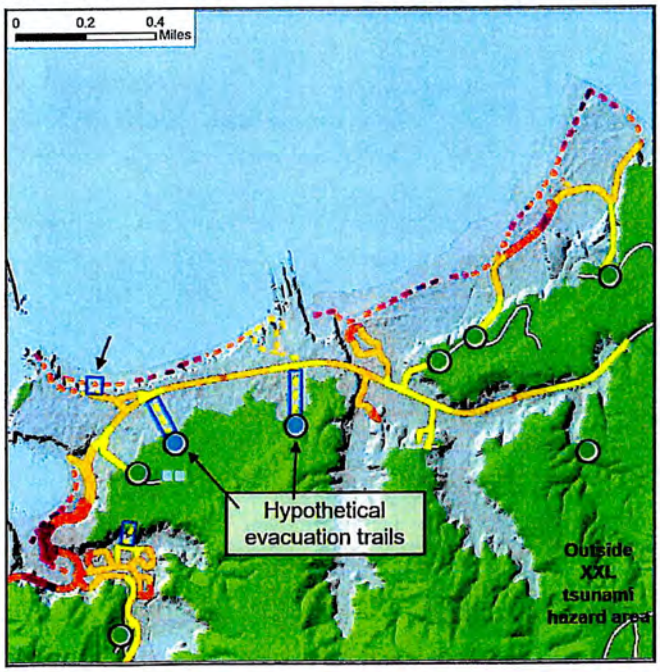
C.7 Shore Acres State Park – pedestrian evacuation speeds:

Beat the Wave pedestrian evacuation speeds are indicated by road color. Green dots indicate safety destinations and green shaded areas are outside of the XXL tsunami inundation zone.



C.8 Sunset Bay State Park with hypothetical mitigation options:

Beat the Wave pedestrian evacuation speeds for Sunset Bay to Bastendorff Beach with hypothetical pedestrian trails indicated in blue boxes (leading to blue dots). Such trails would help reduce evacuation speeds. Green shaded areas are above the XXL tsunami scenario.



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Appendix D: Potential Funding Streams

Potential funding sources identified to finance evacuation improvements:

- FEMA has three funding programs under their Hazard Mitigation Assistance program. The application process and grant administration of these funding programs can be onerous but are worthwhile. Sign up for updates regarding these grant sources through the Oregon Office of Emergency Management Hazard Mitigation Officer who can help guide communities through the application process. DLCD coastal and natural hazard staff can also be used as resources in the development of projects and applications.
    - The **Pre-Disaster Mitigation** (PDM) program provides funds to states, territories, Indian tribal governments, communities, and universities for hazard mitigation planning and the implementation of mitigation projects prior to a disaster event. Funding these plans and projects reduces overall risks to the population and structures, while also reducing reliance on funding from actual disaster declarations. PDM grants are to be awarded on a competitive basis and without reference to state allocations, quotas, or other formula-based allocation of funds. Eligible Applicants include states, local governments, and Indian tribes or other tribal organizations.
    - The **Hazard Mitigation Grant Program** (HMGP) provides grants to states and local governments to implement long-term hazard mitigation measures after a major disaster declaration. The purpose of the HMGP is to reduce the loss of life and property due to natural disasters and to enable mitigation measures to be implemented during the immediate recovery from a disaster. Eligible Applicants include States, local governments, Indian tribes or other tribal organizations, and private non-profit organizations.
    - The **Flood Mitigation Assistance** (FMA) program was created as part of the National Flood Insurance Reform Act (NFIRA) of 1994 (42 U.S.C. 4101) with the goal of reducing or eliminating claims under the National Flood Insurance Program (NFIP). FEMA provides FMA funds to assist States and communities who implement measures that reduce or eliminate the long-term risk of flood damage to buildings, manufactured homes, and other structures insured under NFIP. Eligible Applicants include states, local governments and Indian tribes or other tribal organizations.

- **National Tsunami Hazard Mitigation Program (NTHMP) Funds:** Distributed through the Oregon Office for Emergency Management (OEM) and the Oregon Department of Geology and Mineral Industries (DOGAMI), these funds could be used for a variety of tsunami evacuation improvements, including for signage and wayfinding, and outreach and education. DOGAMI and OEM develop a funding request to NTHMP every year for a variable amount of money. If a jurisdiction is interested in using these funds for a project, talk to staff at DOGAMI or OEM to see if the project can be written into the next funding request. Projects are typically one year in duration. Examples of how this funding has benefited communities in the past: "You are Here" signs, tsunami evacuation route signs, lighted informational kiosks, evacuation drills, and Beat the Wave modeling.

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- **Urban renewal** is a public financing tool to improve local infrastructure for tsunami evacuation and could facilitate new improvements or the redevelopment of existing improvements. It is a valuable tool for those with existing urban renewal programs and those contemplating developing one. Urban renewal is funded through a strategy called tax increment financing. When an urban renewal district is established, the county assessor determines the current assessed value of all property within the district, and freezes that tax base. Once the base is frozen, the property tax revenue local jurisdictions receive from all property within the district is likewise set at a fixed amount until the urban renewal area is terminated. Over time, as property values increase, all tax revenues generated by the "increment" between the frozen value and the current real market value of all properties in the district are directed to improvement projects within the urban renewal district. Assessed values can increase yearly at the 3% maximum allowed amount by state statute, or by more than this if new development occurs within the area. When the urban renewal area expires, the frozen base also expires, and the local taxing jurisdictions resume receiving taxes on the full assessed value of the area.

  Tax increment financing can be used to fund a variety of improvement projects including projects that help mitigate tsunami risk. Projects such as multi-use paths and green spaces that can double as tsunami evacuation routes and assembly areas, infrastructure upgrades (water, sewer, and utility), and the relocation of critical facilities outside of tsunami hazard areas are examples of work that could be accomplished through urban renewal financing.

  For more information about urban renewal visit the following websites:

  - State of Oregon - Urban Renewal Webpage: www.oregon.gov/DOR/PTD/Pages/IC_504_623.aspx
  - Urban Renewal in Oregon: History, Case Studies, Policy Issues, and Latest Developments: www.rockawaybeachor.us/Portals/56/urOregon.pdf
  - An Overview of Urban Renewal: www.oregon.gov/oprd/HCD/PROGRAMS/docs/omsc_2011_ur101_main_street.pdf

- **System Development Charges** (SDCs) are one-time charges on new development, and certain types of redevelopment, to help pay for existing and planned infrastructure to serve the development. SDCs are one means available to local governments for financing growth. State law creates a framework for local SDCs and specifies how, when, and for what improvements they can be imposed. Under ORS 223.297-223.314, SDCs may be used for capital improvements for:
  - Water supply, treatment, and distribution;
  - Wastewater collection, transmission, treatment, and disposal;
  - Drainage and flood control;
  - Transportation; and
  - Parks and recreation.

