EXERCISE SCENARIO DOCUMENT

CASCADIA SUBDUCTION ZONE (CSZ)
CATASTROPHIC EARTHQUAKE AND TSUNAMI

January 2015

Functional Exercise 2016

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FOREWORD

A large magnitude Cascadia Subduction Zone fault earthquake and tsunami is perhaps one of the most complex disaster scenarios that we face as emergency management and public safety officials in the Pacific Northwest. Due to this complexity, life-saving and life-sustaining response operations will hinge on the effective coordination and integration of governments at all levels – cities, counties, state agencies, federal departments, the military, and tribal nations – as well as non-governmental organizations and the private sector. It is this joint-operational whole community approach that we seek to enhance and test during the Cascading Rising exercise.

Our sincere appreciation to the Western Washington University Resilience Institute and the members of the exercise Scenario Sub-Working Group for developing this foundational Exercise Scenario document. We look forward to commencing the design and preparations of the Cascadia Rising exercise, as we work together to improve our joint operational readiness to serve the citizens and the region that we all cherish.

Respectfully,

The Washington and Oregon Whole Community Exercise Design Committee
January 2015

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FEMA

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BACKGROUND

Cascadia Rising is a four day Functional Exercise occurring the week of June 6, 2016. Participating Emergency Operation and Coordination Centers (EOC/ECCs) at all levels of government and the private sector in Washington and Oregon will activate to coordinate simulated field response operations, both within their jurisdictions and also with neighboring communities, the State EOCs, FEMA, and major military commands.

The purpose of this scenario publication is two-fold: (1) to provide information for exercise participants on the potential impacts resulting from a large magnitude Cascadia Subduction Zone (CSZ) earthquake and tsunami, preparing exercise players for some of the challenges they may face during the exercise; and, (2) to provide exercise planner "trusted agents" with information on CSZ damages, assisting them in the preparation of various exercise design products to include in a "Ground Truth" document and the "Master Scenario Events List."

EXERCISE FACTS AND ASSUMPTIONS

In order to achieve the joint objectives of the exercise, the following exercise facts and assumptions should be used by both exercise planners and players in the conduct of the exercise:

- Real-world weather will be in effect during each day of the exercise.

- Emergency Operation and Coordination Centers (EOC/ECCs) are structurally sound and capable of facilitating operations (unless otherwise determined by individual communities).

- A sufficient number of staff will be able to reach respective EOC/ECCs to initiate and sustain operations (unless otherwise determined by individual communities)

DISCLAIMER

The estimates of earthquake impacts presented in this publication were produced using loss estimation modeling software based on current scientific and engineering knowledge. There are uncertainties inherent in any loss estimation technique. Therefore, there may be notable differences between the modeled results contained in this publication and other earthquake and tsunami loss models/studies. The information in this report is not predictive; there may be significant differences between the modeled results in this publication and actual losses following a real-world Cascadia Subduction Zone earthquake and tsunami.

METHODOLOGY

Data taken from several reports and studies were compiled to develop this Cascadia Rising Exercise Scenario Document. The Analytical Baseline Study for the Cascadia Earthquake and Tsunami, a 2011 study commissioned by FEMA Region 10 and conducted by the National Infrastructure Simulation and Analysis Center Homeland Infrastructure Threat and Risk Analysis Center (HITRAC) within the DHS Office of Infrastructure Protection, provides a primary foundation for estimating the impacts of a Cascadia Subduction Zone earthquake. The HITRAC study is based upon a 9.0 magnitude earthquake along the length of the Cascadia Subduction Zone fault as specified by the Cascadia Region Earthquake Workgroup (CREW). The study assumes an epicenter approximately 95 miles west of Eugene, Oregon triggers a tsunami which impacts not only the West Coast, but the entire Pacific Basin. To understand potential losses caused by this large earthquake, HITRAC used FEMA's HAZUS-MH 2.0 Multi-hazard Loss Estimation Methodology tool. The tool considered the effects of ground shaking, liquefaction, and potential landslides on communities and their built environment. This Scenario Document also draws from the FEMA Region 10 Response Plan that developed out of a multi-year, multiregional planning process based upon the HITRAC baseline study. The sections here on geology, tsunami generation and generalized building damage also draw directly from CREW's description of a Cascadia Subduction Zone earthquake and tsunami in their 2013 updated scenario report. Oregon has undergone an extensive resilience planning process and their 2013 Reducing Risk and Improving Recovery for the Next Cascadia Earthquake and Tsunami report added further specificity and accuracy to descriptions of damage in that state. Several published reports and ongoing studies on tsunami evacuation were also used to provide better estimates of tsunami-related injuries and fatalities.

