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Oregon Department of Geology and Mineral Industries
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OPEN-FILE REPORT O-13-05

LANDSLIDE INVENTORY, SUSCEPTIBILITY MAPS, AND RISK ANALYSIS FOR THE CITY OF ASTORIA, CLATSOP COUNTY, OREGON

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NOTICE

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.**

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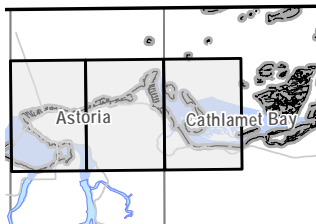
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1.0 EXECUTIVE SUMMARY

On April 15, 2008, the Oregon Department of Geology and Mineral Industries (DOGAMI) entered an intergovernmental agreement with The City of Astoria, Oregon (project no. 41570-03202008) to perform regional landslide hazard evaluation of the City of Astoria.

Deliverables of this study include:

- this report text (including results of landslide risk evaluation)
- hazard maps:
 - landslide inventory maps (Plates 1, 2, and 3)
 - shallow landslide susceptibility maps (Plates 4, 5, and 6)
 - deep landslide susceptibility maps (Plates 7, 8, and 9)
- geographic information system (GIS) files: landslide inventory, shallow susceptibility, deep susceptibility

A protocol for inventory mapping of landslide deposits from light detection and ranging (lidar) imagery (Burns and Madin, 2009) was used to create a landslide inventory of the City of Astoria, Oregon. One-hundred twenty landslide deposits were located within the city limits. Sixty-nine of these were classified as deep and fifty-one as shallow. The average shallow landslide area is roughly 29,959 ft² (2,783 m²), which is approximately the size of half a football field. The average deep-seated landslide area is roughly 779,302 ft² (72,399 m²), which is approximately the size of 13 football fields. In the study area the average depth of failure for shallow-seated landslides is 9.5 ft (2.9 m), and the average depth of failure for deep-seated landslides is 40 ft (12.2 m).

Eighty-three landslides in the inventory are estimated to have moved during historical time (less than 150 years ago). This is a very high number of active-historical landslides for a small city like Astoria. Seventeen of these eighty-three have recorded dates of movement in the landslide inventory database from 1932 to 2007. Several of these 17 landslides caused significant damage. The Irvine Road and 22nd Street landslide destroyed 23 homes in 1950; the First and Commercial Street landslide destroyed roughly 16 homes in 1954 and became active again in 2005. These data indicate a significant landslide hazard exists in the City of Astoria.

A protocol for shallow-landslide susceptibility mapping (Burns and others, 2011) was used to create a shallow-seated landslide susceptibility map of the City of Astoria. Roughly 55% of the city is classified as highly susceptible to shallow-seated landslides; roughly 24% as moderately susceptible to shallow-seated landslides, and 21% as less susceptible to shallow-seated landslides. The deep-seated

landslide susceptibility mapping protocol (Burns, 2008) was used to create deep-seated susceptibility maps of the City of Astoria. Roughly 37% of the city is classified as highly susceptible to deep-seated landslides; roughly 30% as moderately susceptible, and 33% as less susceptible to deep-seated landslides. Again, these results indicate a high susceptibility to both shallow- and deep-seated landslides.

After the landslide inventory and susceptibility maps were complete, they were used to conduct a landslide risk assessment. The basic process involves the identification of hazard (i.e., landslide hazards), inventory of assets, and estimation of damage and losses based on the overlap of the hazard and assets. Two methodologies were used to assess potential damage, potential losses, and exposure associated with the landslide hazards in Astoria:

- earthquake-induced landslide risk assessment (Hazardus-MH [FEMA (Federal Emergency Management Agency), 2007])
- estimated exposure (at risk) to landslide hazards

For the Hazardus-MH method, three scenarios with equal earthquakes and three levels of landslide hazards were examined:

- scenario 1: no landslide hazard (landslide hazards set to 0 out of 10)
- scenario 2: detailed landslide hazard (landslide hazards derived from detailed lidar-based mapping performed as part of this project)
- scenario 3: almost maximum landslide hazard (landslide hazards set to 9 out of 10)

This was done so the change in the loss ratios (ratio of projected loss to total inventory) from the three different levels of landslide hazard could be examined. The result was an increase in loss ratio from 36% (scenario 1) to 64% (scenario 2) to 83% (scenario 3). This indicates that in an area like Astoria, which has very high landslide hazards, losses in a major event like an earthquake are likely to be 50% greater than somewhere with low or no landslide hazards.

The second risk assessment performed as part of this study was an evaluation of exposed assets in Astoria to landslide hazards. A GIS was used to overlay the landslide hazards layers on the assets layer and to calculate the at-risk and at-risk ratios (ratio of at risk to total inventory). The results of this analysis indicate that roughly 27% of the city is at risk to landslides. All the at-risk ratios are slightly greater than 50%; however, the real market value is highest for the residential lots. Also, residential property valued at greater than 0.5 billion dollars is at-risk to landslides.

The maps and GIS databases created as part of this study are intended to provide users with basic information regarding landslides and susceptibility to landslides within the City of Astoria. The maps and GIS databases contain useful information to guide site-specific investigations for future development, to assist in regional planning and development, to mitigate existing landslides and slopes, and to prepare for emergency situations, such as storm events and earthquakes. This information is not appropriate for site-specific evaluations, but it is valuable for regional screening for landslides and selection of appropriate areas on which to focus site-specific studies.

The maps and GIS databases are particularly suitable for the activities listed below:

- public awareness campaigns
- city development ordinance
- issuance of building permit or proposed grading permit conditions
- public works planning and operations
- environmental and sustainability issues
- regional risk-reduction planning and activities
- neighborhood-scale risk-reduction activities
- avoidance of very high hazard areas
- emergency management
- buy-outs in very high or life threatening hazard areas

The primary purpose of the risk analysis portion this study is to provide users with an understanding of the general landslide risk. With the risk assessment estimate results, one can begin to:

- identify vulnerable areas that may require planning considerations
- engage stakeholders
- assess the level of readiness and preparedness to deal with a disaster before disaster occurs
- estimate potential losses from specific hazard events (before or after a disaster hits)
- decide how to allocate resources for most effective and efficient response and recovery
- prioritize mitigation measures that need to be implemented to reduce future losses

2.0 BACKGROUND

Landslides are one of the most widespread and damaging natural hazards in Oregon. In order to begin reducing losses from landslides (mitigation), areas of landslide hazard must first be located. The first step in landslide hazard identification is to create an inventory of past (historic and prehistoric) landslides. The inventory can then be used to create susceptibility maps that display areas with potential future landslide hazard.

The purpose of this study was to evaluate the regional relative landslide hazard, to perform a landslide risk analysis, and to provide recommendations to the City of Astoria (Figure 1). Seismic, civil, and environmental evaluation of any kind are beyond the scope of this project.

We performed our services in accordance with the inter-governmental agreement with the City of Astoria (project no. 41570-03202008). DOGAMI is not responsible for

independent conclusions, opinions, or recommendations made by others on the basis of information provided in this report.

Considering the dynamic environment in Oregon, the inherent risks associated with development in hilly areas, and the fact that all geologic hazard processes are not completely known to the professional and research community at this time, we warn that our report does not assure any safety or warranty from geologic hazards. The maps in this study were developed with input from many sources and expertise gained from years of experience; however, several limitations underscore that these maps are designed for regional applications and should not be used as an alternative to site-specific studies. These limitations are described in detail in Plates 1–9.

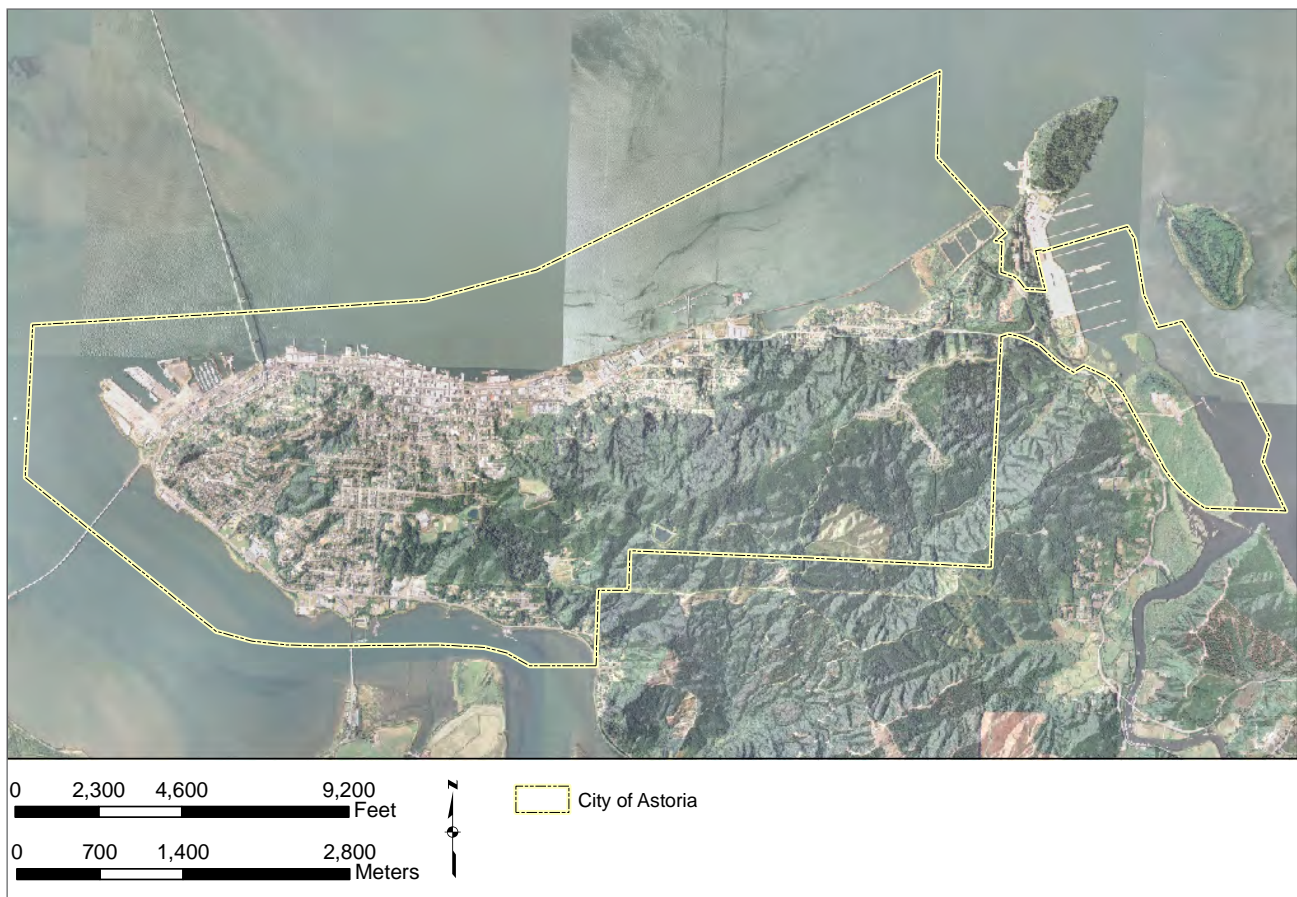


Figure 1. City of Astoria (outlined in yellow), Clatsop County, Oregon.

3.0 METHODS

As part of this study, we created three landslide hazard maps: 1) landslide inventory, 2) shallow-landslide susceptibility, and 3) deep-landslide susceptibility. The other part of this study includes a landslide risk analysis using two methodologies to assess the potential damage and losses and the exposure associated with the landslide hazards in Astoria:

1. earthquake-induced landslide risk assessment (Hazardus-MH [FEMA, 2009]) and
2. estimated exposure (at risk) to landslide hazards

The methods employed to create these maps and to perform the risk analysis are described below.

3.1 Lidar-based landslide inventory

Recently, high-resolution digital elevation models (DEM) developed using light detection and ranging (lidar) data have become available for parts of Oregon. These new data give us a much better image of the surface geomorphology and allow for identification of features associated with landslides, such as concave slope depressions, vertical or steep scarps, shear zones located along the flanks of a landslide, and shortening features of landslides such as toes, transverse ridges, and snouts (Burns, 1999). Recognition of such features can be used to identify landslides with a high level of certainty and to map them accurately. In the past, most accurate, higher-certainty landslide maps were created using a combination of aerial photography and extensive field survey. The use of a lidar-derived DEM is the key to the landslide mapping performed in this study.

Prior to beginning lidar-based mapping of landslides in the City of Astoria, we reviewed three existing landslide inventories: 1) the 1996-1997 storm events inventory (DOGAMI Special Paper 34 [Hofmeister, 2000]), 2) the Statewide Landslide Information Database for Oregon, release 1 (SLIDO-1) (Burns and others, 2008), and 3) the City of Astoria's database on historical landslides.

The latest geologic maps of the area, DOGAMI Oil and Gas Investigation OGI-14 (Niem and Niem, 1985) and DOGAMI Bulletin B-74 (Schlicker and others, 1972), were also reviewed. Niem and Niem (1985) did not identify any landslides within the City. Schlicker and others (1972) identified roughly 12 areas of "active landslide," "inactive land-

slide," and "landslide topography" within the city boundary. Hofmeister (2000) identified three landslides that occurred during 1996-1997 (Figure 2). We also reviewed DOGAMI Interpretive Map 22 (Hofmeister and others, 2002), which identified some isolated areas of potential debris flow hazards (Figure 2).

After review of regional landslide hazard studies, we mapped the entire Astoria U.S. Geological Survey 7.5 minute topographic quadrangle and the western portion of the Cathlamet Bay U.S. Geological Survey 7.5 minute topographic quadrangle (which encompass the City of Astoria) using lidar-derived DEM and DEM derivatives including shaded relief (hillshades), slope maps, and topographic contours. In addition to the lidar-derived images, we used an orthophoto of similar age to the lidar data to help differentiate between some man-made and natural landforms. We identified landslides solely from ground surface morphology. Morphologic features include head scarps, hummocky topography, convex and concave slope areas, offset drainages, flank shear offsets, and internal scarps. We created the inventory for this area following the protocol defined by Burns and Madin (2009).

Because landslides and landslide features are not all the same size, we mapped at several different scales, in this order:

- 1:24,000 scale (the native scale of a standard printed 7.5 minute topographic quadrangle)
- 1:10,000
- 1:4,000

Spatial data and tabular data were mapped into a GIS. Spatial data include the following four elements:

- polygon (outline) of the mapped landslide deposit
- polygon (outline) of the landslide head scarp
- line of the uppermost extent of the head scarp
- lines of internal scarps

However, all four of these features may not have been present or determinable at every landslide. The kinds of tabular data collected are shown in (Table 1); some of these tabular data may not have been present or determinable at every landslide. Some items are described in more detail on Plate 1.

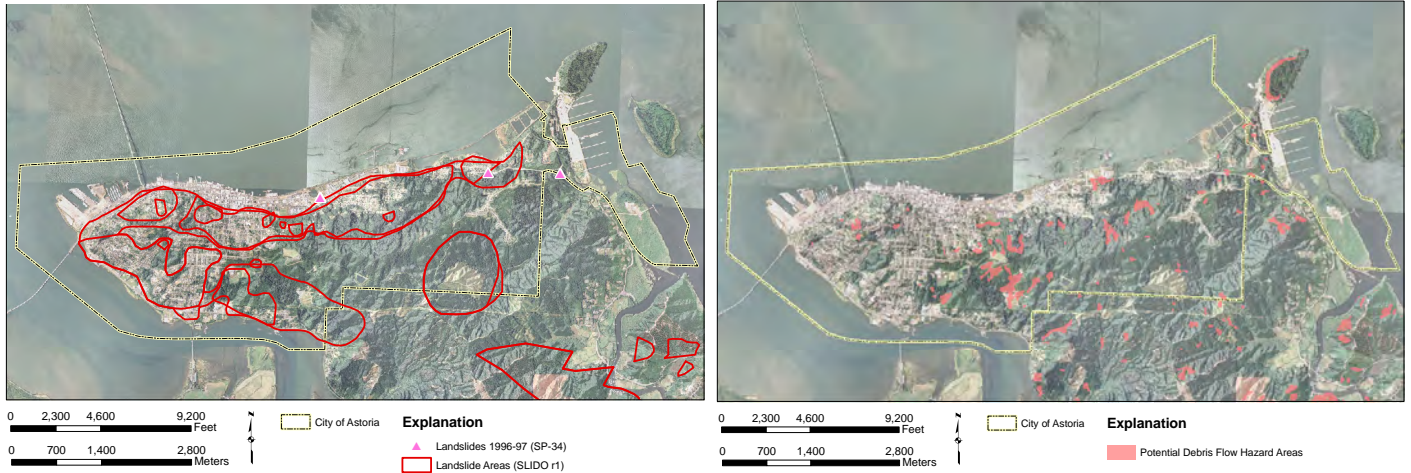


Figure 2. (left) Map of identified landslides from DOGAMI SP-34 (Hofmeister, 2000) and SLIDO-1 (Burns and others, 2008), and (right) map of potential debris flow hazard areas from DOGAMI IMS-22 (Hofmeister and others, 2002).

Table 1. Tabular data fields used for lidar-based landslide inventory.

Field Name	Brief Description
QUADNAME	7.5 minute quadrangle name
UNIQUE_ID	"QUADNAME"_"ID" *
TYPE_MOVE	type of movement
MOVE_CLASS	movement classification name
MOVE_CODE	movement classification code
CONFIDENCE	confidence of identification
AGE	estimated age
DATE_MOVE	date of last known movement
NAME	landslide name
GEOL	geologic unit
SLOPE	adjacent slope angle
HS_HEIGHT	Head scarp height: change in elevation from bottom to top of head scarp
FAIL_DEPTH	Failure depth, estimated and/or calculated slope normal thickness of failure depth
FAN_HEIGHT	change in elevation from top to toe of fan

Field Name	Brief Description
FAN_DEPTH	estimated and/or calculated fan depth
DEEP_SHAL	deep or shallow seated
HS_IS1	horizontal distance from head scarp to internal scarp no. 1
IS1_IS2	horizontal distance from internal scarp no. 1 to internal scarp no. 2
IS2_IS3	horizontal distance from internal scarp no. 2 to internal scarp no. 3
IS3_IS4	horizontal distance from internal scarp no. 3 to internal scarp no. 4
HD_AVE	Average horizontal distance between internal scarps: calculated average horizontal distance between scarps
DIRECT	direction of movement
AREA	area of landslide deposit
VOL	volume of landslide deposit

*Identification numbers (IDs) are sequential numbers (starting at 1 for the first mapped landslide) for each landslide mapped in each 7.5-minute quadrangle. The UNIQUE_ID is a concatenation of the QUADNAME and ID fields. UNIQUE_ID result in a unique code for every landslide mapped in the state of Oregon. An example of a unique ID is **Portland_1**, which indicates the first landslide mapped within the Portland quadrangle, for example.

One important tabular datum in the landslide inventory is the estimated depth of failure, which was calculated for each identified landslide as shown in Figure 3 (Burns and others, 1998; Burns, 1999; Burns and Madin, 2009).

Using estimated failure depth, we classified each landslide as deep or shallow seated. This differentiation is necessary because different models are used to calculate or estimate regional stability or susceptibility for different depths and for different types of landslides. There is no widely accepted value of division between deep and shallow landslides, so we based our value on the combination of several factors and several other studies (Sidle and Ochiai, 2006; Burns, 1999; Harp and others, 2006). We selected a division value of 15 ft (4.5 m) between shallow- and deep-seated landsliding. Burns and Madin (2009) discussed in depth the selection of this division value.

After lidar-derived DEM mapping and tabular database entry were completed, we performed ground reconnaissance to field verify the suspected landslide features. Observations made during the reconnaissance were used to revise the lidar-based landslide inventory map, as appropriate.

To assist visualization, we created 1:8,000-scale maps (Plates 1, 2, 3; reduced-size version of plate 1 in Figure 4) that display lidar-based landslide inventory data (Astoria_LSdeposits, Astoria_LSheadscarps, and Astoria_LScarps; these GIS files are provided as part of this report). These inventory maps cannot serve as substitutes for site-specific investigations by qualified practitioners. Site-specific data may give results that differ from those shown on these maps. Several other limitations about the landslide inventory mapping are listed on Plates 1, 2, and 3.