System development charges may be charged to new development based on a fee to reimburse for unused infrastructure capacity and/or to make planned improvements that increase infrastructure capacity. System development charge revenues may only be used for capital costs. They cannot be used for ongoing system or facility maintenance or projects that fix existing system deficiencies or replace existing capacity.

Local governments must establish their SDCs by ordinance. They must have a methodology to calculate a reimbursement fee and/or an improvement fee and provide credit if a developer finances a qualified capital improvement. Prior to imposing an SCD based on an improvement fee for capital facilities, the local government must have in place: 1) a capital improvement plan; 2) a public facilities plan or comparable plan that lists improvements to be funded with the improvement fee portion of the SDC; and 3) an estimate of the cost and timing for each improvement.

System development charges could be utilized for evacuation route component financing if those components are directly related to capital improvements that SDCs can legally fund (e.g. transportation, parks, and recreation) and the charges are developed consistent with ORS 223-297. These SDCs should be directly linked to the local government's capital improvement plan and the TEFIP which has comparable components to a public facilities plan. The plan must include specific associated standards for evacuation route paths, bridges and other related improvements (i.e. size, width, seismic capacity, and cost for each listed improvement). As indicated in the applicable statute, development of a legal formula to apply system development charges to these improvements is required and addresses rough proportionality as necessary. Improvements may be evacuation route facilities associated with the transportation system (e.g. streets/bridges). They may also be associated with multi-use paths or trails that would fall within the transportation, park, or recreation systems of the community.

The local government should seek guidance and direction from its legal counsel and other qualified professionals to assist in the use of this option and in potential development of this tool. Local government organizations (LOC, AOC) may also have information on this option. For more information about system development charges, visit the following websites:

- ORS 223-297(SDCs):
  www.leg.state.or.us/ors/223.html
  www.oregonlaws.org/ors/223.302

- **Legal Exactions** refers to a broad range of regulatory techniques used by local governments to require developers to contribute to the cost of community public facilities. Specifically, exactions require contributions toward public improvements that fall outside the boundary of the development (such as access roads or off-site drainage easements), or will serve larger segments of the community in addition to the specified development (such as new parks or a new evacuation route needed to adequately serve the area where the development is located).

  The underlying and common legal issue with respect to fees, dedications, and exactions is the connection, also referred to as the "nexus," to the impact of land development. Without this nexus, land development regulations that impose exactions may be deemed unconstitutional takings of property without just compensation.

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The United States Supreme Court has held that under limited circumstances, a government may have the right to limit certain uses, and invoke certain permit conditions and exactions if they are necessary to limit or avoid specific public harms threatened by the development. The Court has set forth a three part test to determine whether an exaction results in an unconstitutional taking. To avoid resulting in a taking, an exaction must:

- Substantially advance a legitimate public purpose;
- Be based on an essential nexus between that purpose and the harm threatened by the proposed use; and
- Be roughly proportional to the degree of threatened harm.

The public purpose advanced by exactions for tsunami evacuation improvements is to reduce life safety risk. New or intensified development within the tsunami hazard area will, by definition, place more people at risk from tsunami; thus the clear nexus for evacuation related exactions is to mitigate the harm presented by this increased risk. Proportionality can be addressed by establishing a process for evaluating the impacts of new development in terms of increased risk exposure, and identifying evacuation improvements or other measures that are roughly proportional to those impacts.

In adopting regulations that establish evacuation system related exactions, jurisdictions should incorporate findings that address these three requirements. Such findings should clearly articulate the purpose of the regulations, the essential nexus between new development and increased risk, and the process for determining proportionality. The TEFIP provides a key foundation for these findings and the establishment of regulation based exactions.

The local government should seek guidance and direction from its legal counsel and other qualified professionals to assist in development of this option. Local government organizations such as the League of Oregon Cities and Association of Oregon Counties also may have helpful information on this topic.

- Local improvement districts, or special assessment districts, function as mainstays of local improvement financing. A local improvement district is a geographic area in which real property is taxed to defray all or part of the cost of a public improvement. The distinctive feature of a special assessment is that its costs are apportioned according to the established benefit that will accrue to each property. In Oregon, local improvement districts are governed by local ordinances, but the Bancroft Bonding Act (ORS 223.205-295) addresses the means by which local governments may finance public improvements.

  In the case of tsunami evacuation route improvements, a local government can use this financing mechanism to work with neighborhoods lacking needed route facilities to help them overcome those deficiencies in their portion of the evacuation route system. The costs of the needed evacuation route improvements would be apportioned to each property owner according to the direct benefit of the route improvement to the property.

The local government should seek guidance and direction from its legal counsel and other qualified professionals to assist in development of this tool. Local government organizations (LOC, AOC) may also have information on this option.

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- A **land trust** is a nonprofit organization that, as all or part of its mission, actively works to conserve land by undertaking or assisting in land or conservation easement acquisition, or by its stewardship of such land or easements. Land trusts work with landowners and the community to conserve land by accepting donations of land, purchasing land, negotiating private, voluntary conservation agreements on land, and stewarding conserved land through the generations to come. Land trusts can be used in tsunami mitigation to:
    - Acquire developable land in high risk areas;
    - Create buffer zones to protect urban development from tsunami impacts;
    - Acquire open space for community assembly areas.

For more information about land trusts, visit the following websites:

- Oregon Land Trust Contacts: www.opb.org/programs/oregonstory/land_trusts/resources/page_2.html
- Land Trust Alliance: www.landtrustalliance.org/

- A **conservation easement**, which is a legal agreement between a landowner and a land trust or government agency, can be used to permanently limit the use of land in order to protect its conservation value. It allows landowners to continue to own, use, or sell their land.
  When a conservation easement is put in place by a landowner, some of the rights associated with the land are given up. For example, in high-risk tsunami inundation areas, the right to build certain types of structures could be given up, while retaining some or all of the land as open space. Conservation easements are permanent, and future owners are also bound by the easement terms. The easement holder is responsible for making sure the easement's terms are followed. Easement holders are typically a land trust or other conservation oriented NGO, but may also be governmental entities. While conservation easement are typically focused on preserving important natural resource or open space values, as voluntary, non-regulatory mechanisms for limiting development, conservation easements may also serve to help reduce exposure to tsunami risk. For more information, see:
    - Conservation Easements Oregon:
    - www.nature.org/about-us/private-lands-conservation/conservation-easements/
    - Southern Oregon Land Conservancy:
    - www.landconserve.org/content/conservation-easements
    - Cannon Beach Conservation Easement:
    - www.ci.cannon-beach.or.us/News/EcolaCreek/OWEBease.pdf
    - Land Trust Alliance – Conservation Easements Webpage: www.landtrustalliance.org/conservation/landowners/conservation-easements
    - National Park Service: www.nps.gov/tps/tax-incentives/taxdocs/easements-historic-properties.pdf

- **Transferable Development Credits** (TDC) is more widely known as "Transfer of Development Rights" or TDR. Currently this option has limited utility as current Oregon statute (ORS 94.531-538) on "TDR" sending areas is limited to "resource lands." The term "resource lands" is defined in a way that would not allow sending areas to be designated based solely on tsunami hazard/risk; sending areas would have to possess other defined natural resource/conservation values in order to qualify. However, if a jurisdiction has an existing TDR program it may be able to provide secondary hazard mitigation value in addition to its primary purpose of conserving "resource lands."