Loss estimation does not provide definitive results. Rather, estimations are couched in probabilities of infrastructure experiencing a set of specified damage states. The narrative for this Cascadia Rising exercise relies upon the 90th percentile damage – the damage state with only a 10 percent estimated chance of being exceeded. By using a worst case scenario model, it accounts for some of the potential compounding effects of aftershocks and landslide impacts that are not well-captured by the HAZUS-MH 2.0 tool. Thus, the damage estimates outlined in this report should be considered as potentially less than the 90th percentile of the scenario event and all subsequent secondary events that are likely to occur following the modeled Cascadia Subduction Zone earthquake.

Further, the fragility curves for tall buildings are not well understood for prolonged shaking (4-6 minutes). Therefore, the accuracy of structural damage modeling may vary by building type. However, despite these limitations, the HAZUS-MH 2.0 model provides the most credible estimate of aggregate losses to date. Additional damage data from actual earthquakes will improve future HAZUS-MH models.

Damage estimates in this Scenario Document are provided for the purposes of the Cascadia Rising functional exercise, based upon modeling of a seismic event of a particular magnitude, location and faulting mechanism. They should not be read as a definitive statement of likely damages from any one of many possible Cascadia Subduction Zone events. To reinforce the limits of this loss estimation, all quantities in the Cascadia Rising Scenario Document have been rounded or given in broad ranges and, for most types of damages, provided for broad infrastructure sector categories, rather than damages at specific facilities.

Damages to the infrastructure sectors described herein are broken into three broad categories: low, medium, and high damage. While broad, these categories provide a general indication of the functionality of the infrastructure. In general, infrastructure with low damage is likely to have only degradation of functionality. Much of this damaged infrastructure will be immediately usable in the response to the Cascadia event, though no infrastructure functions in isolation. Infrastructure with medium damage is likely to require substantial repairs following the Cascadia event. Medium damage indicates a degraded functionality or facilities that cannot be immediately occupied or utilized without at least temporary repairs. Infrastructure in the high damage category may have some functionality, but may require extensive repairs or even full replacement to regain pre-event functionality. Table 1 shows the estimated percentage of damage for each corresponding damage state. In all cases, damages to energy, transportation, fuel, communications and other infrastructure systems and networks may degrade functionality of other infrastructures and physical systems independent of immediate damage to the infrastructure component in question.

Injuries and fatality estimates from the Cascadia Rising tsunami event are particularly challenging to estimate. To date, HAZUS-MH 2.0 does not include a tsunami loss estimation module; it estimates only fatalities and injuries from earthquake shaking, including co-occurring landslides and liquefaction. Furthermore,

Table 1. Percentage of damage for each damage state

Low	Medium	High
< 5% damaged	5 - 50% damaged	51 - 100% damaged

the HITRAC study originally estimated tsunami injuries and fatalities based upon a limited number of study areas, not the entirety of the Washington and Oregon coasts.

To provide more robust estimates of these losses, this Scenario Document relies upon evacuation studies conducted in 2013 by Wood, Jones, Spielman, and Schmidtlein. These studies quantify the number of facilities and residents in the inundation zone and estimate the number and percentage of individuals that will be able to walk out of the inundation zone before the waves arrive. For this scenario document, residents in the inundation zone were assumed to evacuate at a slow walk, a speed that appears accurate in other tsunami events and may help account for initial disorientation, injury and damage to evacuation routes.

While the 2013 evacuation studies provide estimates of fatalities, they do not provide information on tsunami-related injuries. To provide a rough estimate of tsunami-related injuries, this Scenario Document uses the FEMA Region 10 CSZ Response Plan estimates, but increases them proportionally to the ratio of the evacuation study fatalities to HITRAC fatalities.