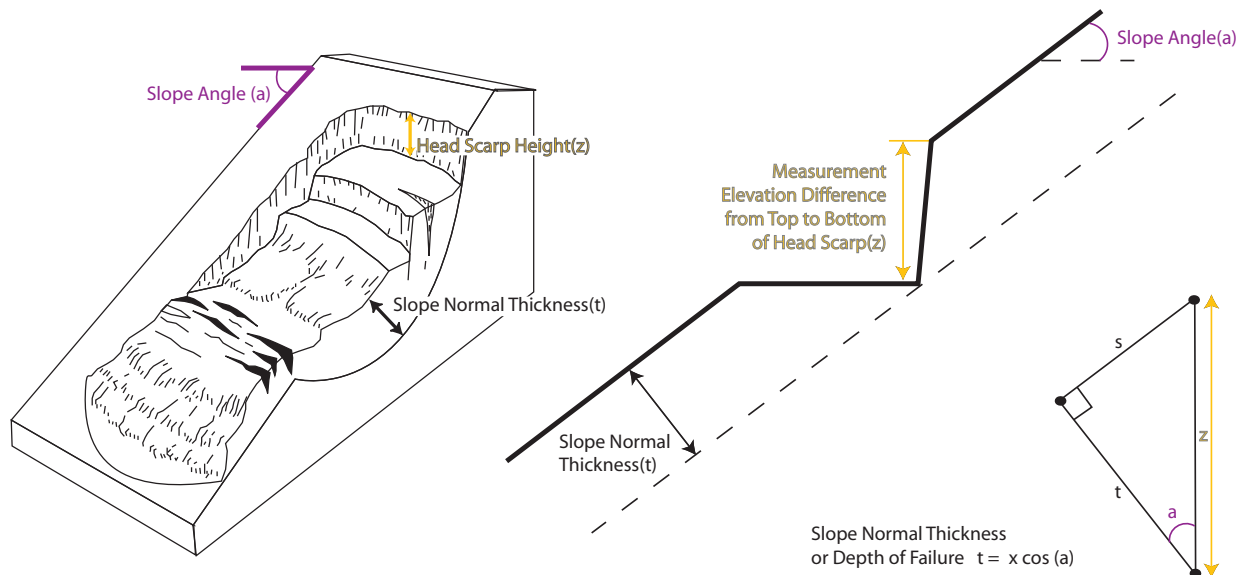
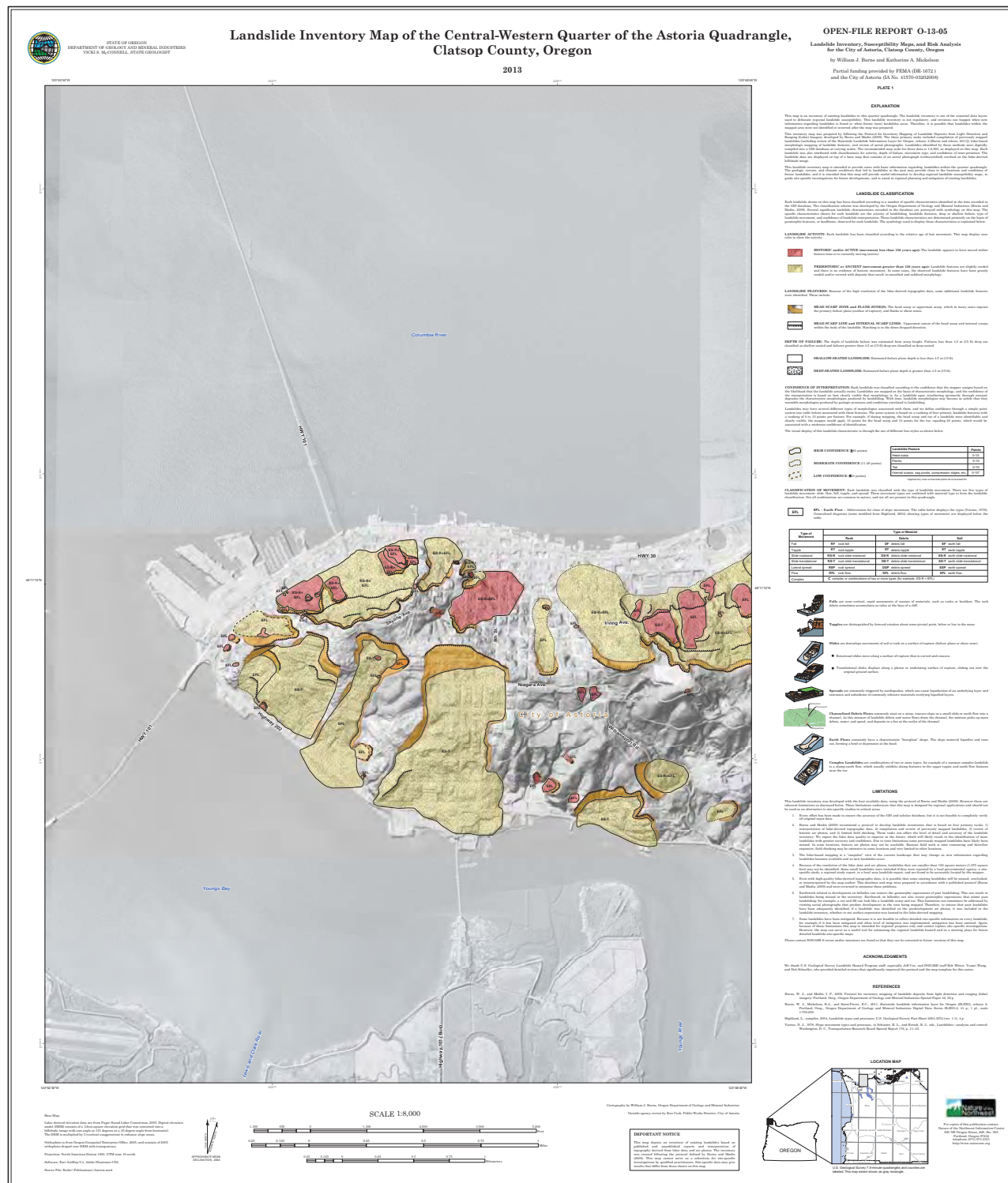


Figure 3. Diagram and equation for calculation of estimated depth of failure (after Burns and Madin, 2009).



3.2 Shallow-landslide susceptibility

The Protocol for Shallow-Landslide Susceptibility Mapping (Burns and others, 2011) was used to create the shallow-seated landslide susceptibility map. The four main components used in the protocol are (Burns and others, 2011):

- landslide inventory
- calculation of regional factor of safety (FOS)
- removal of isolated small elevation changes (noise) from the model
- buffers

Finally, the previous four factors were combined into final susceptibility hazard zones.

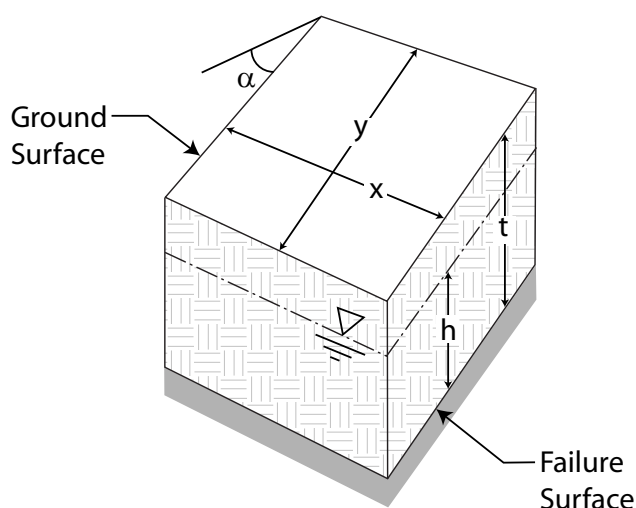
All nonchannelized debris flow deposits were queried out of the lidar-based landslide inventory database and saved to a separate GIS file.

To calculate the factor of safety (FOS) for shallow landsliding, we used the infinite-slope equation shown in Figure 5.

Because the infinite-slope equation for regional stability analysis is limited to a grid type analysis (i.e., the results are a calculated FOS for each individual grid, which does not consider the potential impact of adjacent slopes, etc.), we took a conservative approach in most steps to calculate the FOS. The limitations are discussed in greater detail later in this section and in the protocol (Burns and others, 2011).

Several data sets are needed to calculate FOS throughout the area:

- geology — material properties
- depth of failure surface
- groundwater
- slope angle



Material Properties

- c' = Cohesion (effective)
- ϕ' = Angle of Internal Friction (effective)
- γ = Soil Density (unit weight)
- γ_w = Groundwater Density (unit weight)

Other Variables

- t = Depth to Failure Surface
- m = Groundwater Depth Ratio
- α = Slope Angle (degrees)
- x = Horizontal Grid Distance (on DEM)
- y = Vertical Grid Distance (on DEM)

$$\text{Factor of Safety (FOS)} = \frac{c'}{\gamma t \sin \alpha} + \frac{\tan \phi'}{\tan \alpha} - \frac{m \gamma_w \tan \phi'}{\gamma \tan \alpha}$$

Figure 5. Infinite-slope analysis: diagram, parameters, and equation (Burns and others, 2011).

Material properties consist of cohesion, angle of internal friction, soil density, and water density. Because these properties can vary from geologic unit to unit, we constructed a digital geologic map that contains the material properties for each unit (Figure 6). These properties can also vary within a particular geologic unit, so conservative values were used for each unit.

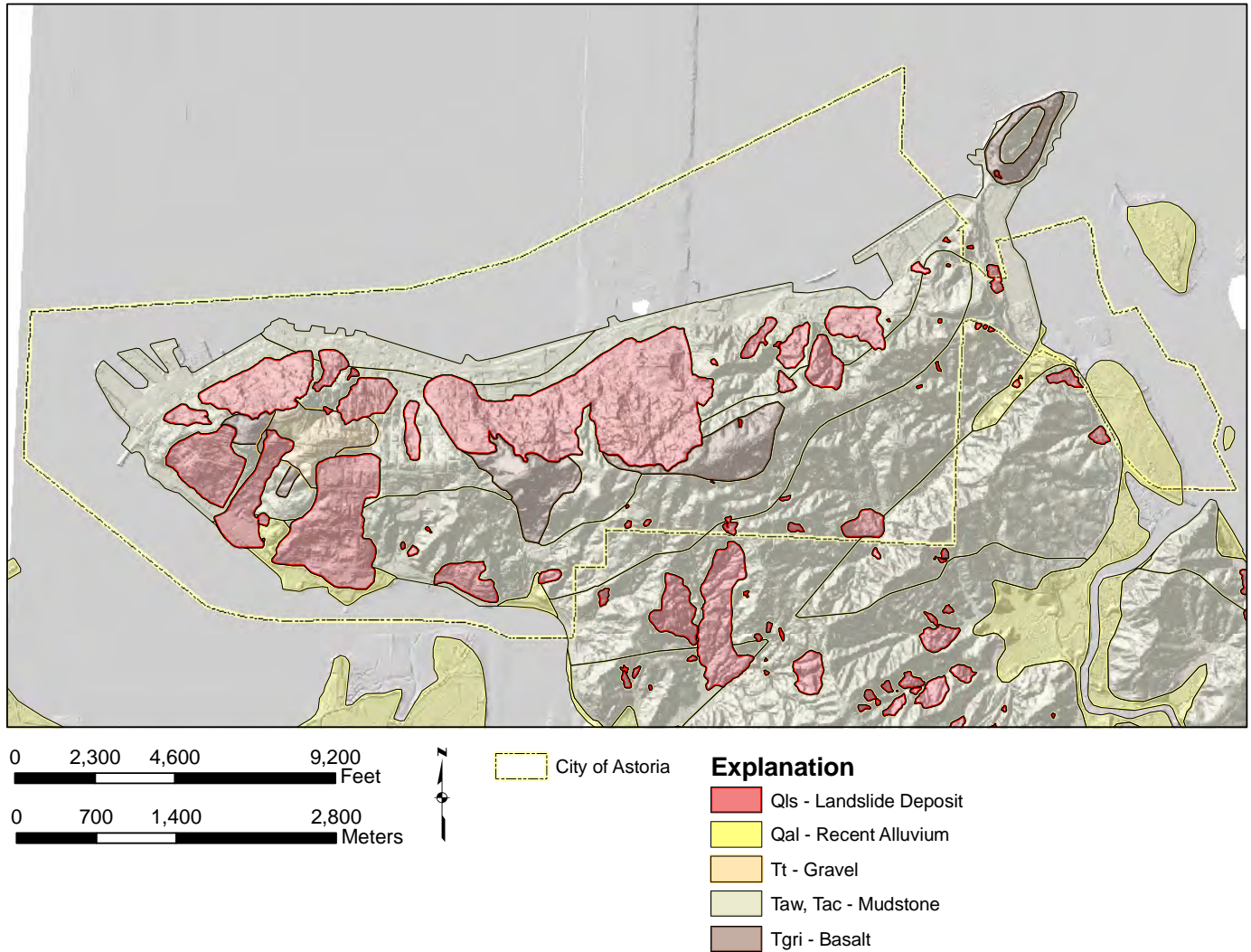


Figure 6. Geologic-material properties map of the City of Astoria (Niem and Niem, 1985).

Because material properties are not readily available for the region, we constructed and used a set of general values (Table 2).

The maximum depth of failure surface, as defined by the cutoff between shallow- and deep-seated landslides, is 4.5 m (15 ft); however, the majority (mean) of shallow landslides in the region have a failure surface roughly 2.4 m (8 ft) deep. Thus a depth of 2.4 m (8 ft) was used in the infinite-slope equation (Figure 5).

Table 2. General soil and rock material properties (Burns and others, 2011).

Common Lithology Description	Common Unit or Formation Name	Common Unit Label	Raster Value GeolCode	Angle of Internal Friction (ϕ) (degrees)	Cohesion (c)		Unit Weight (Saturated)		Slope	
					(kPa)	(lb/ft ²)	(kN/m ³)	(lb/ft ³)	Factor of Safety > 1.5	Factor of Safety > 1.25
Sheared landslide debris (silts, clays, sands)	landslide	Qls	—	10	0	0	19	122	3.0	4.0
Shearing mainly along deep failure plane	landslide, colluvium	Qls, Qc	1	28	0	0	19	122	9.5	11.5
Sand, silt, gravel, debris mixtures	artificial fill	Fill, Qf	2	30	0	0	19	122	10.5	12.5
Silt, sand	Quaternary alluvium, loess	Qal, Qff, Ql	3	30	0	0	19	122	10.5	12.5
Sand, gravel, boulders	Quaternary alluvium, gravel fan	Qal, Qcf	4	34	0	0	19	122	12.0	14.5
Sand, silt, clay, gravel	glacial till	Qva, Qt	5	34	10	209	19	122	16.5	19.5
Silty clay with boulders	Columbia River Basalt	Tcr	6	28	24	501	19	122	20.0	24.0
Silty sand, sandy silt, silty gravel	Troutdale Formation	Tt	7	30	10	209	19	122	14.5	17.5

The groundwater parameter can vary widely spatially and with time. Because of these potential variations, we selected a worst-case scenario (most conservative) approach: complete saturation, i.e., z , depth of failure surface, equal to h , groundwater height above failure surface (Figure 5).

The high-resolution lidar-derived digital elevation model (DEM) was used to create a map of slope angles for each grid cell (Figure 7), satisfying the slope angle parameter in the infinite slope equation.

Once the FOS was calculated, we removed isolated small elevation changes from the resulting FOS map. This was done by calculating the range of elevation changes (i.e., flat areas, slopes, to vertical escarpments) within a horizontal distance of 15 ft of any grid cell. After the range of elevation change had been calculated, all cells with values less than 4 ft were removed from the high or moderate FOS class (Burns and others, 2011).

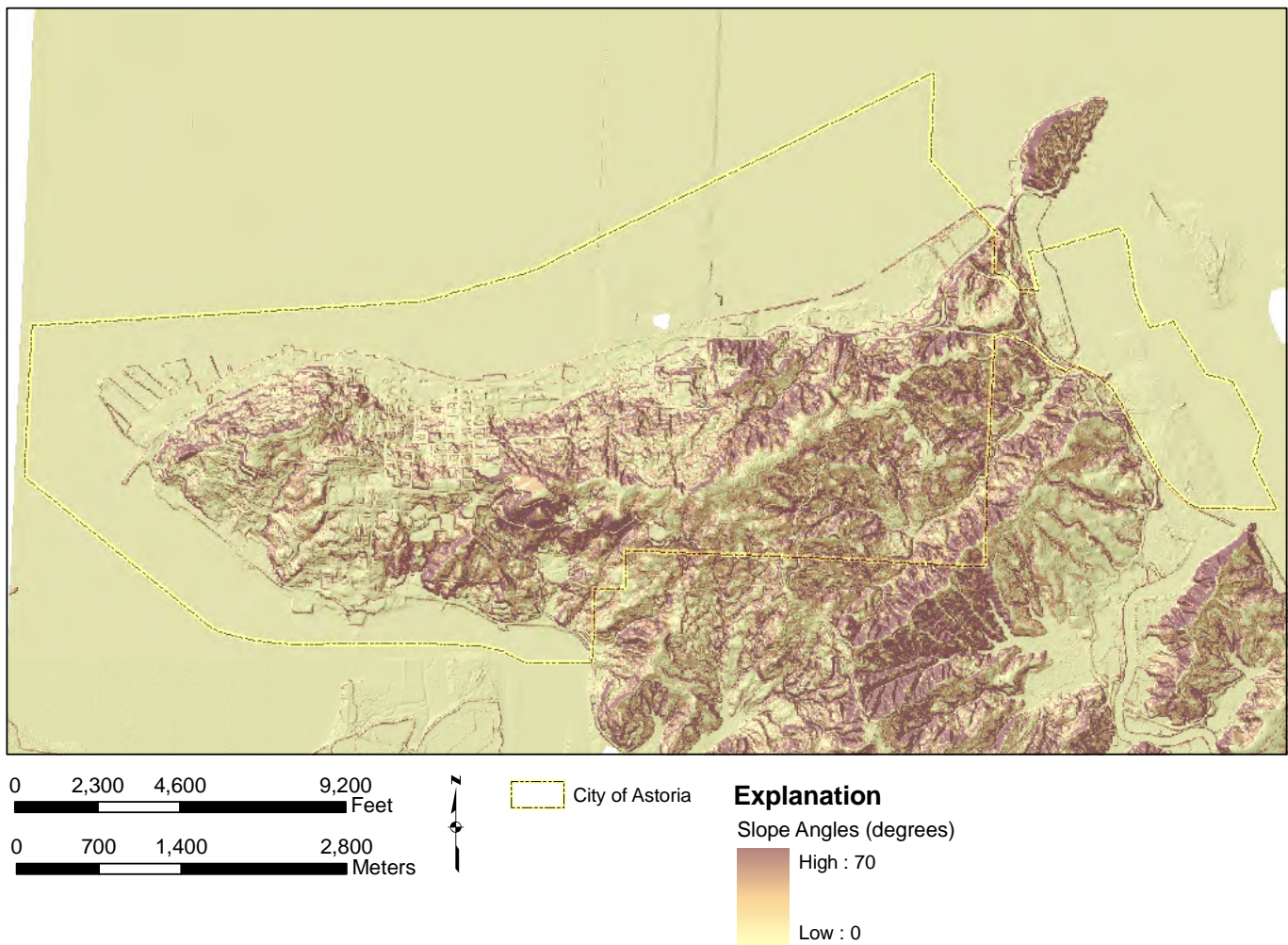


Figure 7. Slope map of the City of Astoria, created from lidar-derived digital elevation model.

Because there are many limitations to regional stability analysis using the infinite slope equation and unknowns due to general lack of material properties data spatially, we applied a 2:1 horizontal to vertical distance ratio (2H:1V; Figure 8) buffer to both the head scarp and the FOS, as described below.

Most landslides tend to leave a near-vertical head scarp above the failed mass. Commonly, this head scarp area will fail retrogressively or a separate landslide will form above

the head scarp due to loss of resisting forces. Generally, the area above the head scarp has a relatively low slope angle; thus, the factor of safety calculated using the infinite-slope equation on a grid is relatively high — indicating a low susceptibility of future failure. To account for the increase in susceptibility of this area above the head scarp, which is missed when using the infinite-slope equation alone, we used a 2:1 horizontal to vertical distance ratio (2H:1V) head scarp buffer (Figure 9).

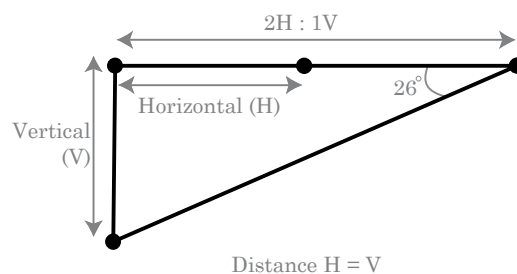


Figure 8. Diagram of the 2:1 horizontal to vertical distance ratio (2H:1V) (Burns and others, 2011).