In cases where qualifying resource land sending areas are within a tsunami hazard area, Transfer Development Rights (TDR) would be another incentive-based approach that could be used to limit development in high risk inundation zones and encourage development outside of inundation zones. For more information about this strategy visit the following website:

  - ORS 94.531-538: www.leg.state.or.us/ors/094.html

- **ODOT Bicycle & Pedestrian Program Grants:** Multi-use paths and transportation facilities can also serve a dual purpose as evacuation routes when these transportation facilities are also identified as necessary routes within the community's TEFIP. Information for this funding source is located at: www.oregon.gov/ODOT/HWY/BIKEPED/pages/grants1.aspx.

- **Recreation Related Funding Sources:**
  Recreation District: ORS 198.010 and 198.335 authorize 28 types of districts, including "park and recreation" districts. Special Districts are financed through property taxes, fees for services, or a combination of these. Recreation districts in Oregon are directed by OAR 226 and may provide for a variety of recreational facilities. If the community has a recreation district, or is contemplating developing one, which includes or would include hiking and biking trails and other multi-use facilities, it may be possible to utilize these funds to further develop evacuation routes if the primary purpose of these routes is recreation. The Special Districts Association of Oregon (SDAO) provides support services to member districts throughout the state in the areas of research and technical assistance, legislative representation, training programs, insurance services, information and reference materials, financing services, and employee benefits programs.

  OPRD Recreation Trails Program (RTP) Grants: These federally funded grants provide awards for recreation trail-related projects such as hiking, running, bicycling, off-road motorcycling and all-terrain vehicle riding. Information for this funding source is located at: www.oregon.gov/OPRD/GRANTS/pages/about_us.aspx.

- **Purchase Strategies:** Local governments can purchase property, through fee simple acquisitions for a variety of public purposes. A number of communities have implemented programs to acquire land to conserve critical ecosystems or natural features, as well as to provide open space for recreational benefits to their communities. In some cases, such acquisitions may also serve to remove properties at risk from tsunami hazard from the private market; alternatively, a community could specifically identify tsunami hazard mitigation as an objective for a land acquisition program or strategy. Some communities have successfully used purchase strategies for negotiating/purchasing easements and acquiring new right-of-ways. Other specific tools and strategies may include fee simple purchases, acquisition of development and easement rights, and relocation of existing structures in the hazardous areas pre-disaster. These programs can be costly for local governments; although in certain cases, significant life safety benefits may be realized.

Local governments should seek guidance and direction from legal counsel and other qualified professionals to assist in development of this tool. Local government organizations (LOC, AOC) may also have information on this option.

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Acknowledgements

The Oregon Office of Emergency Management and the Department of Geology and Mineral Industries wishes to thank everyone who helped to craft this guidance document. Your help was invaluable in producing this effort to make Oregon safer for residents and visitors.

This project was funded under award #NA17NWS4670013 by the National Oceanic and Atmospheric Administration (NOAA) through the National Tsunami Hazard Mitigation Program.

Background

Tsunamis are usually generated by great subduction zone earthquakes when the ocean floor is rapidly uplifted during the earthquake. The tsunami wave from a local subduction zone earthquake will arrive at the coast in approximately 10-20 minutes, and tsunami waves will continue to arrive periodically for several hours. When the shaking stops, people must immediately move inland to high ground. It is critical that residents and tourists know the landward extent of the local tsunami inundation zone used on evacuation brochures, their evacuation routes, and the nearest safe zones.

The most visible way to educate the public is to use wayfinding signage that guides the public to safety. According to Webster's Dictionary, *wayfinding* is defined as, "the process or activity of ascertaining one's position and planning and following a route." It is imperative that coastal communities provide clear and consistent wayfinding signage to residents and visitors alike. People will need to be able to move quickly uphill and inland after the ground stops shaking. Proper use of wayfinding signage will help people evacuate safely and quickly no matter the time of day or weather conditions. This guidance document is a starting point for communities developing their own wayfinding system. There are more resources listed at the end of the document.

There are several categories of tsunami signs available:

- tsunami hazard zone,
- tsunami evacuation route,
- tsunami assembly site,
- and entering/leaving tsunami hazard zone.

Each of these are examined in more detail throughout this document.
Several of these signs were originally created in Oregon, while others have been adapted from elsewhere. The tsunami hazard zone and evacuation route signs have been adopted for use by the Pacific states of the National Tsunami Hazard Mitigation Program steering group (Alaska, California, Hawaii, Oregon, and Washington). Other Pacific Rim countries have also either adopted or adapted the signs for their use. To insure consistency of sign placement, the following guidelines were developed for each of the signs. Installation of tsunami signs on state highways must be approved and coordinated with the Oregon Department of Transportation (ODOT).

Government entities can order all signs from the ODOT Sign Shop (503-986-2805). Also contact ODOT for guidelines on sign installation (post size, attachment methods, etc.).

Contact Oregon Office of Emergency Management (503-378-2911) for further information on tsunami evacuation wayfinding, and the Oregon Department of Geology and Mineral Industries (541-574-6658) for sign styles and locations (e.g. blue lines painted on roads, “Entering-” and “Leaving Tsunami Hazard Zone” signs and locations, and You are Here evacuation signs

Tsunami sign placement guidelines

Designing your evacuation route

As your community moves forward to create safe and useful evacuation routes, there are some key things to consider. Begin the process by consulting with the Oregon Department of Geology and Mineral Industries (DOGAMI) and Oregon Emergency Management to identify and locate the best routes to high ground based on the most recent mapping and modeling.

Working with community stakeholder groups, prioritize the routes based on population and level of risk. Develop a public education and outreach program to let the public know more about the routes and how to practice their routes to high ground.

It is important to understand that at the time of the earthquake, the objective of every person is to immediately head to their nearest safety destination (or *escape point*) on high ground, and not necessarily designated Assembly Area sites shown on evacuation maps. The reason is that in many communities these Assembly Areas may not necessarily be the closest safety destination for many residents and tourists. As a result, when educating the public it is important to emphasize that the first objective is to survive the tsunami. This can be achieved by evacuating to the nearest high ground escape point.

Since local tsunami waves will be catastrophic in the first 6 hours and will last at least 12 hours after the start of earthquake shaking, evacuation to the nearest designated Assembly Area site should not be attempted until a minimum of 12 hours has passed. When re-entering the tsunami inundation zone the public will need to adopt a 'cautionary re-entry' approach. This approach will vary based on the unique characteristics of each community and in particularly on how spread out and isolated the public will be. In all likelihood, an official all clear may not come from community leaders, but could be disseminated via NOAA weather radio. Regardless, knowing when and how to re-enter the inundation zone must be part of any education and outreach messaging undertaken in each community. Post-tsunami help will likely be provided at designated Assembly Area sites first.