While all of these documents are useful for understanding the potential effects of a subduction earthquake, their analysis only provides a general assessment of how the area might fare in a 9.0-magnitude earthquake. Because there are so many variables in earthquake and tsunami events, the actual event will undoubtedly be different than the scenario on which this analysis is based. Furthermore, these documents provide only an initial estimate of impacts; they do not factor in additional impacts from successive aftershocks.

The information presented in this Scenario Document presents a snapshot in time based on the analyses of data currently available. Ongoing research on the CSZ fault system and the impacts of seismic shaking and inundation on communities and their built environment may not be reflected in this report.

Each critical infrastructure system includes a regional overview of impacts, a table describing each damage state level, and photos of damage. Impacts for both Washington and Oregon are included as subsections within each critical infrastructure section. Each state subsection includes a short narrative describing state impacts, one or more maps displaying the location of the damaged critical facility, and a table displaying the distribution of damage states by Areas of Operation. The geography of Washington and Oregon creates three distinct Areas of Operation defined as follows:

1) Coastal: Area between the Pacific Ocean and the Coast Mountain Ranges.

2) I-5 corridor: Area between the Coast Ranges and the Cascade Mountains

3) East: Area east of the Cascade Mountains

Because shaking intensities decrease rapidly east of the Cascade Mountains, direct damages to the eastern portion of the Washington and Oregon were not calculated. These eastern regions will, however, be impacted by an event of this size. Not only will they be an important response resource for the heavily impacted western regions, the interconnectivity of critical infrastructures such as transportation and energy may result in degraded services even for communities in the eastern portions of the two states.

CASCADIA REGION OVERVIEW

The sections on the Cascadia region; subduction zone; tsunami; aftershocks; landslides and liquefaction; and future risks are based upon a Cascadia Region Earthquake Working group (CREW) report describing the Cascadia Subduction Zone earthquake scenario. CREW has kindly provided permission for their reprint here, with minor modification. For the full text, see their 2013 report.

The Cascadia Region is comprised of the area west of the Cascade Mountains stretching from Northern California, through Oregon and Washington and into British Columbia. This region, known for its stunning mountain ranges, rich farmlands and vineyards, beautiful beaches, great rivers, and green forests, is also home to many vibrant communities, bustling international ports, and thriving businesses. Residents and visitors alike enjoy the cultural offerings of Cascadia's cities and the diversity of outdoor activities in its natural areas. But the geologic forces that shaped the Pacific Northwest are still active: Cascadia is a region of earthquakes.

More than 8 million people live and work within the projected CSZ earthquake damage zone in Washington and Oregon.[i] Of these, over 6 million people reside in urban areas.[ii] The region is also home to some of the nation's most iconic companies and largest employers including Boeing, Microsoft, Starbucks, Amazon, Nike and many others. When combined, the Seattle and Portland Metropolitan Areas alone represent the sixth largest metro area by gross domestic product (GDP) in the United States at nearly $450 billion dollars annually.[iii] Vancouver, British Columbia is the third largest city in Canada by nominal GDP at just over $100 billion dollars annually.[iv]

The Cascadia Region boasts a tremendously talented and educated workforce across many sectors. Amongst U.S. cities, Seattle ranks first in the nation in educational attainment based on the number of residents with a bachelor's degree or higher at 52 percent. Portland is not far behind at eighth and 40 percent respectively.[v] Some experts and historical events suggest that a lengthy post-earthquake recovery period could result in a sharp reduction in the region's skilled workforce as residents relocate to other states and provinces. This phenomenon may be the result of individual decision making, or the result of corporate relocation (both temporary and permanent).