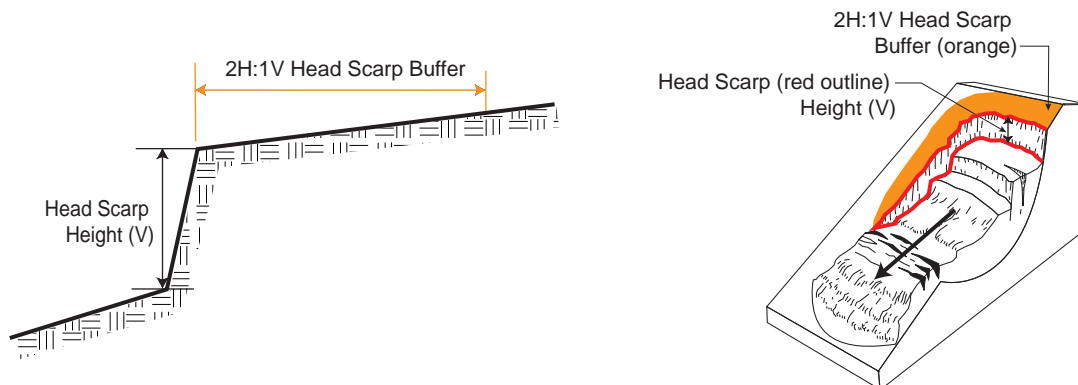


Figure 9. Diagram of the two horizontal to one vertical distance ratio (2H:1V) head scarp buffer (Burns and others, 2011).

Because use of the infinite slope equation for regional stability analysis is limited to a grid type analysis (i.e., the results are a calculated FOS for each individual grid, which does not consider the potential impact of adjacent slopes, etc.), we applied a buffer to all areas with a calculated FOS less than 1.5 or the areas considered to be potentially unstable. This buffer was applied both up and down slope of the areas with a calculated FOS less than 1.5 as shown in Figure 10.

To create the final shallow-landslide hazard zones, we combined the contributing factors (Table 3).

The shallow-landslide susceptibility zones are presented on 1:8,000-scale maps (Plates 4, 5, and 6; reduced-size version of Plate 4 in Figure 11) to display the lidar-based shallow-landslide susceptibility data (LSshallow-suscept; these GIS files are provided as part of this report). We created the susceptibility zones following the protocol defined by Burns and others (2011). These maps cannot serve as substitutes for site-specific investigations by qualified practitioners. Site-specific data may give results that differ from those shown on the maps. Several other limitations are listed on Plates 4, 5, and 6.

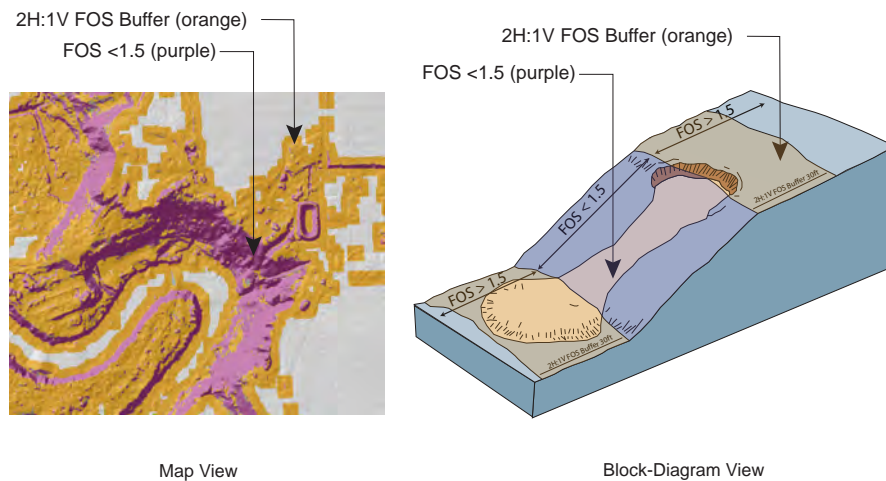


Figure 10. Diagram of the two horizontal to one vertical distance ratio (2H:1V) buffer (Burns and others, 2011).

Table 3. Final hazard zone matrix for shallow landslides.

Contributing Factors	Final Susceptibility Zones		
	High	Moderate	Low
❶ Factor of Safety (FOS)	less than 1.25	1.25 – 1.5	greater than 1.5
❷ Landslide Deposits and Head Scarps	included	—	—
❸ Buffers	2H:1V (head scarps)	2H:1V (FOS less than 1.5)	—

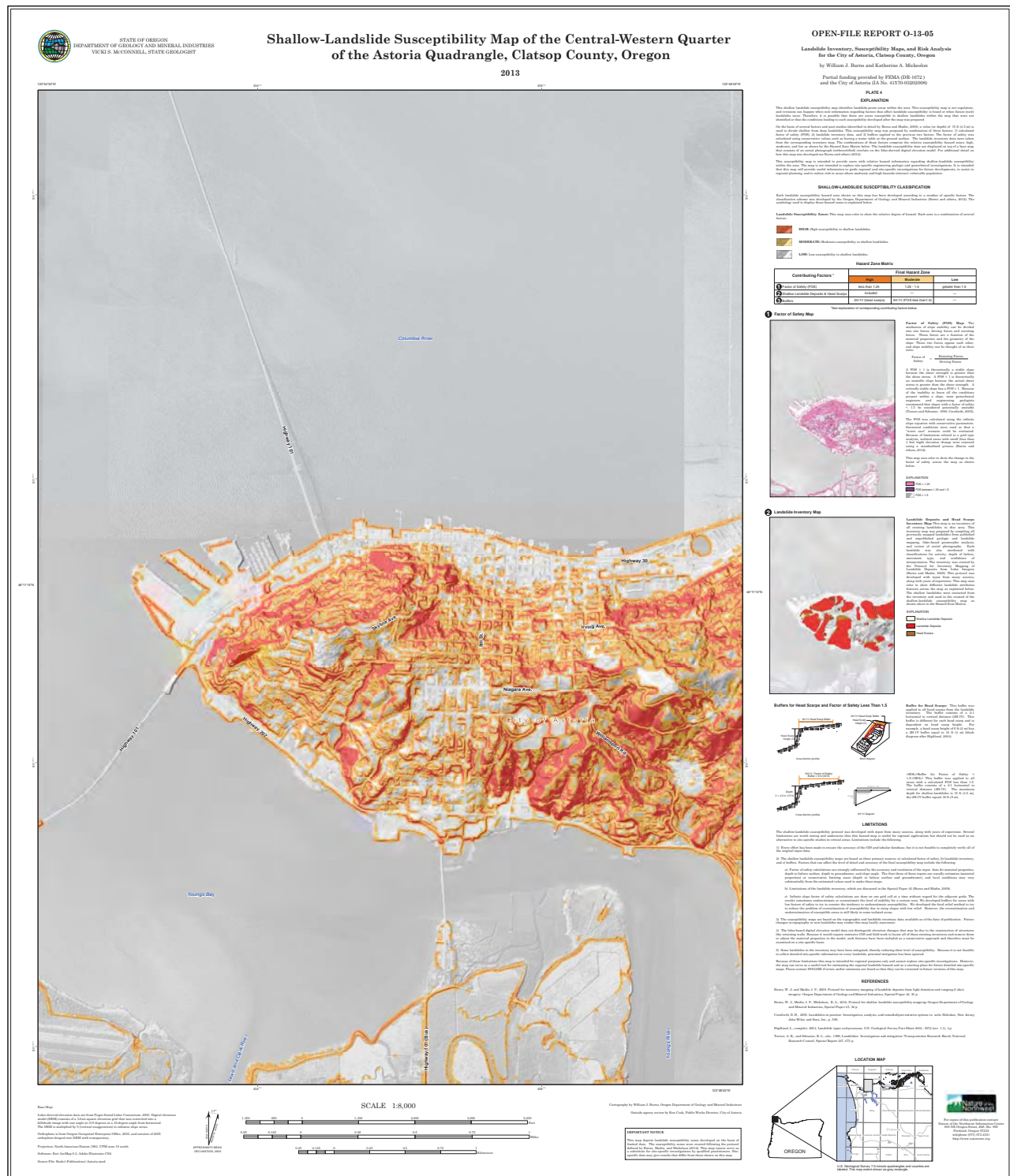


Figure 11. Shallow-seated landslide susceptibility map (reduced size image of Plate 4 of this report) of the central-western portion of the Astoria quadrangle, Clatsop County, Oregon.

3.3 Deep-landslide susceptibility

Using the lidar-based landslide inventory and several other data sets, we created a deep-landslide (depth greater than 15 ft [4.5 m]) susceptibility map using four main components following the method developed by Burns (2008):

- deep-landslide inventory
- buffers
- geologic units and slope angles
- combination of the previous three factors into final susceptibility hazard zones

All deep slides, flows, and spreads were queried out of the lidar-based landslide inventory database and saved to a separate GIS file.

Many deep landslides move repeatedly over hundreds or thousands of years and, commonly, the continued movement is through retrogressive failure or progressive upslope failure of the head scarp. To account for this potential upslope hazard, we applied a buffer to all mapped deep-seated landslide deposits as shown in Figure 12.

Because there are many unknowns involved with regional susceptibility models, we also applied a 2H:1V buffer on all landslide head scarps as shown in Figure 13.

These two buffers were applied to all head scarps from the deep-landslide inventory. In all cases the greater of the two buffers was used.

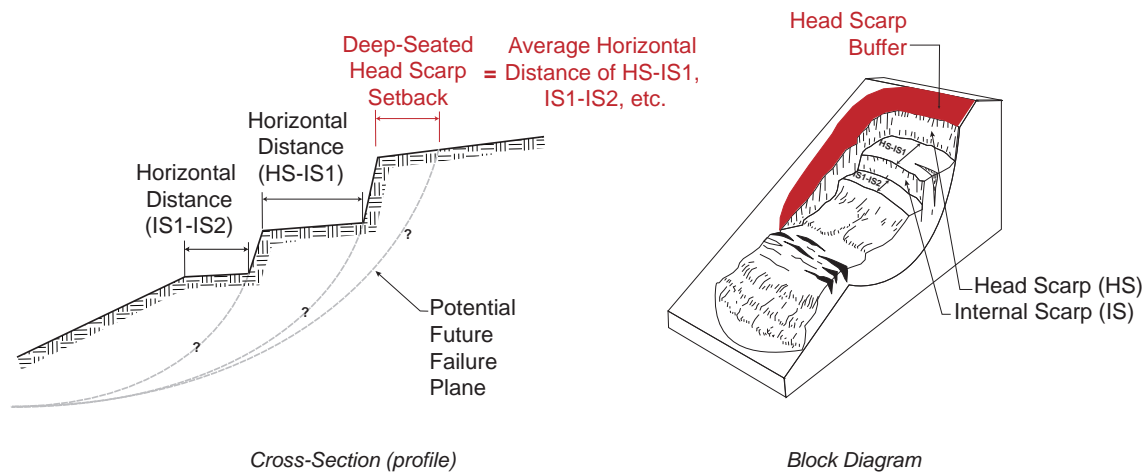


Figure 12. Head scarp retrogression buffer (Burns and Madin, 2009).

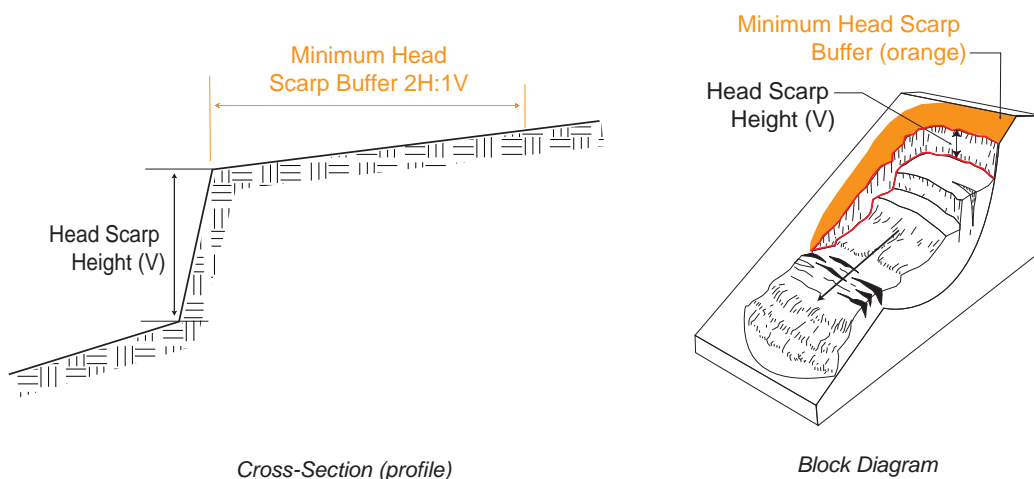


Figure 13. Head scarp buffer (Burns and Madin, 2009).

The last component in the deep-seated landslide susceptibility model is a combination of four factors:

- susceptible geologic units or units that contain identified deep-seated landslides from the inventory
- slope angles greater than 10 degrees
- relative proximity to identified deep landslides from the inventory
- educated judgment of the mapper

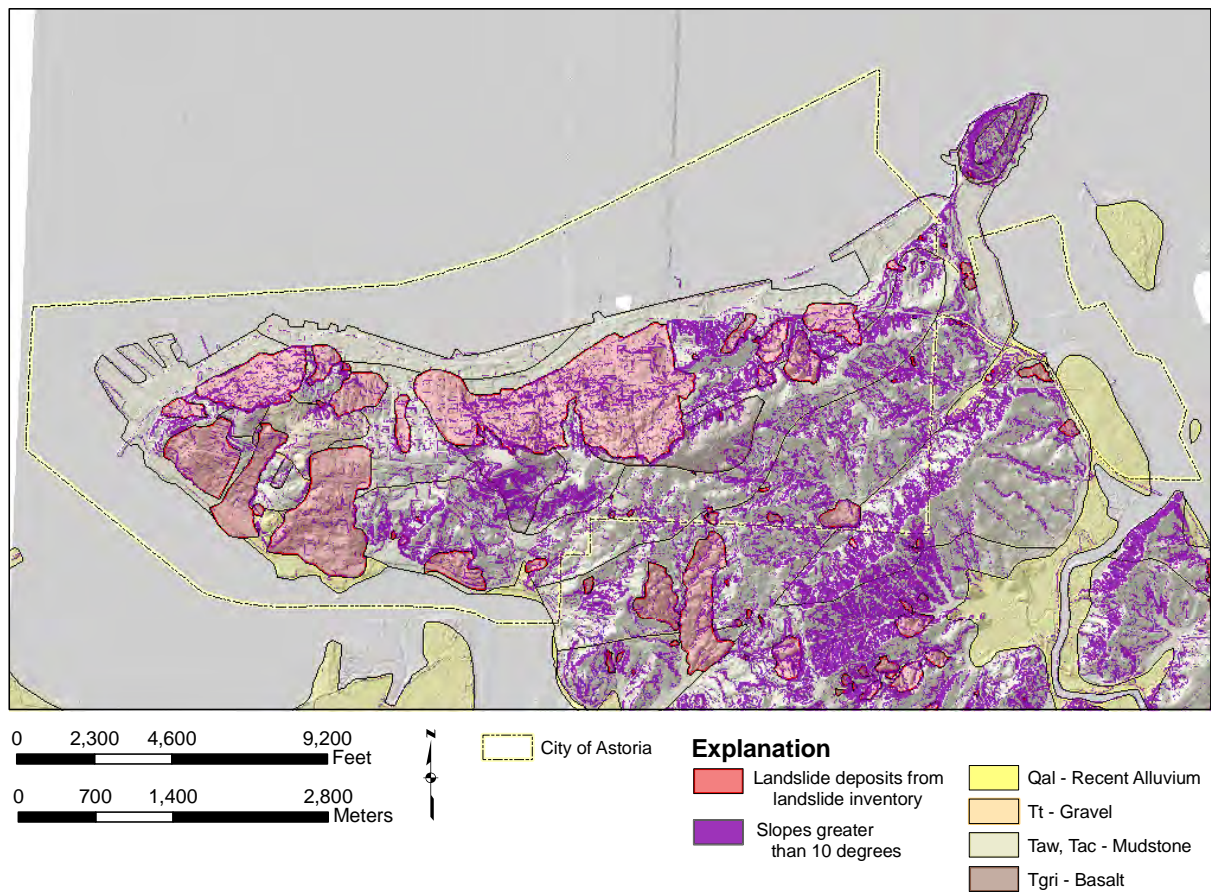
First, we set up a generalized geologic map overlain with slopes greater than 10 degrees (Figure 14). These two data sets, along with the other two factors (proximity and judgment), were used to create the boundary between the moderate and low deep-seated landslide susceptibility zones.

A slope angle of 10 degrees was selected on the basis of the lowest measured slope in the landslide inventory database.

We followed the lidar-based deep-landslide susceptibility mapping protocol (Burns, 2008) to create the moderate and low deep-landslide susceptibility hazard zones. The map uses color to show different geologic units and slopes across the map.

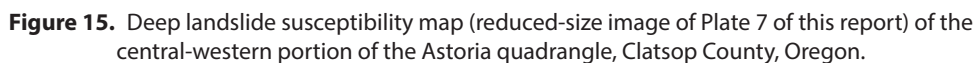
To create the final deep-landslide hazard zones, we combined several contributing factors (Table 4).

The lidar-based deep-landslide susceptibility data (LSdeep-suscept; these GIS files are provided as part of this report) are presented on 1:8,000-scale maps (Plates 7, 8, and 9; reduced-size version of Plate 7 in Figure 15). Suscep-



Contributing Factors	Final Hazard Zone		
	High	Moderate	Low
Landslide Inventory	included	—	—
Head Scarp Buffers	included	—	—
Additional Factors	—	included	included

Table 4. Final hazard zone matrix for deep landslides (Burns and Madin, 2009).



tibility zones were created following the protocol defined by Burns (2008). These maps cannot serve as substitutes for site-specific investigations by qualified practitioners. Site-specific data may give results that differ from those shown on the maps. Several other limitations are listed on Plates 7, 8, and 9.

3.4 Risk assessment

After we completed the landslide inventory and susceptibility maps, we used them to conduct a landslide hazard risk assessment of the City of Astoria. The basic process involves identification of hazard (i.e., landslide hazards), inventory of assets, and estimation of damage and losses based on the overlap of the hazard and assets (Figure 16).

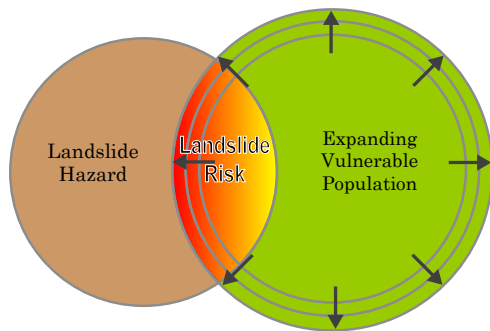


Figure 16. Risk diagram displaying the overlap of the landslide hazard and the vulnerable population (modified after Wood, 2007).

Risk analysis can range from the simple overlap of the hazard and assets to very complicated probabilistic hazards and detailed asset vulnerability analysis. There is no current standard of practice for performing landslide risk analysis, such as Hazus-MH for evaluating earthquake, wind, and flood risk (FEMA, 2009). Therefore, we propose using two methods that, when used together, create a relatively comprehensive landslide risk analysis.

The two methodologies we used to assess the potential damage and losses and the exposure associated with the landslide hazards in Astoria are:

- earthquake-induced landslide risk assessment (Hazus-MH: FEMA, 2009), and
- estimated exposure (at risk) to landslide hazards.