Community route planning should therefore account for the entire route from beach to nearest safety destination (high ground escape point). Every route should ideally have a destination assembly point or collection area. These should be clearly distinguished from official post-tsunami assembly areas where caches or amenities have been stored, and post disaster response planning will be targeted first. Having clearly defined assembly areas will aid in post-tsunami response as people will know to go there after the event.

Along the route, there will be decision points such as intersections. There should be clear line-of-sight signage or route markers so that the person evacuating always knows which direction to go, even in low light.

Tsunami sign placement guidelines

The most visible way to educate the public about escape routes and shelters is to post signs. Where available, sign placement should be guided by evacuation (Beat the Wave) modelling results that have been completed by DOGAMI. These data can be found on the Oregon Tsunami Clearinghouse web site[1]. Additional guidance information may be found in local 'Tsunami Evacuation Facilities Improvement Plans (TEFIP)' that is being spearheaded by the Department of Land Conservation and Development agency in consultation with local communities[2].

Unfortunately, there is no clear guidance for what is the ideal spacing of signage. What is evident from efforts implemented around the world is that evacuation routes should be clearly marked with appropriate signage along the <u>entire route</u> (e.g. Figure 1). Such signage need to be installed in advance of the event and will need to be maintained into perpetuity. Funding to assist this effort may be obtained through DOGAMI and OEM, via the National Tsunami Hazard Mitigation Program (NTHMP).

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[1] http://www.oregongeology.org/tsuclearinghouse/beatthewave.htm

[2] https://www .oregon.gov/LCD/OCMP/Pages/TsunamiGuideIntro.aspx

Wayfinding signage should reflect an end-to-end plan that incorporates signage in high traffic areas such as State Parks or public waysides (Figure 1, top left). Signs should also be visible from the beach. The example in Figure 1 (top right) is a beach stair access in Cannon Beach, with additional signage established on posts along the evacuation route. Appropriate signage may also include signs painted on roads or the footpath, and may include additional information such as distance to safety (Figure 1, bottom left). Finally, a leaving tsunami sign may be used to define the point at which one reaches the nearest safety destination and leaves the tsunami inundation zone (Figure 1, bottom right). Such signage should include Spanish translation.

Effective sign placement and spacing is a function of visibility (line of site, lighting (day vs night vs fog), the presence of vegetation, and curves in the road or trail) and the ability of the person to read the text. In road engineering, it is well established that *icons are much easier to comprehend and understood* compared with text, and hence can be interpreted further away. In general, 3" size text can be viewed by the average person ~100 ft away; text of this size is most easily read at ~30 ft from the sign. For 6" size text, the signs can be read ~200 ft away, while easy readability is at ~60 ft. These data suggest that signs are probably best spaced ~60 ft apart (if the goal is to read the text), but may be as much as 100- 200 ft apart given the use of a combination of text and icons.

As noted previously, visibility under different conditions is a major consideration. Since the above readability values are based on the average person under ideal conditions, communities should be mindful of the fact that wayfinding signage need to be visible in both daylight and at night. The worse-case situation is almost certainly a Cascadia event occurring at night, which suggests that signs will probably need to be spaced more closely together. Consideration of other means to illuminate signs should also be evaluated. For example, signs painted on pathways could utilize fluorescence, while signs on post could incorporate solar panels and energy efficient LEDs. In all cases, the placement of signs along given evacuation routes should be carefully evaluated to ensure the correct spacing and messaging.