The Pacific Northwest is one of the preeminent tourist destinations for both domestic and international travelers. While this is a positive for the region's economy, it complicates disaster response efforts, especially those which would be required in the aftermath of a catastrophic event like a major CSZ earthquake. Washington State ranked thirteenth in the U.S. for overseas visitors in 2010 at approximately 501,000 with the Seattle Metropolitan Area receiving approximately 95 percent of this total.[vi] The Blaine, Washington U.S. - Canadian land-passenger gateway is the eighth busiest international border crossing in the United States with just shy of 7 million personal vehicle passengers received annually.[vii]

CASCADIA SUBDUCTION ZONE

Lying mostly offshore, the CSZ plate interface is a giant fault—approximately 700 miles long (1,130 km). Here, the set of tectonic plates to the west is sliding (subducting) beneath the North American Plate. The movement of these plates is neither constant nor smooth: the plates are stuck, and the stress will build up until the fault suddenly breaks. This last happened in January 1700. The result was an earthquake on the order of magnitude 9.0, followed within minutes by a large tsunami—much like the earthquake and tsunami that struck Japan on March 11, 2011. Stresses have now been building along the Cascadia subduction zone for more than 300 years, and the communities of Cascadia can be certain that another great quake will again shake the region.

The last Cascadia Subduction Zone event in 1700 offers no written eye-witness accounts, although a few Native American and First Nations oral stories do relate some of the effects. Instead, scientists found the record of Cascadia's past activity in the landscape itself, which was altered suddenly and in characteristic ways by these great earthquakes and the tsunamis they triggered. Once scientists discovered what to look for, they found evidence up and down the coastline, on land and on the seafloor, from British Columbia to California.

The world's largest quakes occur along subduction zones. Dubbed great earthquakes, the magnitude of these events ranges from 8.0 to 9.0+ (the largest on record was a magnitude 9.5 quake off the coast of Chile in 1960). Their characteristics include prolonged ground shaking, large tsunamis, and numerous aftershocks. Because the magnitude scale is logarithmic, each increase of one unit signifies that the waves radiated by the earthquake are 10-times larger and 32-times more energetic. This means that a M9.0 quake releases 1,995 times more energy than a M6.8. The Great Indonesia earthquake and tsunami of 2004 that killed 250,000 persons, and the East Japan earthquake and tsunami of 2011 that killed 16,000 are recent examples of great subduction zone earthquakes.

ANATOMY OF A CASCADIA ZONE EARTHQUAKE

The Cascadia Subduction Zone stretches from Cape Mendocino in northern California to Brooks Peninsula on Vancouver Island in British Columbia, a distance of about 700 miles (1,130 km). All along this zone, which begins beneath the seafloor to the west and extends inland towards the Cascade and Coastal mountains, the subducting plates are forced beneath the North American Plate. At a relatively shallow depth (less than about 20 miles/30 km down), the plates have become stuck. Below this locked zone, warmer temperatures make the plates more pliable, allowing them to move more readily past each other. This freer movement deeper down causes strain to accumulate along the locked zone. Once that strain is great enough to overcome the friction that keeps the plates locked, the fault will rupture: the edge of the North American Plate will lurch suddenly upwards and southwestwards as the subducting plates slip under and northeastwards. With this movement, the deformed western edge of the North American Plate will flex, causing the land along large sections of Cascadia's coastline to drop as much as 6.6 feet (2 m) in elevation—an effect known as co-seismic subsidence. Figure 1 illustrates a subduction zone rupture and the ground deformations it creates.