3.4.1 Earthquake-induced landslide risk assessment method (Hazus-MH)

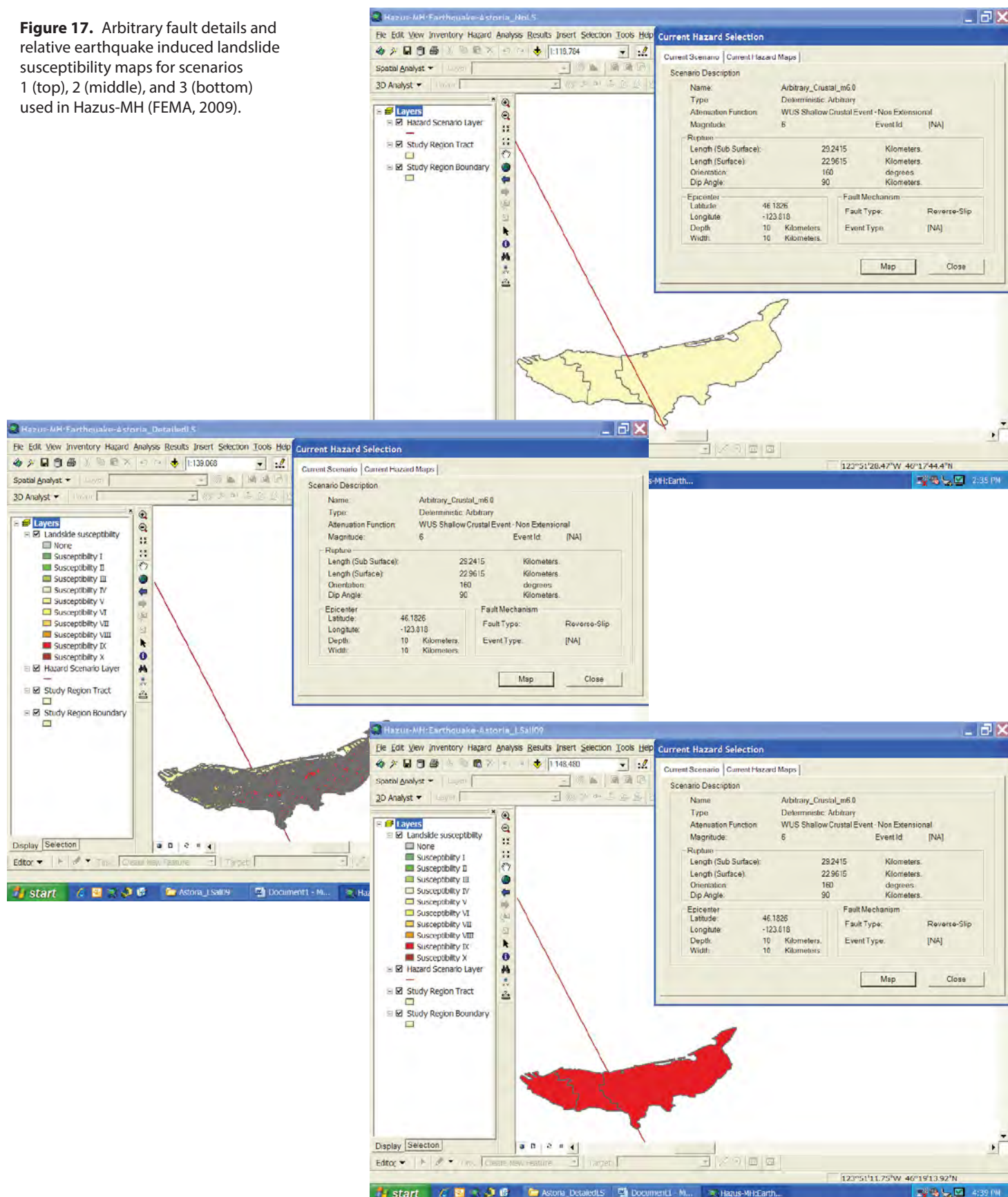
The state of the science in earthquake damage and loss estimation has improved dramatically over the last several years, and new tools allow for relatively quick and reasonably accurate regional loss estimation. One such tool is the Hazus-MH computer program developed by FEMA, the National Institute of Building Sciences (NIBS), and a host of other public and private partners (FEMA, 2009). Hazus-MH software can be used to model a variety of earthquake scenarios and to estimate regional damages such as building damage, lifeline damage (e.g., roads and utilities), and injuries.

The earthquake-induced landslide risk assessment method (hereafter called the Hazus method) was performed using FEMA's Hazus-MH MR3 (2009) software. The software was used to model an arbitrary crustal magnitude 6 earthquake scenario for three levels of landslide hazards including:

- scenario 1: no landslide hazard (landslide hazards set to 0 out of 10; see Appendix A)
- scenario 2: detailed landslide hazard (landslide hazards derived from detailed lidar-based mapping performed as part of this project; see Appendix B)
- scenario 3: almost maximum (landslide hazards set to 9 out of 10; see Appendix C)

This was done in order to estimate the range of potential damage and losses (from minimum to maximum) that can be expected from landsliding during a major earthquake in the Astoria area. The scenario consisted of an arbitrary crustal earthquake with magnitude 6.0. We defined the fault source using the "Deterministic Arbitrary" option within Hazus-MH (Figure 17) (FEMA, 2009). In general, a

Figure 17. Arbitrary fault details and relative earthquake induced landslide susceptibility maps for scenarios 1 (top), 2 (middle), and 3 (bottom) used in Hazus-MH (FEMA, 2009).



best-case scenario (scenario 1: no landslides occur during the earthquake), a realistic scenario (scenario 2: landslides occur at locations selected on the basis of detailed mapping), and a worst-case scenario (scenario 3: landslides occur almost everywhere) were developed. Figure 17 has the location of the arbitrary fault, shown as the dark brown line, and the census tracks within the City of Astoria.

In general, Hazus-MH uses national scale inventory data. The inventory used in the Hazus method for all three analyses was the stock data provided with the Hazus-MH software. Table 5 presents some of these data.

We also ran scenario 2 with a Cascadia magnitude 9.0 earthquake. This scenario is included in Appendix D.

3.4.2 Earthquake exposure (at risk) to landslide hazards method

The second risk assessment performed as part of this study was an evaluation of exposed assets in Astoria to landslide hazards (hereafter called the Exposure method). Estimating exposure is different than estimating damage and loss. Because the detailed asset inventory (provided by the City of Astoria) and detailed landslide hazard data (created as part of this report) were not adequate to estimate damage and loss, exposure (or at risk) inventory was estimated as a step toward a complete evaluation of risk (FEMA, 2005).

The City of Astoria provided an inventory for buildings (Table 6). This inventory and the detailed landslide inventory hazard maps created in this study were used. A GIS was used to overlay these two layers and to calculate the at-risk and at-risk ratio (ratio of at-risk to total inventory). As can be seen from Table 6, the total building value provided by the City of Astoria is roughly \$1.3 billion. The building value provided in Hazus (Table 5) is roughly \$0.9 billion — a difference of \$400 million.

Table 5. Summary of building, critical facility, and infrastructure inventory data for the City of Astoria as provided within the Hazus-MH software.

	Count	Value
Buildings (total)	3,566	\$943,000,000
Residential	3,425	\$691,130,000
Commercial	101	\$179,229,000
<i>Other building types categorized in the Hazus database are not included here in order to facilitate comparison with Table 6.</i>		
Critical facilities		
Hospital	1	
Schools	5	
Fire stations	1	
Police stations	3	
Infrastructure		
Highway		\$1,744,079,000
Waste water		\$76,897,000
Potable water		\$40,361,000
Natural gas		\$1,093,000
Communication		\$339,000

Table 6. Summary of the City of Astoria building inventory as provided by the City of Astoria.

Buildings	Count (Tax Lots)	Percent (of Buildings Total)	Value
Buildings (total)	5,648		\$1,325,319,000
Residential	4,916	87%	\$823,450,000
Commercial	642	11%	\$251,823,000
Public	90	2%	\$12,346,000

4.0 RESULTS AND CONCLUSIONS

The results of this study include three landslide hazard maps: 1) lidar-based landslide inventory, 2) shallow-seated landslide susceptibility, and 3) deep-seated landslide susceptibility; and a landslide risk analysis using two methodologies: 1) earthquake induced landslide risk assessment (Hazus-MH) and 2) estimated exposure (at risk) to landslide hazards. The results are described in greater detail below.

4.1 Landslide hazard maps

We followed the Protocol for Inventory Mapping of Landslide Deposits from Light Detection and Ranging (Lidar) Imagery (Burns and Madin, 2009) to create a landslide inventory of the City of Astoria, Oregon. One-hundred twenty landslide deposits were located within the City of Astoria. Sixty-nine of these were classified as deep and fifty-one as shallow. The average pre-failure slope angle is 24 degrees. Some statistics for deep-seated and shallow-seated landslide areas are shown in Table 7.

In this area the average depth of failure for shallow-seated landslides is 9.5 ft (2.9 m), and the average depth of failure for deep-seated landslides is 40 ft (12.2 m). In general, the Astoria Formation dips south-southeast at roughly 5–30 degrees. As a result, deep-seated landslides located along the south facing slopes (i.e., dip slopes) in the southern half of Astoria appear to be large bedrock translational landslides that are likely failing along bedding planes. In general, this type of landslide results in large, semi-intact blocks of earth moving laterally down slope (Figure 18 on the south side of the main east-west trending ridge).

Table 7. Statistics for deep-seated and shallow-seated landslide areas.

Deep-Seated Landslides	Area (Square Feet)	Area (Number of Football Fields)
Minimum	5,491	0.1
Maximum	10,574,300	183.6
Sum	52,992,567	920.0
Average	779,302	13.5
Shallow-Seated Landslides		
Minimum	1,666	0.03
Maximum	238,986	4.2
Sum	1,468,001	25.5
Average	29,959	0.5

In contrast, the deep-seated landslides located along the north facing slopes (i.e. reverse-dip slopes) in the northern half of Astoria appear to be complex landslides, generally combinations of rotational and translational slides combined with earth flows. The types of landslides occurring in these reverse-dip slope areas, in general, can result in relatively greater internal shearing (than occurs with the translational slides on the south facing slopes), which can result in relatively lower overall material strength (Figure 18). Furthermore, the landslides along the north facing slopes have greater historical activity than do those along south facing slopes.

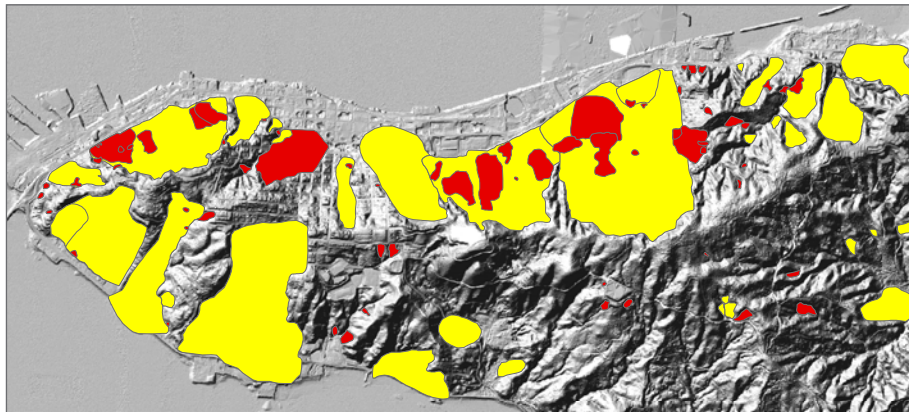


Figure 18. Map of historical (red) and pre-historical (yellow) landslides. Note the higher concentration of historical landslides along the north facing slopes.

Again, this increase in historical activity along the northern slopes is likely due to a combination of factors including: 1) the type of landsliding (i.e., complex slide plus flow slides) caused by the reverse-dip slope structure, 2) a resulting higher frequency of landslide activity caused partially by the landslide type, and 3) the increased grading and storm water runoff caused partially by the denser development during historical time.

Eighty-three of the total landslides in the inventory are estimated to have moved during historical time (within the last 150 years). This is a very high number of active historical landslides for a small city. Seventeen of these eighty-three have recorded dates of movement in the landslide inventory database from 1932 to 2007. Several of these 17 landslides caused significant damage. The Irvine Road and 22nd Street landslide destroyed 23 homes in 1950. The First and Commercial Street landslide destroyed roughly 16 homes in 1954 (Dole, 1954) (Figure 19) and became active again in 2005 (Figure 20). These data indicate a significant pre-historical and historical landslide hazard in the City of Astoria.

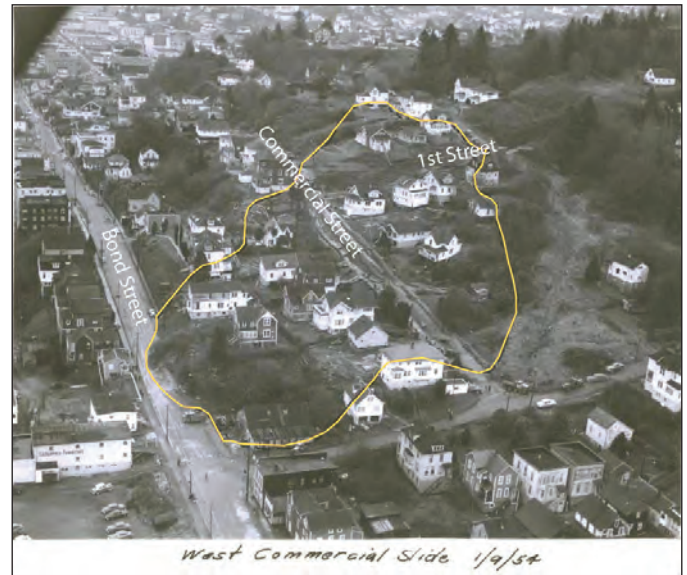


Figure 19. Oblique aerial photo of the 1st and Commercial Street Landslide (1954). Landslide extent shown in yellow. Photo from the City of Astoria.



Figure 20. Photos of the First and Commercial Street landslide near the toe along Bond Street (left) and the head scarp along First Street (right).

One of the landslide threats in 2009 is not within the city limits; however, it poses a threat to the potable water system used by everyone in the city and thus is a high risk (Figure 21).



Figure 21. Photo showing the City of Astoria's potable water main proximity to an active landslide.

We used the Protocol for Shallow-Seated Landslide Susceptibility Mapping (Burns and others, 2009) to create a shallow-seated landslide susceptibility map of the City of Astoria. Roughly 55% of the city is classified as highly susceptible to shallow-seated landslides, roughly 24% as moderately susceptible to shallow-seated landslides, and 21% as less susceptible to shallow-seated landslides.

We used a deep-seated landslide susceptibility mapping protocol (Burns, 2008) to create a deep-seated landslide susceptibility map of the City of Astoria. Roughly 37% of the city is classified as highly susceptible to deep-seated landslides; roughly 30% as moderately susceptible, and 33% as less susceptible to deep-seated landslides.

As previously discussed, we developed the landslide inventory and susceptibility maps with input from many sources and expertise gained from years of experience; however, several limitations underscore that these maps are designed for regional applications and should not be used as an alternative to site-specific studies in critical areas. These limitations are described in detail on Plates 1–9.

4.2 Hazus-MH method results

The second major component of this study was to conduct a landslide hazard risk assessment of the City of Astoria. Again, the Hazus method (earthquake-induced landslide risk assessment) was performed using FEMA Hazus-MH software. The general purpose of risk assessment (damage and loss estimation) is to evaluate potential impacts of the hazard on exposure and to identify areas where planning and mitigation can be implemented most effectively. A number of default databases are included with the Hazus program. The majority of the data are based on national scale information that often does not accurately reflect local conditions. However, the *ratios* of damage and losses to the existing inventory do reflect relatively accurate percentages. Again, the methodology used in this study (i.e., a parametric landslide hazard risk analysis) will result in poor individual counts or amounts of losses; however, the ratios will reflect better expected results. The results from these are summarized in Tables 8, 9, and 10 and Appendices A, B, C, and D.

Table 8, scenario 1 (no landslides) shows that roughly 69 buildings (1.9%) would be completely damaged, and police and fire stations would be functioning at roughly 30%. Table 8, scenario 2 (landslides included) shows that the expected completely damaged building count more than doubles and the functionality of critical facilities is reduced by nearly 50%, with police and fire stations operating at only about 15%.

Table 8. Hazus-MH results for scenarios 1, 2, and 3.

	Expected Damage Count (Complete Damage)	Ratio (Complete Damage / Inventory)	Functionality (Total % After 1 Day)	Losses	Loss Ratio	Total Losses (Buildings and Lifelines)	Total Loss Ratio
Hazus-MH, Scenario 1 Results (landslide hazards set to 0 out of 10)							
Buildings (Total)	69	2%		\$203,040,000	22%	\$341,030,000	12%
Residential	51	2%		\$104,900,000	15%		
Commercial	14	14%		\$75,770,000	42%		
Critical Facilities							
Hospital			13%				
Schools			29%				
Fire stations			27%				
Police stations			28%				
Infrastructure							
Highway				\$99,670,000	6%		
Waste water				\$14,330,000	19%		
Potable water				\$8,481,000	21%		
Natural gas				\$156,000	14%		
Communication				\$73,000	22%		
Hazus-MH, Scenario 2 Results (landslide hazards derived from detailed lidar-based mapping performed as part of this project)							
Buildings (total)	188	5%		\$360,060,000	38%	\$601,190,000	21%
Residential	142	4%		\$178,071,450	26%		
Commercial	34	34%		\$138,801,390	77%		
Critical facilities							
Hospital			3%				
Schools			15%				
Fire stations			14%				
Police stations			14%				
Infrastructure							
Highway				\$188,183,000	11%		
Waste water				\$20,673,000	27%		
Potable water				\$12,026,000	30%		
Natural gas				\$402,000	37%		
Communication				\$102,000	30%		
Hazus-MH, Scenario 3 Results (landslide hazards set to 9 out of 10)							
Buildings (total)	538	15%		\$644,190,000	68.3%	\$786,030,000	27%
Residential	503	15%		\$415,861,300	60.2%		
Commercial	25	25%		\$171,116,810	95.5%		
Critical facilities							
Hospital			0.0%				
Schools			0.0%				
Fire stations			0.0%				
Police stations			0.0%				
Infrastructure							
Highway				\$103,643,000	6%		
Waste water				\$14,232,000	19%		
Potable water				\$8,358,000	21%		
Natural gas				\$52,000	5%		
Communication				\$73,000	22%		

In Figure 22, the total loss ratios for the scenarios are shown to increase from 12% (scenario 1) to 21% (scenario 2) to 27% (scenario 3). These results indicate a significant increase in losses caused by the landslides. The effect of the landslides results in nearly doubling the losses caused by the earthquake shaking alone. This effect is likely to occur in areas with high landslide hazards, like the City of Astoria.

The loss ratios for the lifelines (highway, waste water, potable water, natural gas, communications) ranged from roughly 10% to 40% for scenario 2. These ratios are only for the direct losses to the lifelines and do not include the indirect effects which can be significant and sometimes greater than the direct losses, especially in the case of lifelines. For example, the landslides caused by an earthquake or large storm could close all the major transportation systems in and out of Astoria, which would result in indirect losses due to the halt of the movement of goods and services along those systems.

We also ran scenario 2 with a Cascadia magnitude 9.0 earthquake to compare to the arbitrary crustal event results. In general, the results are increased throughout. For example, the complete building damage for the Cascadia event is 1,325 versus 188 for the arbitrary crustal event. The estimated total economic loss increased from roughly \$600 million (crustal) to roughly \$800 million (Cascadia). The Hazus-generated global summary report is included as Appendix D.

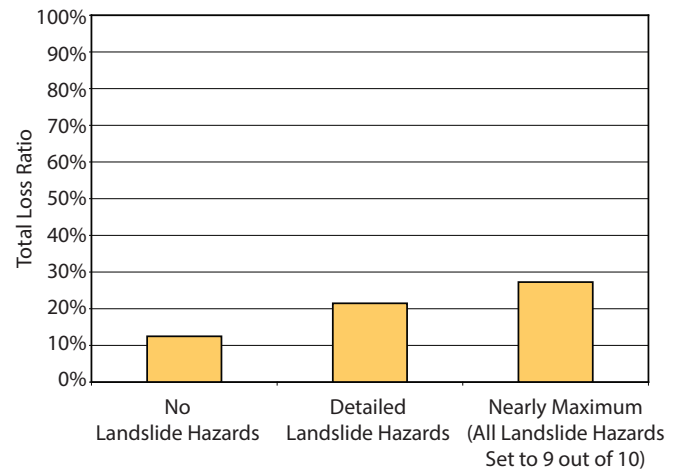


Figure 22. Total loss ratios for Hazus-MH scenarios 1, 2, and 3.

4.3 Exposure (at risk) method results

The second risk assessment performed as part of this study was an evaluation of exposed assets in Astoria to landslide hazards. Again, the City of Astoria provided a building inventory (Table 6). A GIS was used to overlay these two layers and to calculate the at-risk and at-risk ratio (ratio of at-risk to total inventory). The results from this analysis are summarized in Table 9 and Table 10.

Table 9 shows that over one quarter of the area of the City of Astoria is at risk to landslides. Table 10 shows that 3,316 lots in the City of Astoria are at risk to landslides. In Table 10, real market values are shown as a way to compare the at-risk ratios. The at-risk ratios are all slightly greater than 50%; however, the real market value is highest for residential lots. Residential property valued at greater than 0.5 billion dollars is at risk to landslides.

Table 9. Results of exposure evaluation from the landslide inventory and City of Astoria data.

	Area (sq ft)	Number of Slides	Percent of City Limits
City limits (includes only area on land)	176,710,100		
Historical landslides	8,211,000	83	5%
All landslides	48,519,000	120	27%

Table 10. Results of at-risk tax lots, at-risk ratios, and tax lot real market values.