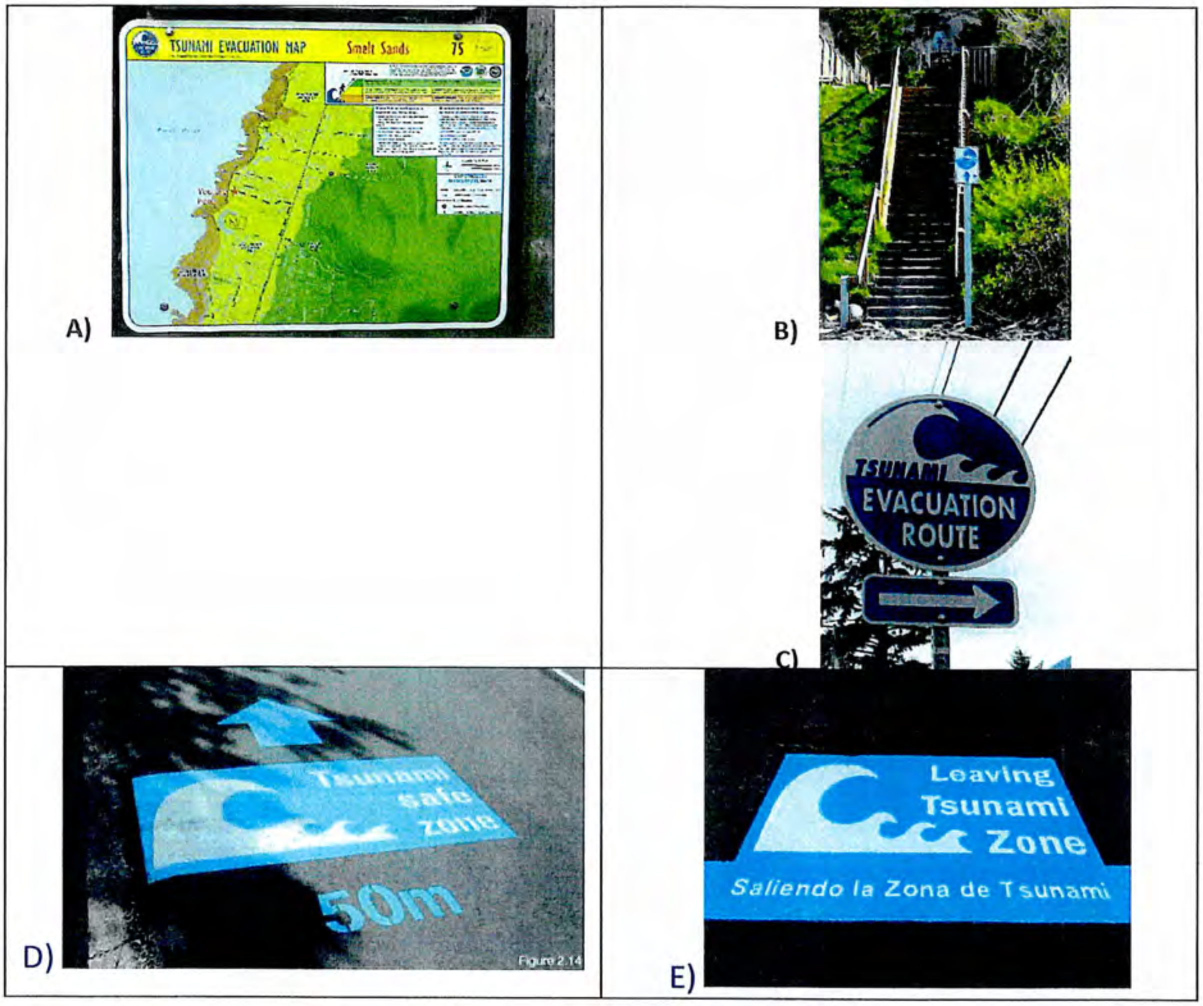

Figure 1. An end-to-end evacuation route plan consists of (*A*) 'You are here' signage and route guidance for high traffic sites; (*B*) Guidance signage established at the start of the route used in Cannon Beach and visible from the beach, as well as signage on posts along the route (*C*). Signage may also be painted on roads or footpaths with distance to safety identified (*D*). Finally, signage indicating that you have reached your safety destination (escape point) and have left the inundation zone needs to be identified along every evacuation route (E).

Tsunami evacuation route signs

Signs that identify the evacuation route could incorporate both vertical signage placed on signposts, as well as signs painted on a road or pathway (Figure 1). A new addition characteristic of Japanese signage is the inclusion of a distance to safety, in addition to the arrow. This is an approach that should be incorporated in evacuation wayfinding signage for the Oregon coast. Examples from Japan include signs affixed to conventional posts (Figure 2), and painted on roadways (Figure 3). Other approaches have utilized solar panels and lights (e.g. LEDs) to illuminate the evacuation route at night (Figure 4).

Figure 2. Examples of evacuation routes signs affixed to posts.

Figure 3. Examples of "You are Here" signage attached to posts, as well as painted on roadways and paths. Note the inclusion of distances on the signage, which help inform people how far they are to safety.

Figure 4. Use of solar panels help to illuminate signs during night time.

(source: Fraser and others, 2012)

Tsunami hazard zone

This sign should be placed at locations within the tsunami hazard zone as defined by local evacuation maps, detailed tsunami inundation maps or, if these are not available, tsunami hazard maps used to implement Oregon Revised Statutes 455.446 and 445.447[3]. The statutes limit construction of critical and essential structures in the mapped tsunami inundation zone.

The sign comes in two sizes: 22 1/2" x 18" and 30" x 24". The size needed depends on where you plan to install the sign. It is important that the sign be visible, especially when located in areas where many people congregate (beaches, parks, and developed waterfronts).

Figure 5: Tsunami Hazard Zone sign

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[3] http://www.oregongeology.org/tsuclearinghouse/pubs-regmaps.htm

You are Here Maps

DOGAMI has been developing "You are Here" tsunami evacuation maps in high traffic sites along the Oregon coast. To date these signs have been established at some 132 sites. In particular, a concerted effort was undertaken in 2017 between DOGAMI, Lincoln County Emergency Management and the Oregon State Parks Recreation Department to establish "You are Here" signage at every beach access point throughout Lincoln County.

These signs are printed on large format 3x4 ft aluminum sheets (4 mm thick). Signs are developed by DOGAMI staff in consultation with the local community, while sign installation is completed by the requesting community. To ensure consistency with the tsunami evacuation brochures, design of the "You are Here" signage is entirely consistent with the evacuation brochures produced by DOGAMI in 2013 (http://www.oregongeology.org/tsuclearinghouse). Signs clearly indicate the following:

- **"You are Here" location (ideally this could include either a distance or time to safety);**
- **Evacuation zones (distant and local);**
- **Green safety zone, along with safety destinations identified on every road or trail;**
- **Primary evacuation route from the "You are Here" location, along with secondary routes for other locations in the map.**
- **Where available, critical facilities that define Assembly Areas, Fire, Police, Hospitals, and Schools.**

Figure 6: Example "You are Here" sign developed for Smelt Sands in Yachats.

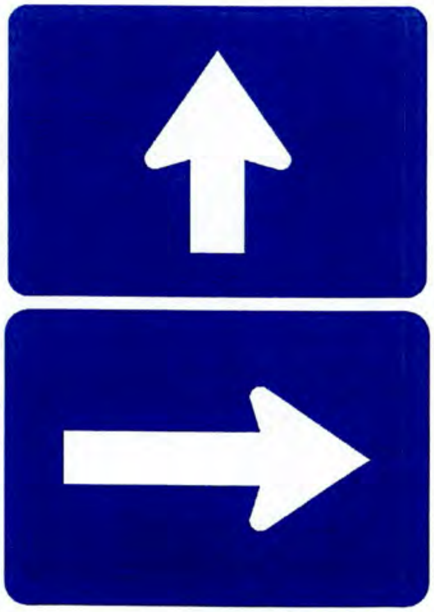
Tsunami evacuation route

This sign should be placed along roads designated as tsunami evacuation routes that take people out of the tsunami hazard zone. Evacuation routes are identified by local governments.

At present the sign comes in two sizes: standard size is 24” in width and a minimum of 18” in width. Due to Federal Standards, ODOT will no longer make the round signs. It is important that the sign be visible; thus the larger sign may be warranted in some situations.

It is recommended that an arrow sign be used in conjunction with the evacuation route sign to insure that people go in the right direction. The orientation of the arrow sign with respect to the evacuation route sign may vary.

An arrow plaque should be used to show the recommended evacuation direction, whether left, right, or straight ahead."




TSUNAMI
EVACUATION
ROUTE


TSUNAMI
EVACUATION
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ROUTE

Tsunami assembly area

This sign can be placed outside of the tsunami evacuation zone indicating that people do not need to go further inland or uphill. It could also be placed at a pre-designated destination or assembly area. An assembly area does not necessarily mean that there will be shelter or supplies available. It is a pre-designated meeting place to aid in response efforts.

This sign also comes in two sizes: 18" x 22" and 24" x 30". Once again the sign should be visible so choose the right sized sign for the location.