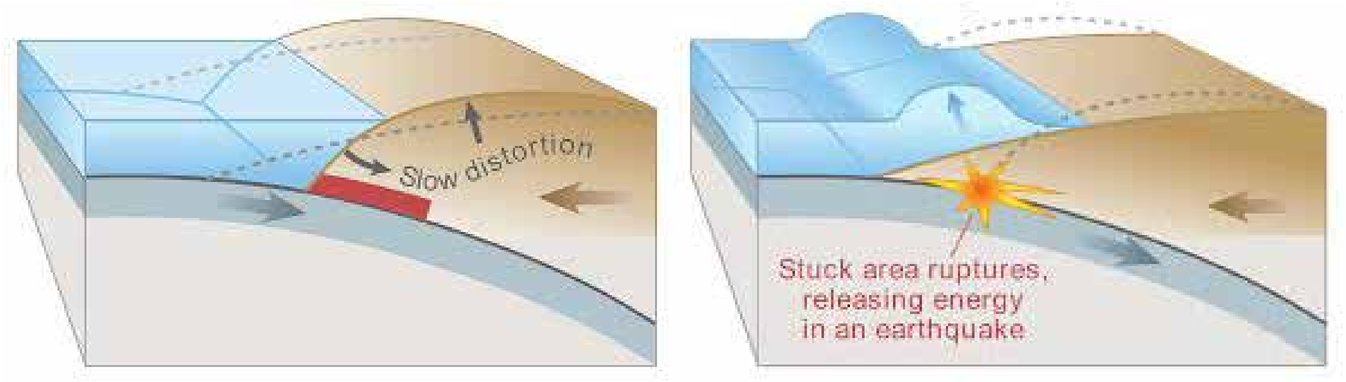

Figure 1. Dynamics of the subduction zone:

The subducting tectonic plate (solid gray) currently stuck against the over-riding North American Plate (brown) along the locked zone (marked in red). This has caused the edge of the North American plate to warp and elevate the land. When the pressure finally causes the fault to rupture, the North American Plate will flex and drop, producing a major earthquake and tsunami. The dotted lines in the left image mark the level of the land when not warped by accumulated strain; on the right, the dotted lines mark the elevation of the distorted plate just before the fault ruptured. Source: Cascadia Region Earthquake Working group (CREW), Cascadia Subduction Zone Earthquakes: A Magnitude 9.0 Earthquake Scenario (2013).

SHAKING INTENSITY

Although it is possible that the Cascadia subduction zone will rupture section by section in a series of large earthquakes (each measuring magnitude 8.0 to 8.5) over a period of years, the earthquake that many scientists and emergency planners anticipate is modeled on the zone's last major quake. The entire fault zone ruptures from end to end, causing one great earthquake measuring magnitude 9.0. The shaking that results from this abrupt shifting of the earth's crust will be felt throughout the Pacific Northwest—and the ground is expected to go on shaking for four to six minutes.

Magnitude is a measure of an earthquake's size: it tells how much energy is released when a fault ruptures. For the people and structures experiencing the earthquake, the intensity of the shaking is what really matters. In general, the intensity and destructiveness of the shaking will be greater the closer one is to the plate interface, with coastal areas experiencing the highest intensities and the level of shaking diminishing the farther inland one goes, as illustrated in Figure 2.

How much the ground shakes, or the shaking intensity, depends on one's location. Proximity is a major factor (the closer you are to the rupture, the more intense the shaking tends to be), but the shape and consistency of the ground makes a big difference. In the 2001 Nisqually earthquake, the greatest shaking intensities were not nearest the rupture, but in areas where the soft soils of river valleys and artificial fill amplified seismic waves, such as on Harbor Island in Seattle.

Shaking intensity is most often described using an intensity scale such as the Modified Mercalli Intensity (MMI) scale. Table 2 provides general descriptions of the observed effects of ground shaking for each MMI level.