	Number of Tax Lots				Tax Lot Real Market Value		
	Total	Average Tax Lot Area (sq ft)	Intersected with Landslides		Total	Intersected with Landslides	
			At-Risk	At-Risk Ratio		At-Risk	At-Risk Ratio
Commercial	4,916	97,000	431	67%	\$251,823,378	\$131,646,219	52%
Public	642	11,000	17	19%	\$19,867,291	\$12,346,795	62%
Residential	90	167,000	2,868	58%	\$823,450,867	\$534,432,903	65%
Total	5,648	—	3,316	59%	\$1,325,319,668	\$678,425,917	51%

5.0 DISCUSSION AND RECOMMENDATIONS

The City of Astoria has a very high landslide hazard and high risk. Over one quarter of the city is underlain by 120 landslides. Eighty-three of these landslides have moved during historical time or are currently active. Tens of these 83 landslides have resulted in significant damage ranging from simple residential street fill embankment failures to significant damage throughout entire neighborhoods with tens of houses, streets, and infrastructure effected. Furthermore, risk analysis indicates that a loss ratio of roughly 65% can be expected in a major earthquake with roughly 50% of the damage and losses resulting from landslides. The exposure analysis indicates that roughly one quarter of the city is at risk to landslides. Taken together, these data indicate that a significant landslide risk exists in the City of Astoria and thus there is a strong need for landslide risk management.

The maps and GIS databases created as part of this study are intended to provide users with basic information regarding landslides and susceptibility to landslides within the City of Astoria. The maps and GIS databases contain useful information to guide site-specific investigations for future development, to assist in regional planning and development, to mitigate existing landslides and slopes, and to prepare for emergency situations, such as storm events and earthquakes. We reiterate that this information is not appropriate for site-specific evaluations, but it is valuable for regional screening for landslides and selection of appropriate areas on which to focus site-specific studies.

The maps and GIS databases are particularly suitable for:

- Public awareness campaigns
- City development regulation-ordinance
- Issuance of building permit or proposed grading permit conditions
- Public works planning and operations
- Environmental and sustainability issues
- Regional risk-reduction planning and activities
- Neighborhood scale risk-reduction activities
- Avoidance of very high hazard areas
- Emergency management
- Buy-outs in very high or life threatening hazard areas

The primary purpose of the risk analysis portion of this study is to provide users with an understanding of the general landslide risk, enable future risk prioritization, and focus resource allocation toward high priority areas as shown in Figure 23. With risk assessments results, one can begin to manage landslide risk by:



Figure 23. Landslide risk management diagram (modified after Wang, 2008).

- Identifying vulnerable areas that may require planning considerations
- Engaging stakeholders
- Assessing the level of readiness and preparedness to deal with a disaster before disaster occurs
- Estimating potential losses from specific hazard events (before or after a disaster hits)
- Deciding how to allocate resources for most effective and efficient response and recovery
- Prioritizing mitigation measures that need to be implemented to reduce future losses

An example of preparedness and post-event community recovery can be examined by looking at fire station functionality the day after the modeled event. For this scenario, one can see the need to mitigate the nonfunctioning 86% of the fire stations (14% functionality, Table 8, scenario 2) so they do not become the weak link in the community's response and recovery from a disaster.

5.1 Emergency management applications

A particularly valuable use of these maps and loss estimation products is as an aid in emergency management activities such as the development and refinement of emergency response plans, public outreach activities, selection of appropriate safe-haven sites, hazard response drills, and

estimation of resource impacts for various hazard scenarios (Spangle Associates, 1998).

In related applications, the City of Astoria can now use the landslide hazard maps to identify infrastructure that is more or less likely to be damaged by major earthquakes and/or landslide-producing storm events. For example, by combining the hazard maps with transportation layers, potential road blockages can be identified and alternative corridors located. Similarly, the hazard maps can be combined with other information (such as the locations of hazardous waste facilities) to evaluate potential effects and to plan for emergency response.

5.2 Land use planning, zoning, and regulations

Common applications of the study outputs in the realm of land use planning, zoning, and regulations include input to comprehensive planning and the development or upgrade of an existing landslide hazard regulation and/or ordinances. While we reiterate that the relative hazard maps are not appropriate for site-specific evaluations, they are valuable for regional screening for hazards and for the selection of appropriate areas on which to focus further site-specific studies.

5.3 Evaluations of infrastructure and other regionally distributed infrastructure

Infrastructure is a general term used to refer to critical transportation and utility infrastructure, including roads and highways, railroads, airports, bridges, overpasses and underpasses, natural gas pipelines, electric lines, and water distribution systems. Infrastructure is commonly characterized by components that are dispersed over broad geographic areas that often require regional (as opposed to site-specific) risk assessments. The hazard maps presented

in this report can be useful for estimating potential future damage and pre-disaster mitigation to infrastructure. A good example is the City of Astoria's potable water main, which is threatened by landslides (Figure 21).

5.4 Landslide risk reduction program

While it is usually more cost effective to take steps toward mitigation before development occurs, the reality is that many buildings and infrastructure components were built prior to understanding the hazard.

For proposed development, land use planning, zoning, and regulations are the best risk reduction. For areas already developed, a collaborative effort including individual land owners, utility owners, city, county, state, and federal government may be required. An example of a collaborative landslide risk reduction program is the Seattle Public Utilities Landslide Awareness and Mitigation Program, started after the winter of devastating landslides of 1996-97. As part of this for landslide risk reduction program the Seattle Landslide Study (Shannon and Wilson, Inc., 2000) includes detailed recommendations regarding surface water, groundwater, retaining structures, soil reinforcement, grading, catchment-diversion structures, and vegetation.

One important landslide risk reduction activity discussed in the Seattle Landslide Study and noted in other landslide studies (for example, the Portland study [Burns and others, 1998]) is the control of surface storm water. Storm water runoff improvements are generally the least costly mitigation. An increase in storm water management will result in a decrease in landslide risk.

Critical facilities, including hospital, fire and police stations, emergency centers, and school buildings are particularly important to the community and should be designed or mitigated to withstand landslide hazards.

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7.0 REFERENCES

- Burns, W. J., 1999, Engineering geology and relative stability of the southern half of Newell Creek canyon, Oregon City, Oregon: Portland State University, Department of Geology, M.S. thesis, 143 p., 3 pls.
- Burns, W. J., 2008, Regional landslide hazard maps of the southwest quarter of the Beaverton quadrangle, West Bull Mountain Planning Area, Washington County, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-08-09, 17 p., scale 1:8,000.
- Burns, W. J., and Madin, I. P., 2009, Protocol for inventory mapping of landslide deposits from light detection and ranging (lidar) imagery: Oregon Department of Geology and Mineral Industries Special Paper 42, 30 p.
- Burns, S. F., Burns, W. J., James, D. H., and Hinkle, J. C., 1998, Landslides in the Portland, Oregon, metropolitan area resulting from the storm of February 1996: Inventory map, database, and evaluation: Portland State University, Department of Geology, report to Metro, contract 905828, 68 p.
- Burns, W. J., Madin, I. P., and Ma, L., 2008, Statewide landslide information database for Oregon (SLIDO), release 1. Web: <http://www.oregongeology.org/slido/>
- Burns, W. J., Madin, I. P., and Mickelson, K. A., 2011, Protocol for shallow-seated landslide susceptibility mapping: Oregon Department of Geology and Mineral Industries Special Paper 45, 32 p., scale 1:8,000.
- Dole, H. M., 1954, The Astoria landslides: Ore.-Bin, v. 16, no. 1, p. 1-2.
- FEMA (Federal Emergency Management Agency), 2005, Hazus-MH software, FEMA's tool for estimating potential losses from natural disasters. Available on CD-ROM disks from the Federal Emergency Management Agency (FEMA) or the National Institute of Building Sciences 1090 Vermont Avenue, NW, Suite 700 Washington, D.C., 20005-4905, phone (202) 289-7800, fax (202) 289-1092, e-mail hazus@nibs.org. Web: <http://www.fema.gov/hazus/>.
- FEMA (Federal Emergency Management Agency), 2009, Hazus-MH, MR3, FEMA's tool for estimating potential losses from natural disasters. Web: <http://www.fema.gov/hazus>
- Harp, E. L., Michael, J. A., and Laprade, W. T., 2006, Shallow-landslide hazard map of Seattle, Washington: U.S. Geological Survey Open-File Report 2006-1139, 20 p.
- Hofmeister, R. J., 2000, Slope failures in Oregon: GIS inventory for three 1996/97 storm events: Oregon Department of Geology and Mineral Industries Special Paper 34, 20 p.
- Hofmeister, R. J., Miller, D. J., Mills, K. A., Hinkle, J. C., and Beier, A. E., 2002, GIS overview map of potential rapidly moving landslide hazards in western Oregon: Oregon Department of Geology and Mineral Industries Interpretive Map IMS-22, 52 p.
- Niem, A. R., and Niem, W. A., 1985, Oil and gas investigations of Astoria basin, Clatsop and northernmost Tillamook Counties, northwestern Oregon: Oregon Department of Geology and Mineral Industries Oil and Gas Investigation OGI-14, 78 p.
- Schlicker, H. G., Deacon, R. J., Beaulieu, J. D., and Olcott, G. W., 1972, Environmental geology of the coastal region of Tillamook and Clatsop Counties, Oregon: Oregon Department of Geology and Mineral Industries Bulletin B-74, 164 p.
- Shannon and Wilson, Inc., 2000, Seattle Landslide Study: Seattle, Washington: Shannon and Wilson, Inc., prepared for Seattle Public Utilities, 164 p. Web: http://www.seattle.gov/dpd/cms/groups/pan/@pan/documents/web_informational/dpdp025740.pdf
- Sidle, R. C., and Ochiai, H., 2006, Landslides: processes, prediction, and lands use: Washington, D.C., American Geophysical Union, Water Resources Monograph 18, 312 p.
- Spangle Associates, 1998, Using earthquake hazard maps: A guide for local governments in the Portland Metropolitan Region: Oregon Department of Geology and Mineral Industries Open-File Report O-98-4, 45 p.
- Wang, Y., 2010, Oregon's Seismic Mitigation Grant Program: aka Courtney grants *in* Reaching beyond Borders, 9th U.S. National and 10th Canadian Conference on Earthquake Engineering, July 25-29, 2010, Toronto, Conference program: Oakland, Calif., Earthquake Engineering Research Institute. Web (conference program: http://materiales.azc.uam.mx/area/Estructuras/2260502/CONG_INT/2-Program%20for%20CD_2010EQConf.pdf
- Wood, N., 2007, Variations in city exposure and sensitivity to tsunami hazards in Oregon: U.S. Geological Survey Scientific Investigations Report 2007-5283, 43 p. Web: <http://pubs.usgs.gov/sir/2007/5283/>

APPENDIX A: HAZUS GLOBAL REPORT FOR SCENARIO 1

HAZUS-MH: Earthquake Event Report

Region Name: Astoria_NoLS

Earthquake Scenario: Arbitrary_Crustal_m6.0

Print Date: March 05, 2009

Totals only reflect data for those census tracts/blocks included in the user's study region.

Disclaimer:

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

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General Description of the Region

HAZUS is a regional earthquake loss estimation model that was developed by the Federal Emergency Management Agency and the National Institute of Building Sciences. The primary purpose of HAZUS is to provide a methodology and software application to develop earthquake losses at a regional scale. These loss estimates would be used primarily by local, state and regional officials to plan and stimulate efforts to reduce risks from earthquakes and to prepare for emergency response and recovery.

The earthquake loss estimates provided in this report was based on a region that includes 1 county(ies) from the following state(s):

Oregon

Note:

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

The geographical size of the region is 6.77 square miles and contains 3 census tracts. There are over 4 thousand households in the region and has a total population of 10,375 people (2000 Census Bureau data). The distribution of population by State and County is provided in Appendix B.

There are an estimated 3 thousand buildings in the region with a total building replacement value (excluding contents) of 943 (millions of dollars). Approximately 96.00 % of the buildings (and 73.00% of the building value) are associated with residential housing.

The replacement value of the transportation and utility lifeline systems is estimated to be 1,815 and 113 (millions of dollars) , respectively.

Building and Lifeline Inventory

Building Inventory

HAZUS estimates that there are 3 thousand buildings in the region which have an aggregate total replacement value of 943 (millions of dollars) . Appendix B provides a general distribution of the building value by State and County.

In terms of building construction types found in the region, wood frame construction makes up 91% of the building inventory. The remaining percentage is distributed between the other general building types.

Critical Facility Inventory

HAZUS breaks critical facilities into two (2) groups: essential facilities and high potential loss (HPL) facilities. Essential facilities include hospitals, medical clinics, schools, fire stations, police stations and emergency operations facilities. High potential loss facilities include dams, levees, military installations, nuclear power plants and hazardous material sites.

For essential facilities, there are 1 hospitals in the region with a total bed capacity of 37 beds. There are 5 schools, 1 fire stations, 3 police stations and 0 emergency operation facilities. With respect to HPL facilities, there are 0 dams identified within the region. Of these, 0 of the dams are classified as 'high hazard'. The inventory also includes 0 hazardous material sites, 0 military installations and 0 nuclear power plants.

Transportation and Utility Lifeline Inventory

Within HAZUS, the lifeline inventory is divided between transportation and utility lifeline systems. There are seven (7) transportation systems that include highways, railways, light rail, bus, ports, ferry and airports. There are six (6) utility systems that include potable water, wastewater, natural gas, crude & refined oil, electric power and communications. The lifeline inventory data are provided in Tables 2 and 3.

The total value of the lifeline inventory is over 1,928.00 (millions of dollars). This inventory includes over 35 kilometers of highways, 5 bridges, 273 kilometers of pipes.

Table 2: Transportation System Lifeline Inventory

System	Component	# locations/ # Segments	Replacement value (millions of dollars)
Highway	Bridges	5	1,630.60
	Segments	12	113.50
	Tunnels	0	0.00
	Subtotal		1,744.10
Railways	Bridges	0	0.00
	Facilities	2	4.90
	Segments	6	21.30
	Tunnels	0	0.00
	Subtotal		26.30
Light Rail	Bridges	0	0.00
	Facilities	0	0.00
	Segments	0	0.00
	Tunnels	0	0.00
	Subtotal		0.00
Bus	Facilities	0	0.00
	Subtotal		0.00
Ferry	Facilities	0	0.00
	Subtotal		0.00
Port	Facilities	19	45.10
	Subtotal		45.10
Airport	Facilities	0	0.00
	Runways	0	0.00
	Subtotal		0.00
		Total	1,815.50

Table 3: Utility System Lifeline Inventory

System	Component	# Locations / Segments	Replacement value (millions of dollars)
Potable Water	Distribution Lines	NA	2.70
	Facilities	1	37.60
	Pipelines	0	0.00
	Subtotal		40.40
Waste Water	Distribution Lines	NA	1.60
	Facilities	1	75.30
	Pipelines	0	0.00
	Subtotal		76.90
Natural Gas	Distribution Lines	NA	1.10
	Facilities	0	0.00
	Pipelines	0	0.00
	Subtotal		1.10
Oil Systems	Facilities	0	0.00
	Pipelines	0	0.00
	Subtotal		0.00
Electrical Power	Facilities	0	0.00
	Subtotal		0.00
Communication	Facilities	3	0.30
	Subtotal		0.30
		Total	118.70

Earthquake Scenario

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

Scenario Name	Arbitrary_Crustal_m6.0
Type of Earthquake	Arbitrary
Fault Name	NA
Historical Epicenter ID #	NA
Probabilistic Return Period	NA
Longitude of Epicenter	-123.82
Latitude of Epicenter	46.18
Earthquake Magnitude	6.00
Depth (Km)	10.00
Rupture Length (Km)	22.96
Rupture Orientation (degrees)	160.00
Attenuation Function	WUS Shallow Crustal Event - Non Extensional

Building Damage

Building Damage

HAZUS estimates that about 1,348 buildings will be at least moderately damaged. This is over 38.00 % of the total number of buildings in the region. There are an estimated 69 buildings that will be damaged beyond repair. The definition of the 'damage states' is provided in Volume 1: Chapter 5 of the HAZUS technical manual. Table 4 below summarizes the expected damage by general occupancy for the buildings in the region. Table 5 summarizes the expected damage by general building type.

Table 4: Expected Building Damage by Occupancy

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	1	0.06	1	0.05	1	0.09	1	0.21	0	0.41
Commercial	12	1.24	16	1.32	33	3.39	26	8.72	14	19.53
Education	1	0.08	1	0.07	2	0.16	1	0.41	1	0.83
Government	2	0.18	2	0.17	4	0.39	3	1.01	1	1.99
Industrial	1	0.14	2	0.13	4	0.37	3	1.02	1	1.99
Other Residential	110	11.30	144	11.55	145	14.71	72	24.37	25	35.77
Religion	1	0.14	2	0.14	3	0.28	2	0.71	1	1.45
Single Family	843	86.86	1,079	86.57	795	80.61	187	63.56	26	38.03
Total	971		1,246		986		294		69	

Table 5: Expected Building Damage by Building Type (All Design Levels)

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Wood	937	96.46	1199	96.18	881	89.34	201	68.56	24	34.67
Steel	6	0.65	6	0.48	19	1.89	18	6.29	9	13.09
Concrete	9	0.91	10	0.79	20	2.08	16	5.38	5	7.46
Precast	2	0.22	2	0.16	6	0.59	7	2.39	3	4.48
RM	1	0.10	1	0.05	2	0.17	2	0.64	1	0.81
URM	11	1.09	18	1.45	33	3.31	27	9.24	20	29.52
MH	6	0.57	11	0.89	26	2.61	22	7.49	7	9.95
Total	971		1,246		986		294		69	

*Note:

RM Reinforced Masonry
URM Unreinforced Masonry
MH Manufactured Housing

Essential Facility Damage

Before the earthquake, the region had 37 hospital beds available for use. On the day of the earthquake, the model estimates that only 4 hospital beds (13.00%) are available for use by patients already in the hospital and those injured by the earthquake. After one week, 38.00% of the beds will be back in service. By 30 days, 83.00% will be operational.

Table 6: Expected Damage to Essential Facilities

Classification	Total	# Facilities		
		At Least Moderate Damage > 50%	Complete Damage > 50%	With Functionality > 50% on day 1
Hospitals	1	1	0	0
Schools	5	0	0	0
EOCs	0	0	0	0
PoliceStations	3	0	0	0
FireStations	1	0	0	0

Transportation and Utility Lifeline Damage

Table 7 provides damage estimates for the transportation system.

Table 7: Expected Damage to the Transportation Systems

System	Component	Number of Locations				
		Locations/ Segments	With at Least Mod. Damage	With Complete Damage	With Functionality > 50 %	
					After Day 1	After Day 7
Highway	Segments	12	0	0	12	12
	Bridges	5	1	0	4	5
	Tunnels	0	0	0	0	0
Railways	Segments	6	0	0	6	6
	Bridges	0	0	0	0	0
	Tunnels	0	0	0	0	0
	Facilities	2	1	0	2	2
Light Rail	Segments	0	0	0	0	0
	Bridges	0	0	0	0	0
	Tunnels	0	0	0	0	0
	Facilities	0	0	0	0	0
Bus	Facilities	0	0	0	0	0
Ferry	Facilities	0	0	0	0	0
Port	Facilities	19	0	0	19	19
Airport	Facilities	0	0	0	0	0
	Runways	0	0	0	0	0

Note: Roadway segments, railroad tracks and light rail tracks are assumed to be damaged by ground failure only. If ground failure maps are not provided, damage estimates to these components will not be computed.

Tables 8-10 provide information on the damage to the utility lifeline systems. Table 8 provides damage to the utility system facilities. Table 9 provides estimates on the number of leaks and breaks by the pipelines of the utility systems. For electric power and potable water, HAZUS performs a simplified system performance analysis. Table 10 provides a summary of the system performance information.

Table 8 : Expected Utility System Facility Damage

System	# of Locations				
	Total #	With at Least Moderate Damage	With Complete Damage	with Functionality > 50 %	
				After Day 1	After Day 7
Potable Water	1	1	0	0	1
Waste Water	1	1	0	0	1
Natural Gas	0	0	0	0	0
Oil Systems	0	0	0	0	0
Electrical Power	0	0	0	0	0
Communication	3	3	0	3	3

Table 9 : Expected Utility System Pipeline Damage (Site Specific)

System	Total Pipelines Length (kms)	Number of Leaks	Number of Breaks
Potable Water	137	41	10
Waste Water	82	33	8
Natural Gas	55	35	9
Oil	0	0	0

Table 10: Expected Potable Water and Electric Power System Performance

	Total # of Households	Number of Households without Service				
		At Day 1	At Day 3	At Day 7	At Day 30	At Day 90
Potable Water	4,253	0	0	0	0	0
Electric Power		0	0	0	0	0

Induced Earthquake Damage

Fire Following Earthquake

Fires often occur after an earthquake. Because of the number of fires and the lack of water to fight the fires, they can often burn out of control. HAZUS uses a Monte Carlo simulation model to estimate the number of ignitions and the amount of burnt area. For this scenario, the model estimates that there will be 1 ignitions that will burn about 0.02 sq. mi 0.29 % of the region's total area.) The model also estimates that the fires will displace about 64 people and burn about 6 (millions of dollars) of building value.