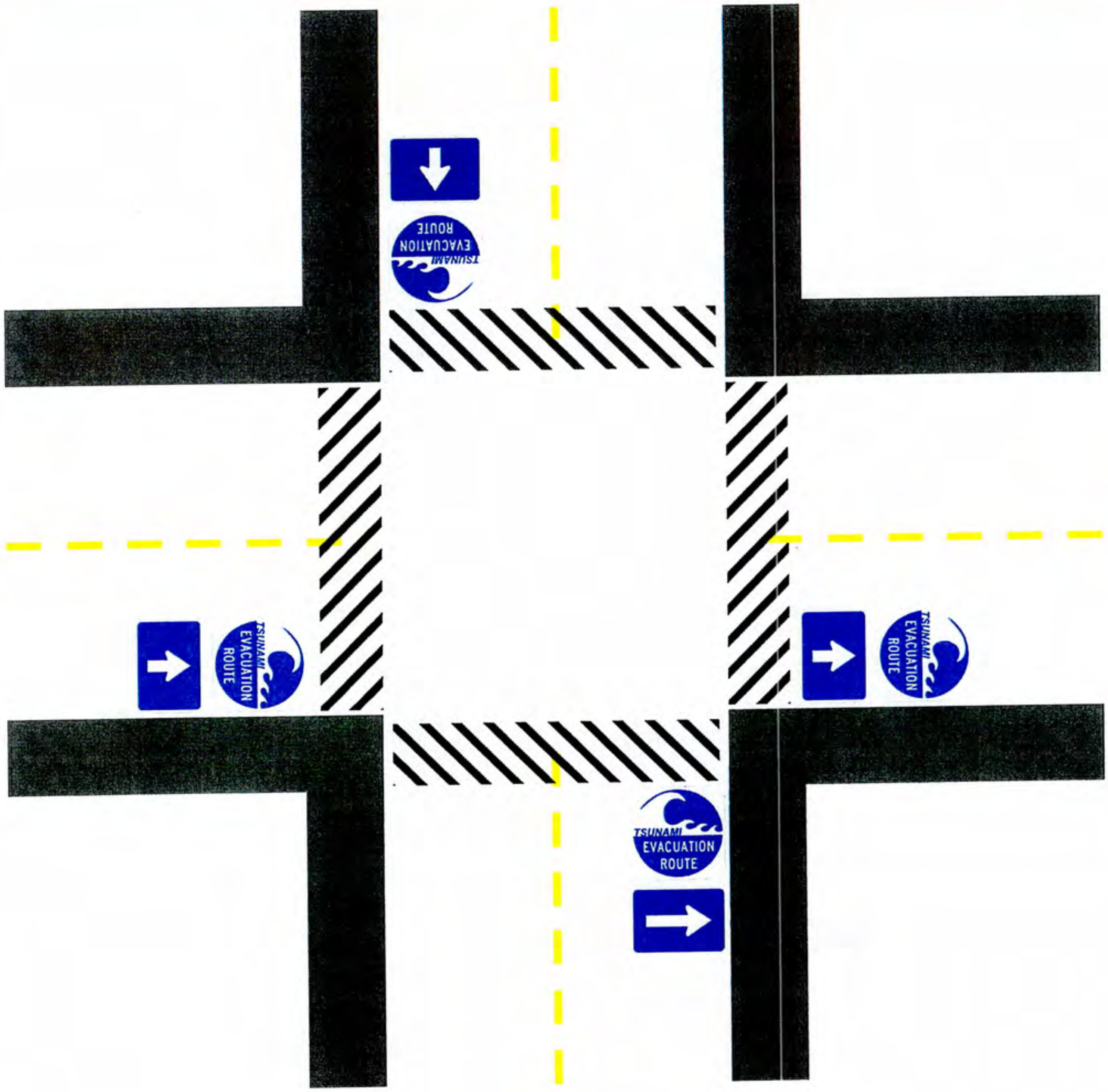
Entering and leaving the tsunami hazards zone

DOGAMI, in partnership with ODOT, is working to ensure Entering and Leaving tsunami hazard zone signs are installed along the length of the Highway 101 system, as well as certain critical secondary highways that intersect with Highway 101. To date, ~175 signs have been installed on the central to northern Oregon coast (Lincoln, Tillamook, and Clatsop counties). The final phase of sign installation planned for the south coast is expected to be completed in late 2019.

These signs should be placed on major state or county roads where the road enters and leaves the tsunami hazard zone. They should be placed on both sides of the road and at both ends of the specific stretch of road within the tsunami hazard zone. However, if the road dead ends, then signs need only be placed at one end where people are entering and leaving, such as a State Park.

The signs come in one size: 42” x 48” so it can be visible by motorists traveling at highways speeds.

Examples of proper placement of hazard zone sign and evacuation route signs

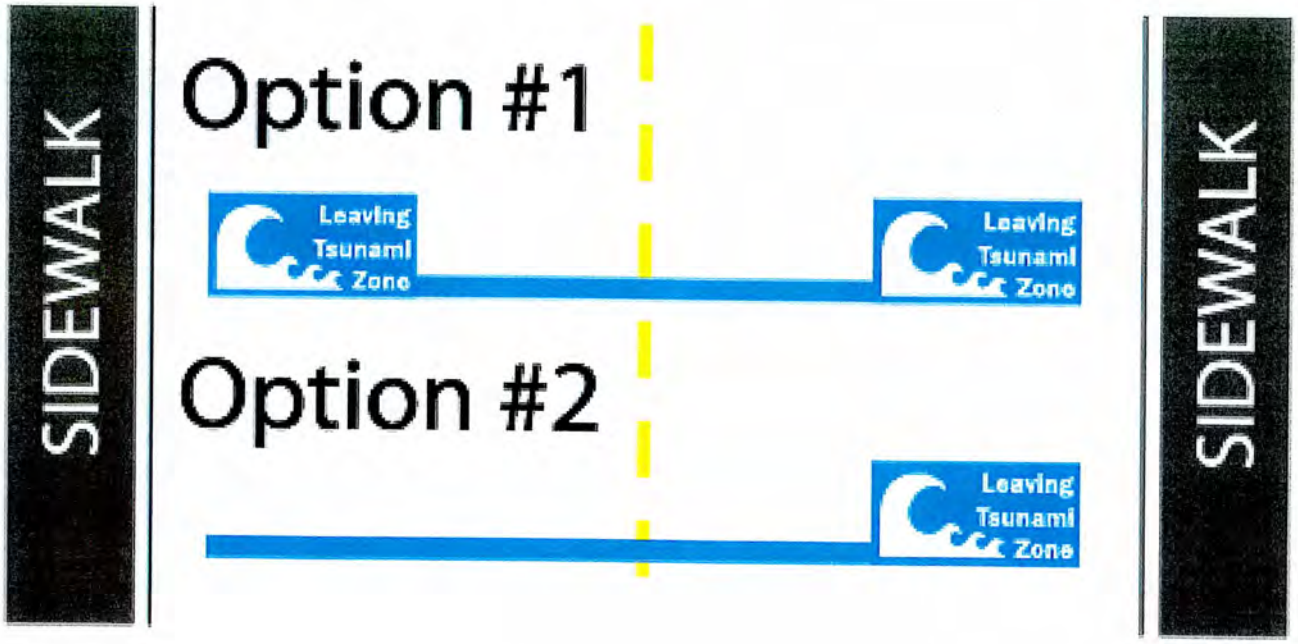

TSUNAMI EVACUATION ROUTE
TSUNAMI EVACUATION ROUTE
TSUNAMI EVACUATION ROUTE
TSUNAMI EVACUATION ROUTE

Blue Line

The tsunami blue line was first developed by the city of Wellington in New Zealand. It has been adopted by Oregon and added to our suite of tsunami evacuation wayfinding signage. This marking shows the demarcation point between the "In the zone" and the "out of the zone". It is very useful in showing the public when they have reached a safe distance from the approaching tsunami.