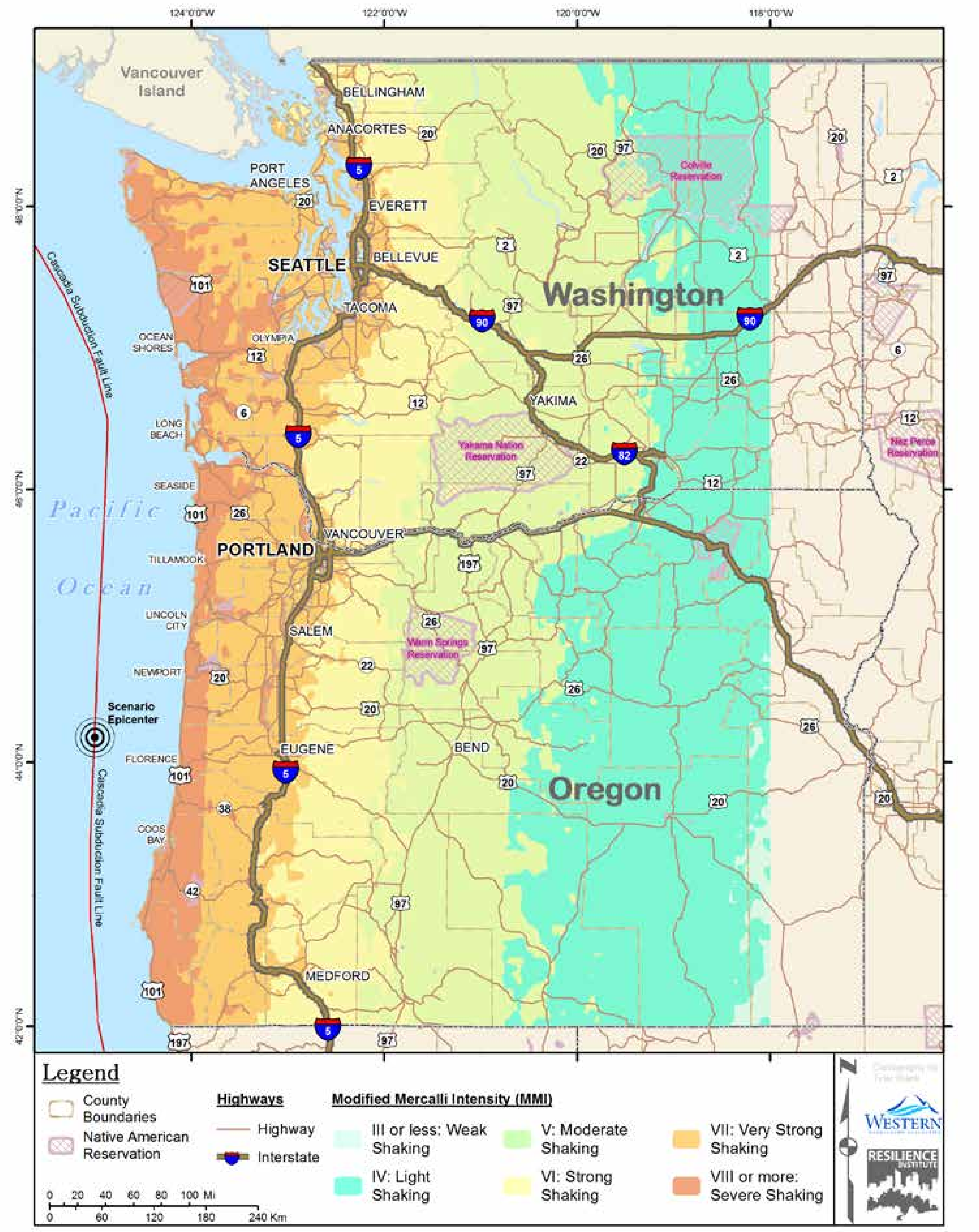

Figure 2. Expected ground shaking intensities from a M9.0 Cascadia Subduction Zone earthquake

THE MODIFIED MERCALLI INTENSITY SCALE

Intensity	Shaking	Description/Damage
I	**Not Felt**	*Not felt except by a very few under especially favorable conditions.*
II	**Weak**	*Felt only by a few persons at rest, especially on upper floors of buildings.*
III	**Weak**	*Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.*
IV	**Light**	*Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.*
V	**Moderate**	*Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.*
VI	**Strong**	*Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.*
VII	**Very Strong**	*Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.*
VIII	**Severe**	*Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.*
IX	**Violent**	*Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.*
X	**Extreme**	*Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.*

Table 2. The Modified Mercalli Intensity (MMI) Scale describes the observed effects of ground shaking at each corresponding shaking intensity level, designated by Roman Numerals.

THE TSUNAMI

Earthquakes cause damage by strong ground shaking and by the secondary effects of ground failures and tsunamis. When the Cascadia Subduction Zone ruptures, it will cause part of the seafloor to move abruptly upward. This displaces the column of water above the rupture. The result is a tsunami – a series of waves that travel outward in all directions from the place where the uplift occurred. Unlike wind-generated waves that travel along the surface, tsunami waves move through the entire body of water from seafloor to surface. Tsunami waves have extremely long wavelengths and contain a much greater volume of water than surface waves. This means that they look and act less like an ordinary wave and more like a vast, moving plateau of water.