Debris Generation

HAZUS estimates the amount of debris that will be generated by the earthquake. The model breaks the debris into two general categories: a) Brick/Wood and b) Reinforced Concrete/Steel. This distinction is made because of the different types of material handling equipment required to handle the debris.

The model estimates that a total of 0.00 million tons of debris will be generated. Of the total amount, Brick/Wood comprises 37.00% of the total, with the remainder being Reinforced Concrete/Steel. If the debris tonnage is converted to an estimated number of truckloads, it will require 0 truckloads (@25 tons/truck) to remove the debris generated by the earthquake.

Social Impact

Shelter Requirement

HAZUS estimates the number of households that are expected to be displaced from their homes due to the earthquake and the number of displaced people that will require accommodations in temporary public shelters. The model estimates 296 households to be displaced due to the earthquake. Of these, 79 people (out of a total population of 10,375) will seek temporary shelter in public shelters.

Casualties

HAZUS estimates the number of people that will be injured and killed by the earthquake. The casualties are broken down into four (4) severity levels that describe the extent of the injuries. The levels are described as follows;

- Severity Level 1: Injuries will require medical attention but hospitalization is not needed.
- Severity Level 2: Injuries will require hospitalization but are not considered life-threatening
- Severity Level 3: Injuries will require hospitalization and can become life threatening if not promptly treated.
- Severity Level 4: Victims are killed by the earthquake.

The casualty estimates are provided for three (3) times of day: 2:00 AM, 2:00 PM and 5:00 PM. These times represent the periods of the day that different sectors of the community are at their peak occupancy loads. The 2:00 AM estimate considers that the residential occupancy load is maximum, the 2:00 PM estimate considers that the educational, commercial and industrial sector loads are maximum and 5:00 PM represents peak commute time.

Table 11 provides a summary of the casualties estimated for this earthquake

Table 11: Casualty Estimates

		Level 1	Level 2	Level 3	Level 4
2 AM	Commercial	1	0	0	0
	Commuting	0	0	0	0
	Educational	0	0	0	0
	Hotels	1	0	0	0
	Industrial	1	0	0	0
	Other-Residential	29	7	1	2
	Single Family	14	2	0	0
	Total	46	10	1	2
2 PM	Commercial	48	13	2	4
	Commuting	0	0	0	0
	Educational	15	4	1	1
	Hotels	0	0	0	0
	Industrial	4	1	0	0
	Other-Residential	6	2	0	0
	Single Family	3	1	0	0
	Total	77	21	3	6
5 PM	Commercial	37	10	2	3
	Commuting	0	0	0	0
	Educational	2	1	0	0
	Hotels	0	0	0	0
	Industrial	3	1	0	0
	Other-Residential	11	3	0	1
	Single Family	6	1	0	0
	Total	59	16	3	5

Economic Loss

The total economic loss estimated for the earthquake is 341.03 (millions of dollars), which includes building and lifeline related losses based on the region's available inventory. The following three sections provide more detailed information about these losses.

Building-Related Losses

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

The total building-related losses were 203.04 (millions of dollars); 18 % of the estimated losses were related to the business interruption of the region. By far, the largest loss was sustained by the residential occupancies which made up over 52 % of the total loss. Table 12 below provides a summary of the losses associated with the building damage.

Table 12: Building-Related Economic Loss Estimates
(Millions of dollars)

Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Losses							
	Wage	0.00	2.32	10.17	0.12	1.13	13.75
	Capital-Related	0.00	0.98	10.02	0.07	0.19	11.25
	Rental	1.43	4.97	4.52	0.03	0.49	11.45
	Relocation	0.17	0.10	0.24	0.00	0.13	0.63
	Subtotal	1.60	8.37	24.95	0.23	1.94	37.08
Capital Stock Losses							
	Structural	7.34	7.26	9.83	0.74	2.82	27.98
	Non_Structural	31.70	32.73	28.25	2.26	8.66	103.59
	Content	8.69	7.22	12.44	1.31	4.14	33.80
	Inventory	0.00	0.00	0.31	0.26	0.03	0.60
	Subtotal	47.73	47.20	50.83	4.56	15.65	165.96
	Total	49.33	55.57	75.77	4.78	17.59	203.04

Transportation and Utility Lifeline Losses

For the transportation and utility lifeline systems, HAZUS computes the direct repair cost for each component only. There are no losses computed by HAZUS for business interruption due to lifeline outages. Tables 13 & 14 provide a detailed breakdown in the expected lifeline losses.

HAZUS estimates the long-term economic impacts to the region for 15 years after the earthquake. The model quantifies this information in terms of income and employment changes within the region. Table 15 presents the results of the region for the given earthquake.

Table 13: Transportation System Economic Losses
(Millions of dollars)

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Highway	Segments	113.46	\$0.00	0.00
	Bridges	1,630.62	\$99.67	6.11
	Tunnels	0.00	\$0.00	0.00
	Subtotal	1744.10	99.70	
Railways	Segments	21.34	\$0.00	0.00
	Bridges	0.00	\$0.00	0.00
	Tunnels	0.00	\$0.00	0.00
	Facilities	4.93	\$1.51	30.65
	Subtotal	26.30	1.50	
Light Rail	Segments	0.00	\$0.00	0.00
	Bridges	0.00	\$0.00	0.00
	Tunnels	0.00	\$0.00	0.00
	Facilities	0.00	\$0.00	0.00
	Subtotal	0.00	0.00	
Bus	Facilities	0.00	\$0.00	0.00
	Subtotal	0.00	0.00	
Ferry	Facilities	0.00	\$0.00	0.00
	Subtotal	0.00	0.00	
Port	Facilities	45.15	\$13.77	30.49
	Subtotal	45.10	13.80	
Airport	Facilities	0.00	\$0.00	0.00
	Runways	0.00	\$0.00	0.00
	Subtotal	0.00	0.00	
Total		1815.50	114.90	

Table 14: Utility System Economic Losses

(Millions of dollars)

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Potable Water	Pipelines	0.00	\$0.00	0.00
	Facilities	37.60	\$8.30	22.05
	Distribution Lines	2.70	\$0.18	6.77
	Subtotal	40.36	\$8.48	
Waste Water	Pipelines	0.00	\$0.00	0.00
	Facilities	75.30	\$14.18	18.85
	Distribution Lines	1.60	\$0.15	8.93
	Subtotal	76.90	\$14.33	
Natural Gas	Pipelines	0.00	\$0.00	0.00
	Facilities	0.00	\$0.00	0.00
	Distribution Lines	1.10	\$0.16	14.30
	Subtotal	1.09	\$0.16	
Oil Systems	Pipelines	0.00	\$0.00	0.00
	Facilities	0.00	\$0.00	0.00
	Subtotal	0.00	\$0.00	
Electrical Power	Facilities	0.00	\$0.00	0.00
	Subtotal	0.00	\$0.00	
Communication	Facilities	0.30	\$0.07	21.47
	Subtotal	0.34	\$0.07	
	Total	118.69	\$23.04	

Table 15. Indirect Economic Impact with outside aid
(Employment as # of people and Income in millions of \$)

	LOSS	Total	%
First Year			
	Employment Impact	0	0.00
	Income Impact	(2)	-2.30
Second Year			
	Employment Impact	0	0.00
	Income Impact	(5)	-7.01
Third Year			
	Employment Impact	0	0.00
	Income Impact	(6)	-9.02
Fourth Year			
	Employment Impact	0	0.00
	Income Impact	(6)	-9.02
Fifth Year			
	Employment Impact	0	0.00
	Income Impact	(6)	-9.02
Years 6 to 15			
	Employment Impact	0	0.00
	Income Impact	(6)	-9.02

Appendix A: County Listing for the Region

Clatsop,OR

Appendix B: Regional Population and Building Value Data

State	County Name	Population	Building Value (millions of dollars)		
			Residential	Non-Residential	Total
Oregon	Clatsop	10,375	691	252	943
Total State		10,375	691	252	943
Total Region		10,375	691	252	943

APPENDIX B: HAZUS GLOBAL REPORT FOR SCENARIO 2

HAZUS-MH: Earthquake Event Report

Region Name: Astoria_DetailedLS

Earthquake Scenario: Arbitrary_Crustal_m6.0

Print Date: March 06, 2009

Totals only reflect data for those census tracts/blocks included in the user's study region.

Disclaimer:

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

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General Description of the Region

HAZUS is a regional earthquake loss estimation model that was developed by the Federal Emergency Management Agency and the National Institute of Building Sciences. The primary purpose of HAZUS is to provide a methodology and software application to develop earthquake losses at a regional scale. These loss estimates would be used primarily by local, state and regional officials to plan and stimulate efforts to reduce risks from earthquakes and to prepare for emergency response and recovery.

The earthquake loss estimates provided in this report was based on a region that includes 1 county(ies) from the following state(s):

Oregon

Note:

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

The geographical size of the region is 6.77 square miles and contains 3 census tracts. There are over 4 thousand households in the region and has a total population of 10,375 people (2000 Census Bureau data). The distribution of population by State and County is provided in Appendix B.

There are an estimated 3 thousand buildings in the region with a total building replacement value (excluding contents) of 943 (millions of dollars). Approximately 96.00 % of the buildings (and 73.00% of the building value) are associated with residential housing.

The replacement value of the transportation and utility lifeline systems is estimated to be 1,815 and 113 (millions of dollars) , respectively.

Building and Lifeline Inventory

Building Inventory

HAZUS estimates that there are 3 thousand buildings in the region which have an aggregate total replacement value of 943 (millions of dollars) . Appendix B provides a general distribution of the building value by State and County.

In terms of building construction types found in the region, wood frame construction makes up 91% of the building inventory. The remaining percentage is distributed between the other general building types.

Critical Facility Inventory

HAZUS breaks critical facilities into two (2) groups: essential facilities and high potential loss (HPL) facilities. Essential facilities include hospitals, medical clinics, schools, fire stations, police stations and emergency operations facilities. High potential loss facilities include dams, levees, military installations, nuclear power plants and hazardous material sites.

For essential facilities, there are 1 hospitals in the region with a total bed capacity of 37 beds. There are 5 schools, 1 fire stations, 3 police stations and 0 emergency operation facilities. With respect to HPL facilities, there are 0 dams identified within the region. Of these, 0 of the dams are classified as 'high hazard'. The inventory also includes 0 hazardous material sites, 0 military installations and 0 nuclear power plants.

Transportation and Utility Lifeline Inventory

Within HAZUS, the lifeline inventory is divided between transportation and utility lifeline systems. There are seven (7) transportation systems that include highways, railways, light rail, bus, ports, ferry and airports. There are six (6) utility systems that include potable water, wastewater, natural gas, crude & refined oil, electric power and communications. The lifeline inventory data are provided in Tables 2 and 3.

The total value of the lifeline inventory is over 1,928.00 (millions of dollars). This inventory includes over 35 kilometers of highways, 5 bridges, 273 kilometers of pipes.

Table 2: Transportation System Lifeline Inventory

System	Component	# locations/ # Segments	Replacement value (millions of dollars)
Highway	Bridges	5	1,630.60
	Segments	12	113.50
	Tunnels	0	0.00
	Subtotal		1,744.10
Railways	Bridges	0	0.00
	Facilities	2	4.90
	Segments	6	21.30
	Tunnels	0	0.00
	Subtotal		26.30
Light Rail	Bridges	0	0.00
	Facilities	0	0.00
	Segments	0	0.00
	Tunnels	0	0.00
	Subtotal		0.00
Bus	Facilities	0	0.00
	Subtotal		0.00
Ferry	Facilities	0	0.00
	Subtotal		0.00
Port	Facilities	19	45.10
	Subtotal		45.10
Airport	Facilities	0	0.00
	Runways	0	0.00
	Subtotal		0.00
		Total	1,815.50

Table 3: Utility System Lifeline Inventory

System	Component	# Locations / Segments	Replacement value (millions of dollars)
Potable Water	Distribution Lines	NA	2.70
	Facilities	1	37.60
	Pipelines	0	0.00
	Subtotal		40.40
Waste Water	Distribution Lines	NA	1.60
	Facilities	1	75.30
	Pipelines	0	0.00
	Subtotal		76.90
Natural Gas	Distribution Lines	NA	1.10
	Facilities	0	0.00
	Pipelines	0	0.00
	Subtotal		1.10
Oil Systems	Facilities	0	0.00
	Pipelines	0	0.00
	Subtotal		0.00
Electrical Power	Facilities	0	0.00
	Subtotal		0.00
Communication	Facilities	3	0.30
	Subtotal		0.30
	Total		118.70

Earthquake Scenario

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

Scenario Name	Arbitrary_Crustal_m6.0
Type of Earthquake	Arbitrary
Fault Name	NA
Historical Epicenter ID #	NA
Probabilistic Return Period	NA
Longitude of Epicenter	-123.82
Latitude of Epicenter	46.18
Earthquake Magnitude	6.00
Depth (Km)	10.00
Rupture Length (Km)	22.96
Rupture Orientation (degrees)	160.00
Attenuation Function	WUS Shallow Crustal Event - Non Extensional

Building Damage

Building Damage

HAZUS estimates that about 1,972 buildings will be at least moderately damaged. This is over 55.00 % of the total number of buildings in the region. There are an estimated 188 buildings that will be damaged beyond repair. The definition of the 'damage states' is provided in Volume 1: Chapter 5 of the HAZUS technical manual. Table 4 below summarizes the expected damage by general occupancy for the buildings in the region. Table 5 summarizes the expected damage by general building type.

Table 4: Expected Building Damage by Occupancy

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	0	0.05	0	0.04	1	0.06	1	0.15	1	0.39
Commercial	3	0.62	7	0.68	25	1.93	32	6.32	34	17.91
Education	0	0.05	1	0.05	1	0.10	1	0.29	1	0.79
Government	1	0.11	1	0.11	3	0.23	4	0.73	4	1.96
Industrial	0	0.07	1	0.06	3	0.20	4	0.72	4	2.00
Other Residential	53	10.59	117	10.74	159	12.44	100	19.61	66	35.18
Religion	1	0.10	1	0.10	2	0.18	3	0.51	3	1.36
Single Family	443	88.41	964	88.22	1,082	84.87	365	71.68	76	40.42
Total	501		1,093		1,275		509		188	

Table 5: Expected Building Damage by Building Type (All Design Levels)

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Wood	491	98.17	1071	97.99	1,203	94.30	401	78.77	75	40.10
Steel	1	0.23	2	0.16	10	0.76	21	4.11	25	13.30
Concrete	2	0.47	4	0.40	15	1.18	21	4.09	18	9.36
Precast	1	0.10	1	0.07	4	0.28	7	1.33	8	4.45
RM	0	0.06	0	0.03	1	0.09	2	0.41	2	1.00
URM	3	0.68	10	0.88	26	2.01	31	6.02	39	21.00
MH	1	0.28	5	0.48	17	1.37	27	5.27	20	10.79
Total	501		1,093		1,275		509		188	

*Note:

RM Reinforced Masonry
URM Unreinforced Masonry
MH Manufactured Housing

Essential Facility Damage

Before the earthquake, the region had 37 hospital beds available for use. On the day of the earthquake, the model estimates that only 1 hospital beds (3.00%) are available for use by patients already in the hospital and those injured by the earthquake. After one week, 14.00% of the beds will be back in service. By 30 days, 54.00% will be operational.

Table 6: Expected Damage to Essential Facilities

Classification	Total	# Facilities		
		At Least Moderate Damage > 50%	Complete Damage > 50%	With Functionality > 50% on day 1
Hospitals	1	1	0	0
Schools	5	3	0	0
EOCs	0	0	0	0
PoliceStations	3	3	0	0
FireStations	1	1	0	0

Transportation and Utility Lifeline Damage

Table 7 provides damage estimates for the transportation system.

Table 7: Expected Damage to the Transportation Systems

System	Component	Number of Locations_				
		Locations/ Segments	With at Least Mod. Damage	With Complete Damage	With Functionality > 50 %	
					After Day 1	After Day 7
Highway	Segments	12	0	0	12	12
	Bridges	5	3	0	2	4
	Tunnels	0	0	0	0	0
Railways	Segments	6	0	0	6	6
	Bridges	0	0	0	0	0
	Tunnels	0	0	0	0	0
	Facilities	2	2	0	2	2
Light Rail	Segments	0	0	0	0	0
	Bridges	0	0	0	0	0
	Tunnels	0	0	0	0	0
	Facilities	0	0	0	0	0
Bus	Facilities	0	0	0	0	0
Ferry	Facilities	0	0	0	0	0
Port	Facilities	19	19	0	19	19
Airport	Facilities	0	0	0	0	0
	Runways	0	0	0	0	0

Note: Roadway segments, railroad tracks and light rail tracks are assumed to be damaged by ground failure only. If ground failure maps are not provided, damage estimates to these components will not be computed.

Tables 8-10 provide information on the damage to the utility lifeline systems. Table 8 provides damage to the utility system facilities. Table 9 provides estimates on the number of leaks and breaks by the pipelines of the utility systems. For electric power and potable water, HAZUS performs a simplified system performance analysis. Table 10 provides a summary of the system performance information.

Table 8 : Expected Utility System Facility Damage

System	# of Locations				
	Total #	With at Least Moderate Damage	With Complete Damage	with Functionality > 50 %	
				After Day 1	After Day 7
Potable Water	1	1	0	0	1
Waste Water	1	1	0	0	1
Natural Gas	0	0	0	0	0
Oil Systems	0	0	0	0	0
Electrical Power	0	0	0	0	0
Communication	3	3	0	3	3

Table 9 : Expected Utility System Pipeline Damage (Site Specific)

System	Total Pipelines Length (kms)	Number of Leaks	Number of Breaks
Potable Water	137	106	26
Waste Water	82	84	21
Natural Gas	55	89	22
Oil	0	0	0

Table 10: Expected Potable Water and Electric Power System Performance

	Total # of Households	Number of Households without Service				
		At Day 1	At Day 3	At Day 7	At Day 30	At Day 90
Potable Water	4,253	17	0	0	0	0
Electric Power		2,890	1,674	620	106	4

Induced Earthquake Damage

Fire Following Earthquake

Fires often occur after an earthquake. Because of the number of fires and the lack of water to fight the fires, they can often burn out of control. HAZUS uses a Monte Carlo simulation model to estimate the number of ignitions and the amount of burnt area. For this scenario, the model estimates that there will be 1 ignitions that will burn about 0.02 sq. mi 0.29 % of the region's total area.) The model also estimates that the fires will displace about 64 people and burn about 6 (millions of dollars) of building value.

Debris Generation

HAZUS estimates the amount of debris that will be generated by the earthquake. The model breaks the debris into two general categories: a) Brick/Wood and b) Reinforced Concrete/Steel. This distinction is made because of the different types of material handling equipment required to handle the debris.

The model estimates that a total of 0.00 million tons of debris will be generated. Of the total amount, Brick/Wood comprises 34.00% of the total, with the remainder being Reinforced Concrete/Steel. If the debris tonnage is converted to an estimated number of truckloads, it will require 0 truckloads (@25 tons/truck) to remove the debris generated by the earthquake.

Social Impact

Shelter Requirement

HAZUS estimates the number of households that are expected to be displaced from their homes due to the earthquake and the number of displaced people that will require accommodations in temporary public shelters. The model estimates 550 households to be displaced due to the earthquake. Of these, 147 people (out of a total population of 10,375) will seek temporary shelter in public shelters.

Casualties

HAZUS estimates the number of people that will be injured and killed by the earthquake. The casualties are broken down into four (4) severity levels that describe the extent of the injuries. The levels are described as follows;

- Severity Level 1: Injuries will require medical attention but hospitalization is not needed.
- Severity Level 2: Injuries will require hospitalization but are not considered life-threatening
- Severity Level 3: Injuries will require hospitalization and can become life threatening if not promptly treated.
- Severity Level 4: Victims are killed by the earthquake.

The casualty estimates are provided for three (3) times of day: 2:00 AM, 2:00 PM and 5:00 PM. These times represent the periods of the day that different sectors of the community are at their peak occupancy loads. The 2:00 AM estimate considers that the residential occupancy load is maximum, the 2:00 PM estimate considers that the educational, commercial and industrial sector loads are maximum and 5:00 PM represents peak commute time.