Communities have flexibility in the material used to create the signage. The can choose thermoplastic or paint, depending on their own needs. The weather on the coast can be a factor in how well they signage endures traffic abrasion.

Color: It is recommended to use a lighter blue for this signage than might be used for the vertical signage. When the pavement is wet, the darker blue can be difficult to see. Reflective material can be added to thermoplastic and to paint to make the markings more visible in low light.



An alternative approach adopted by the City of Newport includes the incorporation of Spanish translation in the sign, with the text and graphic placed in the middle of the lane.

Accessories

Any accessories used in the wayfinding system, should not impede existing traffic control cues. This wayfinding marking allows more flexibility to keep your evacuation route marking in line with your community aesthetics. Using visual cues that the public are already familiar with will help you enculturate your new evacuation routes.

Flexible delineator post

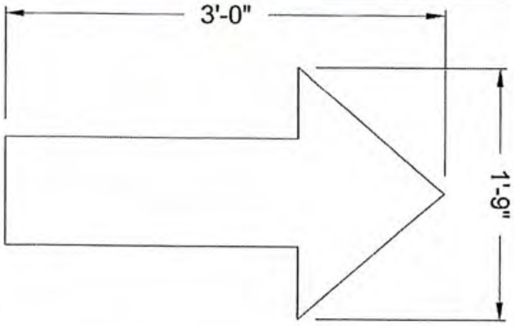
Raised pavement reflector

Additional Resources:

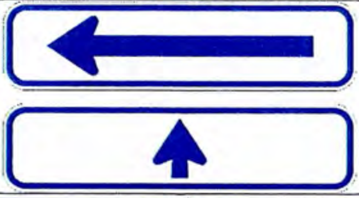
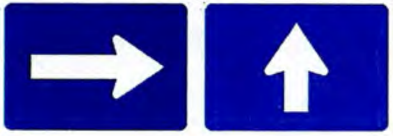
- Tsunami Sign Placement Guidelines
    - http://www.oregongeology.org/sub/earthquakes/Coastal/OFR0306Signs.pdf
- Technical Standard [TS01/08] National Tsunami Signage – New Zealand
    - https://www.civildefence.govt.nz/assets/Uploads/publications/ts-01-08-national-tsunami-signage.pdf
- Signs & Symbols - International Tsunami Information Center
    - http://itic.ioc-unesco.org/index.php?option=com_content&view=category&layout=blog&id=1406&Itemid=1406
- Up and Out Phase1
    - http://www.oregon.gov/oem/Documents/Up_And_Out_Phase1.pdf
- Up and Out Phase 2
    - http://www.oregon.gov/oem/Documents/Up_And_Out_Phase2.pdf
- Tsunami Evacuation Signs
    - https://nws.weather.gov/nthmp/signs/signs.html
- Tsunami Signs - Caltrans - State of California
    - http://www.dot.ca.gov/trafficops/tcd/tsunami.html
- Manual on Uniform Traffic Control Devices, Chapter 2N, Emergency Management Signing
    - https://mutcd.fhwa.dot.gov/pdfs/2009/mutcd2009edition.pdf
- Oregon sign Policy and Guidelines, chapter 5, Guide Signs
    - https://www.oregon.gov/ODOT/Engineering/Documents_TrafficStandards/Sign-Policy-05-Guide.pdf

APPENDIX A: Signage Costs

(AS OF 5/2019)

TYPE	Description	Image	Cost
Thermoplastic	Leaving tsunami zone sign		$328.90
Thermoplastic	"Saliendo la Zona de Tsunami" - spanish translation of "Leaving tsunami zone" imbedded as blue line strip (light color) 12" x 72"		$129.00
Thermoplastic	Blue line (light color) 12" x 30ft		$138.80
Thermoplastic	Tsunami Evacuation Route Sign (round)		$72.30
Thermoplastic	Tsunami Evacuation Arrow Signs		$67.10

Aluminum	Entering Tsunami Hazard Zone Sign: 42"x48" 24"x27" (note: this sign just has "Entering" and "Tsunami Zone"	 	$147.00 $50.00
Aluminum	Leaving Tsunami Hazard Zone Sign: 42"x48" 24"x27" (note: this sign just has "Leaving" and "Tsunami Zone"	 	$147.00 $50.00

Aluminum	Tsunami Evacuation Route Signs (24" round) *Note: may now be produced using a square sign.*		$51.00
Aluminum	Tsunami Evacuation Arrow Signs: 24"x6" long		$10.00
	Tsunami Evacuation Arrow Signs (interstate): 21"x15" long		$20.00
Aluminum	Tsunami Assembly Area Signs: 18"x22" 24"x36"		$20.00 $60.00

Aluminum	Tsunami Evacuation Site Signs size: 12"x18" *Note: various types out there including with/without people*		$20.00
Aluminum	Tsunami Hazard Zone Signs: 22.5"x18" 30"x24"		$30.00 $50.00

SECTION 3.9.500 EROSION

1.1 Critical Streambank Erosion

Streambank erosion (other than by flash flooding) occurs constantly on all rivers and streams in the Coos and Coquille drainage basins. Critical erosion causes a loss of land to streambank cave-ins and can initiate landslides on the adjacent uplands. Critical streambank erosion occurs most commonly along floodplains and at the base of river terraces or landslide deposits in the uplands. Valuable farmland is being lost from the floodplains in the Broadbent area, for example, and along Highway 42 several landslides are kept active by streambank erosion at their bases. The problem is naturally occurring and can be most effectively and most economically controlled by protection of bank vegetation and by careful planning, which can prevent the location of structures in areas threatened by this hazard. Careful engineering of roads is also necessary to prevent frequent need for expensive repairs. Riprap and other structural solutions are less preferred but may be useful or desirable for protection of existing roads or structures and land.

1.2 Coastal Erosion

Coastal erosion is a natural process that continually affects the Oregon coast. Erosion becomes a hazard when human development or public safety is threatened. Beaches, sand spits, dunes, and bluffs are constantly affected by waves, currents, tides, and storms, resulting in chronic erosion, landslides, and flooding. Changes may be gradual over a season or many years. Changes may also be drastic, occurring during the course of a single storm event. Erosion may be caused by large waves, storm surges, rip cell embayments, high winds, rain, runoff, flooding, or increased water levels and ocean conditions caused by periodic El Niños. Coastal dunes and bluffs comprised of uplifted marine terrace deposits are especially vulnerable to chronic and catastrophic erosion. Coastal erosion processes create special challenges for people living near the ocean, requiring thoughtful planning in order to minimize the potential dangers to life and property. Attempts to stabilize the shoreline or beach are often futile, because the forces that shape the coast are persistent and powerful.