A tsunami can travel across the deep ocean at nearly 500 miles (800 km) per hour. In deep water, the amplitude or height of the tsunami is low relative to its length, so the slope of the waves is very low, and they may pass unnoticed under ships. Upon entering shallower water, however, they slow down and gain in height as water piles up behind the wave front. Once it hits shore, a single tsunami wave can take as much as an hour to finish flowing in. The height of the wave and how far inland it travels vary with location: In places along Cascadia's coast, the tsunami may be as high as 30 to 40 feet (9 to 12 m). Much depends on the local topography—the lay of the land—both underwater and along the shore. In general, the inundation will be greater where the land is low or where the topography focuses the waves, such as at bays and river mouths. Other key factors are subsidence and tides: when the fault ruptures, the land in many coastal areas will drop in elevation, increasing the run-up of the subsequent tsunami; and if the quake occurs during high tide, the tsunami will travel farther inland than it would at low tide.

Because the Cascadia Subduction Zone is close to shore, the first wave will reach land soon after the earthquake—within 20 to 30 minutes in some areas. Coastal residents can then expect to witness multiple waves over a period of hours. In addition, because parts of the coastline will have dropped (subsided) during the earthquake, some areas may remain flooded, or may continue to flood during high tide, even after the tsunami retreats.

Figure 3. Following the 2011 Tohoku earthquake, multiple tsunami waves inundated Natori city, over a period of hours. Source: Reuters.

AFTERSHOCKS

The Cascadia earthquake is likely to be followed by aftershocks, which will occur throughout the region and vary in size. After a main shock as large as magnitude 9.0, a few aftershocks are likely to exceed magnitude 7.0. During the first month after the magnitude 8.8 Maule earthquake in 2010, Chile experienced 19 aftershocks larger than magnitude 6.0 (the largest was magnitude 6.9). Japan's magnitude 9.0 Tohoku earthquake in 2011 was preceded by a magnitude 7.5 foreshock and followed by multiple aftershocks, the largest of which measured magnitude 7.9. Some of these aftershocks occurred on the west side of Honshu, demonstrating that such quakes may be triggered some distance from the main shock.

Aftershocks that follow hard on the heels of the main shock can bring down already weakened buildings. While the size and frequency of aftershocks will diminish over time, a few may cause additional damage long after the initial quake. This occurred in New Zealand, where the magnitude 7.0 Darfield earthquake in September of 2010 was followed by a magnitude 6.1 aftershock over five months later, which caused far more damage to the city of Christchurch than the main shock.