Table 11 provides a summary of the casualties estimated for this earthquake

Table 11: Casualty Estimates

		Level 1	Level 2	Level 3	Level 4
2 AM	Commercial	2	0	0	0
	Commuting	0	0	0	0
	Educational	0	0	0	0
	Hotels	2	0	0	0
	Industrial	1	0	0	0
	Other-Residential	60	17	3	5
	Single Family	27	5	0	1
	Total	92	23	3	6
2 PM	Commercial	101	31	5	10
	Commuting	0	0	0	0
	Educational	31	10	2	3
	Hotels	0	0	0	0
	Industrial	10	3	0	1
	Other-Residential	13	4	1	1
	Single Family	6	1	0	0
	Total	162	49	8	16
5 PM	Commercial	78	24	4	8
	Commuting	0	1	1	0
	Educational	4	1	0	0
	Hotels	0	0	0	0
	Industrial	6	2	0	1
	Other-Residential	24	7	1	2
	Single Family	11	2	0	0
	Total	124	37	7	11

Economic Loss

The total economic loss estimated for the earthquake is 601.19 (millions of dollars), which includes building and lifeline related losses based on the region's available inventory. The following three sections provide more detailed information about these losses.

Building-Related Losses

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

The total building-related losses were 360.06 (millions of dollars); 17 % of the estimated losses were related to the business interruption of the region. By far, the largest loss was sustained by the residential occupancies which made up over 49 % of the total loss. Table 12 below provides a summary of the losses associated with the building damage.

Table 12: Building-Related Economic Loss Estimates
(Millions of dollars)

Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Losses							
	Wage	0.00	3.93	16.76	0.22	1.88	22.79
	Capital-Related	0.00	1.65	16.53	0.12	0.32	18.62
	Rental	2.45	8.30	7.11	0.05	0.81	18.72
	Relocation	0.29	0.15	0.37	0.01	0.22	1.04
	Subtotal	2.74	14.04	40.78	0.40	3.22	61.17
Capital Stock Losses							
	Structural	12.81	12.56	17.25	1.30	4.96	48.88
	Non_Structural	51.82	59.17	55.71	4.73	17.14	188.57
	Content	12.47	12.46	24.44	2.72	8.13	60.23
	Inventory	0.00	0.00	0.62	0.53	0.06	1.21
	Subtotal	77.10	84.19	98.02	9.28	30.29	298.88
	Total	79.84	98.23	138.80	9.68	33.51	360.06

Transportation and Utility Lifeline Losses

For the transportation and utility lifeline systems, HAZUS computes the direct repair cost for each component only. There are no losses computed by HAZUS for business interruption due to lifeline outages. Tables 13 & 14 provide a detailed breakdown in the expected lifeline losses.

HAZUS estimates the long-term economic impacts to the region for 15 years after the earthquake. The model quantifies this information in terms of income and employment changes within the region. Table 15 presents the results of the region for the given earthquake.

Table 13: Transportation System Economic Losses
(Millions of dollars)

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Highway	Segments	113.46	\$0.00	0.00
	Bridges	1,630.62	\$188.18	11.54
	Tunnels	0.00	\$0.00	0.00
	Subtotal	1744.10	188.20	
Railways	Segments	21.34	\$0.00	0.00
	Bridges	0.00	\$0.00	0.00
	Tunnels	0.00	\$0.00	0.00
	Facilities	4.93	\$1.94	39.37
	Subtotal	26.30	1.90	
Light Rail	Segments	0.00	\$0.00	0.00
	Bridges	0.00	\$0.00	0.00
	Tunnels	0.00	\$0.00	0.00
	Facilities	0.00	\$0.00	0.00
	Subtotal	0.00	0.00	
Bus	Facilities	0.00	\$0.00	0.00
	Subtotal	0.00	0.00	
Ferry	Facilities	0.00	\$0.00	0.00
	Subtotal	0.00	0.00	
Port	Facilities	45.15	\$17.80	39.43
	Subtotal	45.10	17.80	
Airport	Facilities	0.00	\$0.00	0.00
	Runways	0.00	\$0.00	0.00
	Subtotal	0.00	0.00	
Total		1815.50	207.90	

Table 14: Utility System Economic Losses
(Millions of dollars)

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Potable Water	Pipelines	0.00	\$0.00	0.00
	Facilities	37.60	\$11.55	30.70
	Distribution Lines	2.70	\$0.48	17.40
	Subtotal	40.36	\$12.03	
Waste Water	Pipelines	0.00	\$0.00	0.00
	Facilities	75.30	\$20.30	26.97
	Distribution Lines	1.60	\$0.38	22.94
	Subtotal	76.90	\$20.67	
Natural Gas	Pipelines	0.00	\$0.00	0.00
	Facilities	0.00	\$0.00	0.00
	Distribution Lines	1.10	\$0.40	36.79
	Subtotal	1.09	\$0.40	
Oil Systems	Pipelines	0.00	\$0.00	0.00
	Facilities	0.00	\$0.00	0.00
	Subtotal	0.00	\$0.00	
Electrical Power	Facilities	0.00	\$0.00	0.00
	Subtotal	0.00	\$0.00	
Communication	Facilities	0.30	\$0.10	30.15
	Subtotal	0.34	\$0.10	
	Total	118.69	\$33.20	

Table 15. Indirect Economic Impact with outside aid
(Employment as # of people and Income in millions of \$)

	LOSS	Total	%
First Year			
	Employment Impact	0	0.00
	Income Impact	(3)	-4.16
Second Year			
	Employment Impact	0	0.00
	Income Impact	(9)	-12.65
Third Year			
	Employment Impact	0	0.00
	Income Impact	(11)	-16.28
Fourth Year			
	Employment Impact	0	0.00
	Income Impact	(11)	-16.28
Fifth Year			
	Employment Impact	0	0.00
	Income Impact	(11)	-16.28
Years 6 to 15			
	Employment Impact	0	0.00
	Income Impact	(11)	-16.28

Appendix A: County Listing for the Region

Clatsop,OR

Appendix B: Regional Population and Building Value Data

State	County Name	Population	Building Value (millions of dollars)		
			Residential	Non-Residential	Total
Oregon	Clatsop	10,375	691	252	943
Total State		10,375	691	252	943
Total Region		10,375	691	252	943

APPENDIX C: HAZUS GLOBAL REPORT FOR SCENARIO 3

HAZUS-MH: Earthquake Event Report

Region Name: Astoria_LSall09

Earthquake Scenario: Arbitrary_Crustal_m6.0

Print Date: March 06, 2009

Totals only reflect data for those census tracts/blocks included in the user's study region.

Disclaimer:

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Note:

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The replacement value of the transportation and utility lifeline systems is estimated to be 1,815 and 113 (millions of dollars) , respectively.

Building and Lifeline Inventory

Building Inventory

HAZUS estimates that there are 3 thousand buildings in the region which have an aggregate total replacement value of 943 (millions of dollars) . Appendix B provides a general distribution of the building value by State and County.

In terms of building construction types found in the region, wood frame construction makes up 91% of the building inventory. The remaining percentage is distributed between the other general building types.

Critical Facility Inventory

HAZUS breaks critical facilities into two (2) groups: essential facilities and high potential loss (HPL) facilities. Essential facilities include hospitals, medical clinics, schools, fire stations, police stations and emergency operations facilities. High potential loss facilities include dams, levees, military installations, nuclear power plants and hazardous material sites.

For essential facilities, there are 1 hospitals in the region with a total bed capacity of 37 beds. There are 5 schools, 1 fire stations, 3 police stations and 0 emergency operation facilities. With respect to HPL facilities, there are 0 dams identified within the region. Of these, 0 of the dams are classified as 'high hazard'. The inventory also includes 0 hazardous material sites, 0 military installations and 0 nuclear power plants.

Transportation and Utility Lifeline Inventory

Within HAZUS, the lifeline inventory is divided between transportation and utility lifeline systems. There are seven (7) transportation systems that include highways, railways, light rail, bus, ports, ferry and airports. There are six (6) utility systems that include potable water, wastewater, natural gas, crude & refined oil, electric power and communications. The lifeline inventory data are provided in Tables 2 and 3.

The total value of the lifeline inventory is over 1,928.00 (millions of dollars). This inventory includes over 35 kilometers of highways, 5 bridges, 273 kilometers of pipes.

Table 2: Transportation System Lifeline Inventory

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	Segments	12	113.50
	Tunnels	0	0.00
	Subtotal		1,744.10
Railways	Bridges	0	0.00
	Facilities	2	4.90
	Segments	6	21.30
	Tunnels	0	0.00
	Subtotal		26.30
Light Rail	Bridges	0	0.00
	Facilities	0	0.00
	Segments	0	0.00
	Tunnels	0	0.00
	Subtotal		0.00
Bus	Facilities	0	0.00
	Subtotal		0.00
Ferry	Facilities	0	0.00
	Subtotal		0.00
Port	Facilities	19	45.10
	Subtotal		45.10
Airport	Facilities	0	0.00
	Runways	0	0.00
	Subtotal		0.00
		Total	1,815.50

Table 3: Utility System Lifeline Inventory

System	Component	# Locations / Segments	Replacement value (millions of dollars)
Potable Water	Distribution Lines	NA	2.70
	Facilities	1	37.60
	Pipelines	0	0.00
	Subtotal		40.40
Waste Water	Distribution Lines	NA	1.60
	Facilities	1	75.30
	Pipelines	0	0.00
	Subtotal		76.90
Natural Gas	Distribution Lines	NA	1.10
	Facilities	0	0.00
	Pipelines	0	0.00
	Subtotal		1.10
Oil Systems	Facilities	0	0.00
	Pipelines	0	0.00
	Subtotal		0.00
Electrical Power	Facilities	0	0.00
	Subtotal		0.00
Communication	Facilities	3	0.30
	Subtotal		0.30
		Total	118.70

Earthquake Scenario

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

Scenario Name	Arbitrary_Crustal_m6.0
Type of Earthquake	Arbitrary
Fault Name	NA
Historical Epicenter ID #	NA
Probabilistic Return Period	NA
Longitude of Epicenter	-123.82
Latitude of Epicenter	46.18
Earthquake Magnitude	6.00
Depth (Km)	10.00
Rupture Length (Km)	22.96
Rupture Orientation (degrees)	160.00
Attenuation Function	WUS Shallow Crustal Event - Non Extensional

Building Damage

Building Damage

HAZUS estimates that about 3,566 buildings will be at least moderately damaged. This is over 100.00 % of the total number of buildings in the region. There are an estimated 537 buildings that will be damaged beyond repair. The definition of the 'damage states' is provided in Volume 1: Chapter 5 of the HAZUS technical manual. Table 4 below summarizes the expected damage by general occupancy for the buildings in the region. Table 5 summarizes the expected damage by general building type.

Table 4: Expected Building Damage by Occupancy

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	0	0.00	0	0.00	1	0.07	2	0.08	1	0.12
Commercial	0	0.00	0	0.00	15	1.83	61	2.73	25	4.73
Education	0	0.00	0	0.00	1	0.10	3	0.14	1	0.22
Government	0	0.00	0	0.00	2	0.23	7	0.33	3	0.53
Industrial	0	0.00	0	0.00	2	0.21	7	0.30	3	0.50
Other Residential	0	0.00	0	0.00	99	12.47	308	13.80	88	16.31
Religion	0	0.00	0	0.00	1	0.17	6	0.25	2	0.39
Single Family	0	0.00	0	0.00	677	84.92	1,838	82.37	415	77.21
Total	0		0		797		2,232		538	

Table 5: Expected Building Damage by Building Type (All Design Levels)

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Wood	0	0.00	0	0.00	751	94.21	2,036	91.23	455	84.61
Steel	0	0.00	0	0.00	8	0.95	35	1.58	16	2.93
Concrete	0	0.00	0	0.00	10	1.20	38	1.70	13	2.34
Precast	0	0.00	0	0.00	2	0.30	12	0.55	5	1.00
RM	0	0.00	0	0.00	1	0.10	4	0.16	1	0.23
URM	0	0.00	0	0.00	15	1.88	62	2.76	32	6.02
MH	0	0.00	0	0.00	11	1.36	45	2.02	15	2.87
Total	0		0		797		2,232		538	

*Note:

RM Reinforced Masonry
URM Unreinforced Masonry
MH Manufactured Housing

Essential Facility Damage

Before the earthquake, the region had 37 hospital beds available for use. On the day of the earthquake, the model estimates that only 0 hospital beds (0.00%) are available for use by patients already in the hospital and those injured by the earthquake. After one week, 45.00% of the beds will be back in service. By 30 days, 100.00% will be operational.

Table 6: Expected Damage to Essential Facilities

Classification	Total	# Facilities		
		At Least Moderate Damage > 50%	Complete Damage > 50%	With Functionality > 50% on day 1
Hospitals	1	1	0	0
Schools	5	5	0	0
EOCs	0	0	0	0
PoliceStations	3	3	0	0
FireStations	1	1	0	0

Transportation and Utility Lifeline Damage

Table 7 provides damage estimates for the transportation system.

Table 7: Expected Damage to the Transportation Systems

System	Component	Number of Locations				
		Locations/ Segments	With at Least Mod. Damage	With Complete Damage	With Functionality > 50 %	
					After Day 1	After Day 7
Highway	Segments	12	0	0	12	12
	Bridges	5	1	0	4	5
	Tunnels	0	0	0	0	0
Railways	Segments	6	0	0	6	6
	Bridges	0	0	0	0	0
	Tunnels	0	0	0	0	0
	Facilities	2	1	0	2	2
Light Rail	Segments	0	0	0	0	0
	Bridges	0	0	0	0	0
	Tunnels	0	0	0	0	0
	Facilities	0	0	0	0	0
Bus	Facilities	0	0	0	0	0
Ferry	Facilities	0	0	0	0	0
Port	Facilities	19	0	0	19	19
Airport	Facilities	0	0	0	0	0
	Runways	0	0	0	0	0

Note: Roadway segments, railroad tracks and light rail tracks are assumed to be damaged by ground failure only. If ground failure maps are not provided, damage estimates to these components will not be computed.

Tables 8-10 provide information on the damage to the utility lifeline systems. Table 8 provides damage to the utility system facilities. Table 9 provides estimates on the number of leaks and breaks by the pipelines of the utility systems. For electric power and potable water, HAZUS performs a simplified system performance analysis. Table 10 provides a summary of the system performance information.

Table 8 : Expected Utility System Facility Damage

System	# of Locations				
	Total #	With at Least Moderate Damage	With Complete Damage	with Functionality > 50 %	
				After Day 1	After Day 7
Potable Water	1	1	0	0	1
Waste Water	1	1	0	0	1
Natural Gas	0	0	0	0	0
Oil Systems	0	0	0	0	0
Electrical Power	0	0	0	0	0
Communication	3	3	0	3	3

Table 9 : Expected Utility System Pipeline Damage (Site Specific)

System	Total Pipelines Length (kms)	Number of Leaks	Number of Breaks
Potable Water	137	14	3
Waste Water	82	11	3
Natural Gas	55	12	3
Oil	0	0	0

Table 10: Expected Potable Water and Electric Power System Performance

	Total # of Households	Number of Households without Service				
		At Day 1	At Day 3	At Day 7	At Day 30	At Day 90
Potable Water	4,253	0	0	0	0	0
Electric Power		0	0	0	0	0

Induced Earthquake Damage

Fire Following Earthquake

Fires often occur after an earthquake. Because of the number of fires and the lack of water to fight the fires, they can often burn out of control. HAZUS uses a Monte Carlo simulation model to estimate the number of ignitions and the amount of burnt area. For this scenario, the model estimates that there will be 1 ignitions that will burn about 0.02 sq. mi 0.29 % of the region's total area.) The model also estimates that the fires will displace about 64 people and burn about 6 (millions of dollars) of building value.

Debris Generation

HAZUS estimates the amount of debris that will be generated by the earthquake. The model breaks the debris into two general categories: a) Brick/Wood and b) Reinforced Concrete/Steel. This distinction is made because of the different types of material handling equipment required to handle the debris.

The model estimates that a total of 0.00 million tons of debris will be generated. Of the total amount, Brick/Wood comprises 41.00% of the total, with the remainder being Reinforced Concrete/Steel. If the debris tonnage is converted to an estimated number of truckloads, it will require 0 truckloads (@25 tons/truck) to remove the debris generated by the earthquake.

Social Impact

Shelter Requirement

HAZUS estimates the number of households that are expected to be displaced from their homes due to the earthquake and the number of displaced people that will require accommodations in temporary public shelters. The model estimates 1,665 households to be displaced due to the earthquake. Of these, 445 people (out of a total population of 10,375) will seek temporary shelter in public shelters.

Casualties

HAZUS estimates the number of people that will be injured and killed by the earthquake. The casualties are broken down into four (4) severity levels that describe the extent of the injuries. The levels are described as follows;

- Severity Level 1: Injuries will require medical attention but hospitalization is not needed.
- Severity Level 2: Injuries will require hospitalization but are not considered life-threatening
- Severity Level 3: Injuries will require hospitalization and can become life threatening if not promptly treated.
- Severity Level 4: Victims are killed by the earthquake.

The casualty estimates are provided for three (3) times of day: 2:00 AM, 2:00 PM and 5:00 PM. These times represent the periods of the day that different sectors of the community are at their peak occupancy loads. The 2:00 AM estimate considers that the residential occupancy load is maximum, the 2:00 PM estimate considers that the educational, commercial and industrial sector loads are maximum and 5:00 PM represents peak commute time.

Table 11 provides a summary of the casualties estimated for this earthquake

Table 11: Casualty Estimates

		Level 1	Level 2	Level 3	Level 4
2 AM	Commercial	1	0	0	0
	Commuting	0	0	0	0
	Educational	0	0	0	0
	Hotels	2	0	0	0
	Industrial	1	0	0	0
	Other-Residential	78	19	2	4
	Single Family	100	19	1	2
	Total	182	39	3	6
2 PM	Commercial	90	25	4	8
	Commuting	0	0	0	0
	Educational	28	8	1	2
	Hotels	0	0	0	0
	Industrial	8	2	0	1
	Other-Residential	18	4	1	1
	Single Family	22	4	0	0
	Total	167	44	6	12
5 PM	Commercial	69	19	3	6
	Commuting	0	0	0	0
	Educational	4	1	0	0
	Hotels	1	0	0	0
	Industrial	5	1	0	0
	Other-Residential	31	7	1	2
	Single Family	40	8	1	1
	Total	150	37	5	9

Economic Loss

The total economic loss estimated for the earthquake is 786.03 (millions of dollars), which includes building and lifeline related losses based on the region's available inventory. The following three sections provide more detailed information about these losses.

Building-Related Losses

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

The total building-related losses were 644.19 (millions of dollars); 13 % of the estimated losses were related to the business interruption of the region. By far, the largest loss was sustained by the residential occupancies which made up over 65 % of the total loss. Table 12 below provides a summary of the losses associated with the building damage.

Table 12: Building-Related Economic Loss Estimates
(Millions of dollars)

Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Losses							
	Wage	0.00	7.90	18.18	0.23	2.41	28.73
	Capital-Related	0.00	3.32	17.77	0.13	0.37	21.59
	Rental	7.96	16.00	8.35	0.05	0.95	33.31
	Relocation	0.93	0.29	0.45	0.01	0.26	1.94
	Subtotal	8.89	27.52	44.74	0.42	3.99	85.57
Capital Stock Losses							
	Structural	46.56	21.72	19.37	1.39	5.97	95.00
	Non_Structural	142.22	104.83	68.73	5.79	22.04	343.60
	Content	37.98	26.15	37.34	3.95	12.79	118.21
	Inventory	0.00	0.00	0.93	0.78	0.10	1.81
	Subtotal	226.75	152.70	126.37	11.91	40.89	558.62
	Total	235.64	180.22	171.12	12.33	44.88	644.19

Transportation and Utility Lifeline Losses

For the transportation and utility lifeline systems, HAZUS computes the direct repair cost for each component only. There are no losses computed by HAZUS for business interruption due to lifeline outages. Tables 13 & 14 provide a detailed breakdown in the expected lifeline losses.

HAZUS estimates the long-term economic impacts to the region for 15 years after the earthquake. The model quantifies this information in terms of income and employment changes within the region. Table 15 presents the results of the region for the given earthquake.