1.3 Wind Erosion and Deposits

Wind erosion and deposits are essentially coastal processes locally and, together with wave action, contribute to our changing coastline. Areas subject to the effects of wind erosion and deposition are indicated in the mapping and include the sand dune areas inland from the Coos-Umpqua beach in the Oregon Dunes National Recreation Area, the Bandon spit on the Coquille River, and the New River area.

Blowing sand can be a nuisance to recreational users and a long-term hazard to structures located in the path of migrating dunes, which can move as much as 6 feet per year. This is a hazardous factor in local planning because of an abundant sand supply, persistent winds, and an absence of stabilizing vegetation. Identification and mapping of areas subject to wind erosion and deposition can aid in planning the optional location on development. Concern should also be shown for the impact of development on currently stabilized areas.[9]

Such development could open new deposits of loose sand causing problems on adjacent properties. Protecting existing vegetation and requiring revegetation as soon as possible when the plant cover must

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[9] See "Dunes and Ocean and Lake Shorelands" (Section 3.8, this document) for a discussion of the hazards of development in dune areas. "Stabilized areas" refers both to recently stabilized dunes and older established dunes (DS, DC, and OSC; and ODS respectively on the sand dunes maps in the Background Document, pp. 15-11 through 15-13). Older stabilized dunes generally have well-developed soil profiles. Both types are vegetated, whereas active dune forms are not.

be disturbed are ways of reducing this hazard. Additional hazards of development in dune areas are covered in the section on dunes (Section 3.8).

Section 3.9.600 Other Coastal Erosion

1.1 Winds

Persistent winds are a feature of much of Coos County and are of particular importance as a potential hazard to the siting of mobile homes. Accordingly, the State Department of Commerce enforces siting and tie-down regulations that govern the placement of mobile homes.

1.2 High Groundwater and Ponding

High groundwater and ponding are most common in the coastal lowlands, marine terraces, inland floodplains, and some areas of Coos County's sand dunes. Uneven settling, flooding of basements, floatation of septic tanks, and septic system failure are common consequences of development in these areas. Potential for pollution of domestic water sources is also high. Since public health is at issue, encouraging development of public water and/or sewer systems where dense development already exists in such areas is desirable.

1.3 Shoreline Erosion and Deposition

Beach and headland erosion occur along the entire Coos County coastline. These hazards are addressed in greater detail in Section 3.8, "Dunes and Ocean and Lake Shorelands." Areas of beach erosion and deposition and coastal headland erosion rates are shown on the map accompanying that section.

Wave erosion poses a major hazard to coastal development. Wave energy is highest during winter months, and erosion is consequently greater then. Broad summer beaches become narrow and steep as vast amounts of sand are moved offshore. Development that appears to be a safe distance from the sea becomes threatened when a particularly powerful series of storms pound the coast, as in the winter of 1976-1977.

The pattern of erosion of upland areas by waves depends on the geology. Sheared or crumbly rock leads to earthflow and slumping with rapid rates of erosion. Development in such areas can be dangerous. Wave erosion of hard bedrock forms cliffs and erosion rates are slow (except along faults or joints); when significant erosion does occur, it is be the breaking off of large chunks of rock. Hazard, however, is slight and moderate setbacks are generally considered adequate protection. Removal of driftwood and rock debris from the bases of cliffs and areas where mass movement is occurring probably increases erosion rates significantly.

Sand is constantly being moved by wave and current action. Interruption of this movement can cause formation of new beaches, as at Bastendorff following jetty construction. This generally occurs at the expense of other areas – existing beaches may get smaller or disappear altogether and headland erosion may increase. Placement of large rocks (riprap) and construction of protective structures like seawalls (which are parallel to the coast) and groins (rigid structures which project outward from the shore), then, should be discouraged since they have a negative impact on the properties of others by typing up sand that would have been deposited elsewhere and in some instances by removing a source of beach sand. They may also increase future costs to the public; on the East Coast and in California increased threat to coastal developments have lead to a hue and cry for publicly-funded coastal protection projects, many of which seem to be fraught with unforeseen impacts. One means of dealing with beach erosion holds much promise: beach nourishment (supplying sand, generally from dredging projects or from well offshore) is being tried by the Army Corps of Engineers in the Miama, Florida, area and elsewhere. The mining and removal of sand from beaches also increases erosion and should be carefully controlled.

SECTION 3.9.700 WILDFIRE

Fire poses a major hazard to development in forested areas of the county and especially to the residential development in brushy coastal areas such as the Bandon area where there are extensive stands of highly inflammable gorse and broom. The problem is often compounded by inadequate roads serving residential developments in forested areas.

Community Wildfire Protection Plans (CWPPs) have helped communities work together to achieve common goals and deal with often controversial issues. CWPPs have offered many valuable opportunities to communities, allowing them to identify local priorities for community protection and resource management. In addition to enhancing safety and reducing risk to human structures and watersheds, communities with CWPPs are also given priority for USFS and BLM funded hazardous fuels reduction projects as authorized under the Healthy Forest Restoration Act of 2003 (HFRA). In the end, CWPPs have helped communities better protect themselves for fire risk and better manage their forested landscape.

The collaborative efforts of foresters from the federal and state agencies, rural fire departments, private landowners, local government agencies, volunteer organizations, and concerned citizens who live in the wildland urban interface, have resulted in signed CWPPs in every county and many communities across Oregon.

Coos County developed a Community Wildfire Protection Plan through a partnership among the University of Oregon's Community Service Center, local wildfire planning experts, and a range of federal, state, and local stakeholders. The project is funded through federal Title III funds. The project utilized a four-phase planning process developed in part based on guidance contained in Preparing a Community Wildfire Protection Plan: A Handbook for Wildland-Urban Interface Communities (2004) and the Community Guide to Preparing and Implementing a Community Wildfire Protection Plan (2008). The CWPP is hereby adopted by reference in the Coos County Comprehensive Plan.

Gorse (*Ulex* europaeus) is a perennial, heavily armored evergreen shrub growing from 3 to over 10 feet tall. Gorse plants are shrubby with stout and erect spreading branches covered in terminal thorns frequently forming dense thickets. Clusters of yellow pea-like flowers can be found on the plant throughout the year but peak bloom occurs March through May. Seedpods are hairy ½ to ¾ inch long, and brown when ripe. Mature pods burst, scattering seeds for several feet. Gorse was introduced from Europe in the 1890's at Bandon as an ornamental and living fence. Worldwide, European settlers brought the plant with them to more than 15 countries or islands where it has escaped causing significant economic harm. Currently Oregon has at least 55,000 acres at some level of infestation.

This plant is highly flammable and the morning of Saturday, Sept. 26, 1936, was the reason the City of Bandon burnt to the ground. The first started as a small forest fire but bursts of flame became fueled by the gorse. The fire completely consumed the City of Bandon, population 1,800. At least 10 people were killed, and all but a handful of buildings burned to the ground. Coos County is working to make sure this fire hazard is reduced through vegetation management requirements.