Table 13: Transportation System Economic Losses
(Millions of dollars)

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Highway	Segments	113.46	\$3.97	3.50
	Bridges	1,630.62	\$99.67	6.11
	Tunnels	0.00	\$0.00	0.00
	Subtotal	1744.10	103.60	
Railways	Segments	21.34	\$0.21	0.98
	Bridges	0.00	\$0.00	0.00
	Tunnels	0.00	\$0.00	0.00
	Facilities	4.93	\$1.51	30.65
	Subtotal	26.30	1.70	
Light Rail	Segments	0.00	\$0.00	0.00
	Bridges	0.00	\$0.00	0.00
	Tunnels	0.00	\$0.00	0.00
	Facilities	0.00	\$0.00	0.00
	Subtotal	0.00	0.00	
Bus	Facilities	0.00	\$0.00	0.00
	Subtotal	0.00	0.00	
Ferry	Facilities	0.00	\$0.00	0.00
	Subtotal	0.00	0.00	
Port	Facilities	45.15	\$13.77	30.49
	Subtotal	45.10	13.80	
Airport	Facilities	0.00	\$0.00	0.00
	Runways	0.00	\$0.00	0.00
	Subtotal	0.00	0.00	
Total		1815.50	119.10	

Table 14: Utility System Economic Losses
(Millions of dollars)

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Potable Water	Pipelines	0.00	\$0.00	0.00
	Facilities	37.60	\$8.30	22.05
	Distribution Lines	2.70	\$0.06	2.25
	Subtotal	40.36	\$8.36	
Waste Water	Pipelines	0.00	\$0.00	0.00
	Facilities	75.30	\$14.18	18.85
	Distribution Lines	1.60	\$0.05	2.98
	Subtotal	76.90	\$14.23	
Natural Gas	Pipelines	0.00	\$0.00	0.00
	Facilities	0.00	\$0.00	0.00
	Distribution Lines	1.10	\$0.05	4.77
	Subtotal	1.09	\$0.05	
Oil Systems	Pipelines	0.00	\$0.00	0.00
	Facilities	0.00	\$0.00	0.00
	Subtotal	0.00	\$0.00	
Electrical Power	Facilities	0.00	\$0.00	0.00
	Subtotal	0.00	\$0.00	
Communication	Facilities	0.30	\$0.07	21.47
	Subtotal	0.34	\$0.07	
	Total	118.69	\$22.72	

Table 15. Indirect Economic Impact with outside aid
(Employment as # of people and Income in millions of \$)

	LOSS	Total	%
First Year			
	Employment Impact	0	0.00
	Income Impact	(5)	-7.68
Second Year			
	Employment Impact	0	0.00
	Income Impact	(16)	-23.36
Third Year			
	Employment Impact	0	0.00
	Income Impact	(21)	-30.06
Fourth Year			
	Employment Impact	0	0.00
	Income Impact	(21)	-30.06
Fifth Year			
	Employment Impact	0	0.00
	Income Impact	(21)	-30.06
Years 6 to 15			
	Employment Impact	0	0.00
	Income Impact	(21)	-30.06

Appendix A: County Listing for the Region

Clatsop,OR

Appendix B: Regional Population and Building Value Data

State	County Name	Population	Building Value (millions of dollars)		
			Residential	Non-Residential	Total
Oregon	Clatsop	10,375	691	252	943
Total State		10,375	691	252	943
Total Region		10,375	691	252	943

APPENDIX D: HAZUS GLOBAL REPORT FOR SCENARIO 2 (CASCADIA)

HAZUS-MH: Earthquake Event Report

Region Name: Astoria_DetailedLS_Cascadia

Earthquake Scenario: Cascadia Magnitude 9.0

Print Date: April 10, 2009

Totals only reflect data for those census tracts/blocks included in the user's study region.

Disclaimer:

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

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General Description of the Region

HAZUS is a regional earthquake loss estimation model that was developed by the Federal Emergency Management Agency and the National Institute of Building Sciences. The primary purpose of HAZUS is to provide a methodology and software application to develop earthquake losses at a regional scale. These loss estimates would be used primarily by local, state and regional officials to plan and stimulate efforts to reduce risks from earthquakes and to prepare for emergency response and recovery.

The earthquake loss estimates provided in this report was based on a region that includes 1 county(ies) from the following state(s):

Oregon

Note:

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

The geographical size of the region is 6.77 square miles and contains 3 census tracts. There are over 4 thousand households in the region and has a total population of 10,375 people (2000 Census Bureau data). The distribution of population by State and County is provided in Appendix B.

There are an estimated 3 thousand buildings in the region with a total building replacement value (excluding contents) of 943 (millions of dollars). Approximately 96.00 % of the buildings (and 73.00% of the building value) are associated with residential housing.

The replacement value of the transportation and utility lifeline systems is estimated to be 1,815 and 113 (millions of dollars) , respectively.

Building and Lifeline Inventory

Building Inventory

HAZUS estimates that there are 3 thousand buildings in the region which have an aggregate total replacement value of 943 (millions of dollars) . Appendix B provides a general distribution of the building value by State and County.

In terms of building construction types found in the region, wood frame construction makes up 91% of the building inventory. The remaining percentage is distributed between the other general building types.

Critical Facility Inventory

HAZUS breaks critical facilities into two (2) groups: essential facilities and high potential loss (HPL) facilities. Essential facilities include hospitals, medical clinics, schools, fire stations, police stations and emergency operations facilities. High potential loss facilities include dams, levees, military installations, nuclear power plants and hazardous material sites.

For essential facilities, there are 1 hospitals in the region with a total bed capacity of 37 beds. There are 5 schools, 1 fire stations, 3 police stations and 0 emergency operation facilities. With respect to HPL facilities, there are 0 dams identified within the region. Of these, 0 of the dams are classified as 'high hazard'. The inventory also includes 0 hazardous material sites, 0 military installations and 0 nuclear power plants.

Transportation and Utility Lifeline Inventory

Within HAZUS, the lifeline inventory is divided between transportation and utility lifeline systems. There are seven (7) transportation systems that include highways, railways, light rail, bus, ports, ferry and airports. There are six (6) utility systems that include potable water, wastewater, natural gas, crude & refined oil, electric power and communications. The lifeline inventory data are provided in Tables 2 and 3.

The total value of the lifeline inventory is over 1,928.00 (millions of dollars). This inventory includes over 35 kilometers of highways, 5 bridges, 273 kilometers of pipes.

Table 2: Transportation System Lifeline Inventory

System	Component	# locations/ # Segments	Replacement value (millions of dollars)
Highway	Bridges	5	1,630.60
	Segments	12	113.50
	Tunnels	0	0.00
	Subtotal		1,744.10
Railways	Bridges	0	0.00
	Facilities	2	4.90
	Segments	6	21.30
	Tunnels	0	0.00
	Subtotal		26.30
Light Rail	Bridges	0	0.00
	Facilities	0	0.00
	Segments	0	0.00
	Tunnels	0	0.00
	Subtotal		0.00
Bus	Facilities	0	0.00
	Subtotal		0.00
Ferry	Facilities	0	0.00
	Subtotal		0.00
Port	Facilities	19	45.10
	Subtotal		45.10
Airport	Facilities	0	0.00
	Runways	0	0.00
	Subtotal		0.00
		Total	1,815.50

Table 3: Utility System Lifeline Inventory

System	Component	# Locations / Segments	Replacement value (millions of dollars)
Potable Water	Distribution Lines	NA	2.70
	Facilities	1	37.60
	Pipelines	0	0.00
	Subtotal		40.40
Waste Water	Distribution Lines	NA	1.60
	Facilities	1	75.30
	Pipelines	0	0.00
	Subtotal		76.90
Natural Gas	Distribution Lines	NA	1.10
	Facilities	0	0.00
	Pipelines	0	0.00
	Subtotal		1.10
Oil Systems	Facilities	0	0.00
	Pipelines	0	0.00
	Subtotal		0.00
Electrical Power	Facilities	0	0.00
	Subtotal		0.00
Communication	Facilities	3	0.30
	Subtotal		0.30
	Total		118.70

Earthquake Scenario

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

Scenario Name	Cascadia Magnitude 9.0
Type of Earthquake	User-defined
Fault Name	NA
Historical Epicenter ID #	NA
Probabilistic Return Period	NA
Longitude of Epicenter	NA
Latitude of Epicenter	NA
Earthquake Magnitude	8.50
Depth (Km)	NA
Rupture Length (Km)	NA
Rupture Orientation (degrees)	NA
Attenuation Function	NA

Building Damage

Building Damage

HAZUS estimates that about 2,232 buildings will be at least moderately damaged. This is over 63.00 % of the total number of buildings in the region. There are an estimated 1,324 buildings that will be damaged beyond repair. The definition of the 'damage states' is provided in Volume 1: Chapter 5 of the HAZUS technical manual. Table 4 below summarizes the expected damage by general occupancy for the buildings in the region. Table 5 summarizes the expected damage by general building type.

Table 4: Expected Building Damage by Occupancy

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	0	0.03	0	0.04	0	0.05	0	0.26	2	0.13
Commercial	0	0.01	1	0.05	11	1.41	31	21.28	58	4.39
Education	0	0.02	0	0.03	0	0.06	1	0.84	3	0.22
Government	0	0.07	1	0.06	1	0.15	3	1.99	7	0.54
Industrial	0	0.00	0	0.00	1	0.09	2	1.57	8	0.60
Other Residential	16	9.30	129	11.12	100	13.17	56	37.66	194	14.65
Religion	0	0.13	1	0.09	1	0.13	2	1.36	5	0.36
Single Family	157	90.45	1,028	88.61	646	84.94	52	35.02	1,048	79.11
Total	173		1,160		760		148		1,325	

Table 5: Expected Building Damage by Building Type (All Design Levels)

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Wood	173	99.99	1158	99.89	733	96.44	58	39.42	1,118	84.41
Steel	0	0.00	0	0.00	1	0.14	11	7.58	46	3.48
Concrete	0	0.00	0	0.02	5	0.65	19	12.85	36	2.72
Precast	0	0.00	0	0.00	1	0.07	4	2.80	15	1.16
RM	0	0.00	0	0.00	0	0.04	2	1.25	4	0.27
URM	0	0.00	1	0.05	11	1.42	32	21.78	65	4.93
MH	0	0.00	0	0.04	9	1.24	21	14.33	40	3.03
Total	173		1,160		760		148		1,325	

*Note:

RM Reinforced Masonry
URM Unreinforced Masonry
MH Manufactured Housing

Essential Facility Damage

Before the earthquake, the region had 37 hospital beds available for use. On the day of the earthquake, the model estimates that only 0 hospital beds (0.00%) are available for use by patients already in the hospital and those injured by the earthquake. After one week, 1.00% of the beds will be back in service. By 30 days, 33.00% will be operational.

Table 6: Expected Damage to Essential Facilities

Classification	Total	# Facilities		
		At Least Moderate Damage > 50%	Complete Damage > 50%	With Functionality > 50% on day 1
Hospitals	1	1	0	0
Schools	5	1	1	0
EOCs	0	0	0	0
PoliceStations	3	0	0	0
FireStations	1	0	0	0

Transportation and Utility Lifeline Damage

Table 7 provides damage estimates for the transportation system.

Table 7: Expected Damage to the Transportation Systems

System	Component	Number of Locations_				
		Locations/ Segments	With at Least Mod. Damage	With Complete Damage	With Functionality > 50 %	
					After Day 1	After Day 7
Highway	Segments	12	0	0	12	12
	Bridges	5	1	0	4	5
	Tunnels	0	0	0	0	0
Railways	Segments	6	0	0	6	6
	Bridges	0	0	0	0	0
	Tunnels	0	0	0	0	0
	Facilities	2	0	0	2	2
Light Rail	Segments	0	0	0	0	0
	Bridges	0	0	0	0	0
	Tunnels	0	0	0	0	0
	Facilities	0	0	0	0	0
Bus	Facilities	0	0	0	0	0
Ferry	Facilities	0	0	0	0	0
Port	Facilities	19	0	0	19	19
Airport	Facilities	0	0	0	0	0
	Runways	0	0	0	0	0

Note: Roadway segments, railroad tracks and light rail tracks are assumed to be damaged by ground failure only. If ground failure maps are not provided, damage estimates to these components will not be computed.

Tables 8-10 provide information on the damage to the utility lifeline systems. Table 8 provides damage to the utility system facilities. Table 9 provides estimates on the number of leaks and breaks by the pipelines of the utility systems. For electric power and potable water, HAZUS performs a simplified system performance analysis. Table 10 provides a summary of the system performance information.

Table 8 : Expected Utility System Facility Damage

System	# of Locations				
	Total #	With at Least Moderate Damage	With Complete Damage	with Functionality > 50 %	
				After Day 1	After Day 7
Potable Water	1	1	0	0	1
Waste Water	1	0	0	0	1
Natural Gas	0	0	0	0	0
Oil Systems	0	0	0	0	0
Electrical Power	0	0	0	0	0
Communication	3	3	0	3	3

Table 9 : Expected Utility System Pipeline Damage (Site Specific)

System	Total Pipelines Length (kms)	Number of Leaks	Number of Breaks
Potable Water	137	32	8
Waste Water	82	25	6
Natural Gas	55	27	7
Oil	0	0	0

Table 10: Expected Potable Water and Electric Power System Performance

	Total # of Households	Number of Households without Service				
		At Day 1	At Day 3	At Day 7	At Day 30	At Day 90
Potable Water	4,253	0	0	0	0	0
Electric Power		0	0	0	0	0

Induced Earthquake Damage

Fire Following Earthquake

Fires often occur after an earthquake. Because of the number of fires and the lack of water to fight the fires, they can often burn out of control. HAZUS uses a Monte Carlo simulation model to estimate the number of ignitions and the amount of burnt area. For this scenario, the model estimates that there will be 1 ignitions that will burn about 0.02 sq. mi 0.29 % of the region's total area.) The model also estimates that the fires will displace about 64 people and burn about 6 (millions of dollars) of building value.

Debris Generation

HAZUS estimates the amount of debris that will be generated by the earthquake. The model breaks the debris into two general categories: a) Brick/Wood and b) Reinforced Concrete/Steel. This distinction is made because of the different types of material handling equipment required to handle the debris.

The model estimates that a total of 0.00 million tons of debris will be generated. Of the total amount, Brick/Wood comprises 34.00% of the total, with the remainder being Reinforced Concrete/Steel. If the debris tonnage is converted to an estimated number of truckloads, it will require 0 truckloads (@25 tons/truck) to remove the debris generated by the earthquake.

Social Impact

Shelter Requirement

HAZUS estimates the number of households that are expected to be displaced from their homes due to the earthquake and the number of displaced people that will require accommodations in temporary public shelters. The model estimates 1,704 households to be displaced due to the earthquake. Of these, 451 people (out of a total population of 10,375) will seek temporary shelter in public shelters.

Casualties

HAZUS estimates the number of people that will be injured and killed by the earthquake. The casualties are broken down into four (4) severity levels that describe the extent of the injuries. The levels are described as follows;

- Severity Level 1: Injuries will require medical attention but hospitalization is not needed.
- Severity Level 2: Injuries will require hospitalization but are not considered life-threatening
- Severity Level 3: Injuries will require hospitalization and can become life threatening if not promptly treated.
- Severity Level 4: Victims are killed by the earthquake.

The casualty estimates are provided for three (3) times of day: 2:00 AM, 2:00 PM and 5:00 PM. These times represent the periods of the day that different sectors of the community are at their peak occupancy loads. The 2:00 AM estimate considers that the residential occupancy load is maximum, the 2:00 PM estimate considers that the educational, commercial and industrial sector loads are maximum and 5:00 PM represents peak commute time.

Table 11 provides a summary of the casualties estimated for this earthquake

Table 11: Casualty Estimates

		Level 1	Level 2	Level 3	Level 4
2 AM	Commercial	3	1	0	0
	Commuting	0	0	0	0
	Educational	0	0	0	0
	Hotels	2	1	0	0
	Industrial	2	1	0	0
	Other-Residential	122	36	5	9
	Single Family	155	40	3	4
	Total	285	78	8	15
2 PM	Commercial	174	56	9	19
	Commuting	0	0	0	0
	Educational	60	19	3	6
	Hotels	0	0	0	0
	Industrial	17	5	1	2
	Other-Residential	26	8	1	2
	Single Family	32	8	1	1
	Total	310	97	16	30
5 PM	Commercial	138	45	8	15
	Commuting	0	0	1	0
	Educational	8	3	0	1
	Hotels	1	0	0	0
	Industrial	11	3	1	1
	Other-Residential	48	14	2	4
	Single Family	63	16	1	2
	Total	269	82	13	22

Economic Loss

The total economic loss estimated for the earthquake is 814.61 (millions of dollars), which includes building and lifeline related losses based on the region's available inventory. The following three sections provide more detailed information about these losses.

Building-Related Losses

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

The total building-related losses were 650.27 (millions of dollars); 14 % of the estimated losses were related to the business interruption of the region. By far, the largest loss was sustained by the residential occupancies which made up over 58 % of the total loss. Table 12 below provides a summary of the losses associated with the building damage.

Table 12: Building-Related Economic Loss Estimates
(Millions of dollars)

Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Losses							
	Wage	0.00	5.03	22.95	0.34	2.57	30.89
	Capital-Related	0.00	2.13	22.89	0.19	0.45	25.66
	Rental	6.56	13.67	9.66	0.06	1.11	31.07
	Relocation	0.75	0.24	0.50	0.01	0.30	1.81
	Subtotal	7.32	21.08	56.01	0.59	4.43	89.43
Capital Stock Losses							
	Structural	38.99	20.05	25.33	1.94	7.33	93.65
	Non_Structural	131.59	100.89	87.18	8.24	27.23	355.14
	Content	33.11	21.63	37.82	4.57	12.92	110.05
	Inventory	0.00	0.00	1.01	0.90	0.10	2.01
	Subtotal	203.70	142.57	151.33	15.66	47.58	560.84
	Total	211.02	163.65	207.34	16.25	52.00	650.27

Transportation and Utility Lifeline Losses

For the transportation and utility lifeline systems, HAZUS computes the direct repair cost for each component only. There are no losses computed by HAZUS for business interruption due to lifeline outages. Tables 13 & 14 provide a detailed breakdown in the expected lifeline losses.

HAZUS estimates the long-term economic impacts to the region for 15 years after the earthquake. The model quantifies this information in terms of income and employment changes within the region. Table 15 presents the results of the region for the given earthquake.

Table 13: Transportation System Economic Losses
(Millions of dollars)

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Highway	Segments	113.46	\$2.92	2.57
	Bridges	1,630.62	\$130.89	8.03
	Tunnels	0.00	\$0.00	0.00
	Subtotal	1744.10	133.80	
Railways	Segments	21.34	\$0.11	0.51
	Bridges	0.00	\$0.00	0.00
	Tunnels	0.00	\$0.00	0.00
	Facilities	4.93	\$1.28	26.04
	Subtotal	26.30	1.40	
Light Rail	Segments	0.00	\$0.00	0.00
	Bridges	0.00	\$0.00	0.00
	Tunnels	0.00	\$0.00	0.00
	Facilities	0.00	\$0.00	0.00
	Subtotal	0.00	0.00	
Bus	Facilities	0.00	\$0.00	0.00
	Subtotal	0.00	0.00	
Ferry	Facilities	0.00	\$0.00	0.00
	Subtotal	0.00	0.00	
Port	Facilities	45.15	\$11.25	24.93
	Subtotal	45.10	11.30	
Airport	Facilities	0.00	\$0.00	0.00
	Runways	0.00	\$0.00	0.00
	Subtotal	0.00	0.00	
Total		1815.50	146.50	

Table 14: Utility System Economic Losses
(Millions of dollars)

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Potable Water	Pipelines	0.00	\$0.00	0.00
	Facilities	37.60	\$5.92	15.74
	Distribution Lines	2.70	\$0.14	5.26
	Subtotal	40.36	\$6.07	
Waste Water	Pipelines	0.00	\$0.00	0.00
	Facilities	75.30	\$11.52	15.31
	Distribution Lines	1.60	\$0.11	6.94
	Subtotal	76.90	\$11.64	
Natural Gas	Pipelines	0.00	\$0.00	0.00
	Facilities	0.00	\$0.00	0.00
	Distribution Lines	1.10	\$0.12	11.12
	Subtotal	1.09	\$0.12	
Oil Systems	Pipelines	0.00	\$0.00	0.00
	Facilities	0.00	\$0.00	0.00
	Subtotal	0.00	\$0.00	
Electrical Power	Facilities	0.00	\$0.00	0.00
	Subtotal	0.00	\$0.00	
Communication	Facilities	0.30	\$0.05	15.87
	Subtotal	0.34	\$0.05	
	Total	118.69	\$17.88	

Table 15. Indirect Economic Impact with outside aid
(Employment as # of people and Income in millions of \$)

	LOSS	Total	%
First Year			
	Employment Impact	0	0.00
	Income Impact	(5)	-7.85
Second Year			
	Employment Impact	0	0.00
	Income Impact	(16)	-23.90
Third Year			
	Employment Impact	0	0.00
	Income Impact	(21)	-30.76
Fourth Year			
	Employment Impact	0	0.00
	Income Impact	(21)	-30.76
Fifth Year			
	Employment Impact	0	0.00
	Income Impact	(21)	-30.76
Years 6 to 15			
	Employment Impact	0	0.00
	Income Impact	(21)	-30.76

Appendix A: County Listing for the Region

Clatsop,OR

Appendix B: Regional Population and Building Value Data

State	County Name	Population	Building Value (millions of dollars)		
			Residential	Non-Residential	Total
Oregon	Clatsop	10,375	691	252	943
Total State		10,375	691	252	943
Total Region		10,375	691	252	943