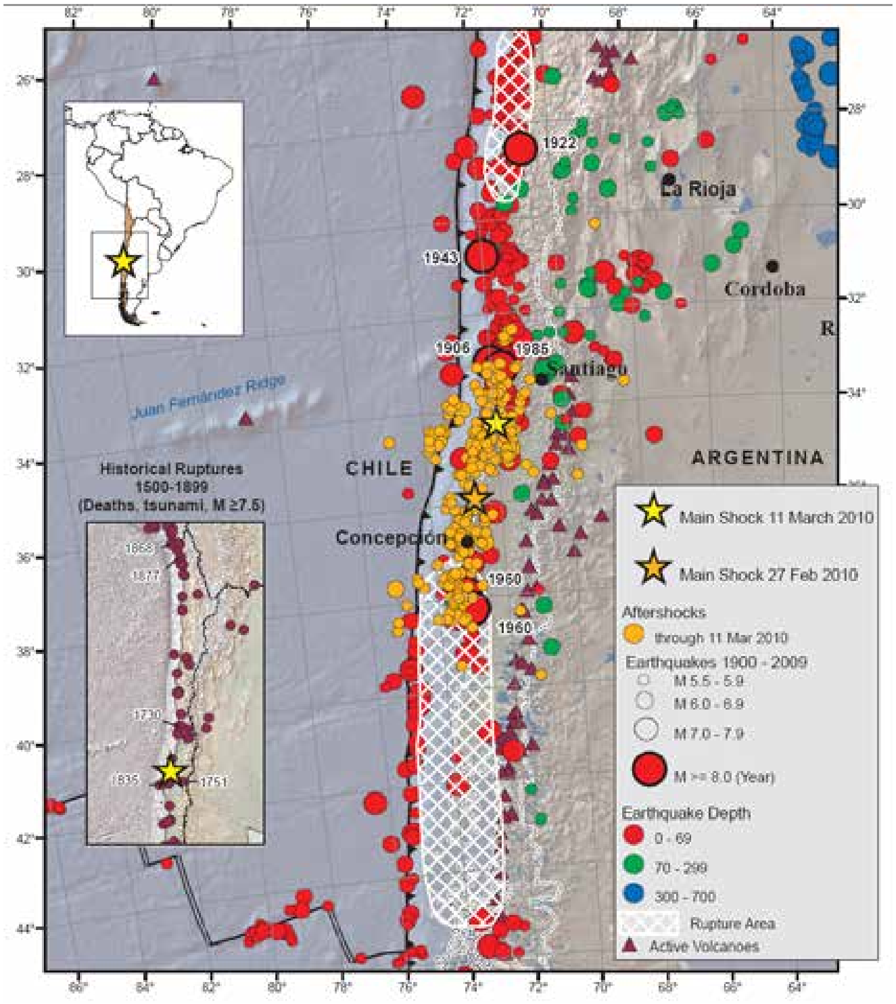

Figure 4. Chile's M8.8 Maule earthquake in 2010 occurred on a subduction zone similar to Cascadia. On this map, green dots mark aftershocks that followed the Maule quake; red dots mark past earthquakes greater than M7.0 (1900 to 2002). Earthquakes larger than M7.0 are rarer in Cascadia than in Chile, but a great quake on the Cascadia subduction zone is expected to trigger multiple aftershocks—including some far from the faulted area of the main shock. On the map, a solid white line encircles the section of the plate interface that broke in the Maule quake; white cross-hatching marks past ruptures. Photo: USGS

LANDSLIDES AND LIQUEFACTION

Local geologic conditions, including soil type, can increase or decrease the intensity of the shaking and produce a range of secondary effects, including landslides, liquefaction, and lateral spreads.

Liquefaction is one of the most damaging effects of ground shaking. Certain soils, such as water-saturated silt and sand, can become dangerously unstable during an earthquake. The shaking increases water pressure, forcing the water to move in between the individual grains of soil; as the grains lose contact with each other, the soil begins to act like a liquid. Overlying layers of sediment can slump and spread laterally. Structures built on such soils may shift position or sink, while buried pipes and tanks become buoyant and float to the surface. Liquefaction-prone soils are common in river valleys, along waterfronts, and in places covered with artificial fill. Unfortunately, these sites are often prime locations for important structures, including bridges, ports, airports, and industrial facilities. Many of the region's most densely populated areas -- such as along the I-5 corridor between Eugene and Portland in Oregon and between Olympia and Everett in Washington -- are likely to experience the damaging effects of liquefaction.

Areas on the steep slopes of mountain ranges in Washington and Oregon are susceptible to landslides and rock falls. Landslides can cause damage to critical infrastructure, residential and commercial structures. They can also isolate communities when landslides and rockfalls cross roadways or knock out power or communications lines. Shaking from earthquakes and aftershocks often trigger many landslides and rocksfalls. The risk of landslides and liquefaction can increase when heavy rainfall causes soil to become waterlogged and saturated.

Figure 5-7 show some of the damage of the impacts landslides and liquefaction can have on communities. Figure 8 indicates areas susceptible to landslides triggered by seismic activity.

Figure 5. Earthquakes can trigger preexisting landslides. This could happen immediately or days to weeks later. The 2001 Nisqually earthquake triggered a landslide three days after the earthquake. The same hillside slid after the 1949 South Puget Sound earthquake. Photo: Dave Sherrod, USGS.

Figure 6. The 2011 Canterbury earthquake in New Zealand caused the loose sand and silt supporting the paved surfaces to liquefy and loose its ability to support this automobile. Liquefaction often results in uneven patterns of ground settlement. Photo: Martin Luff.

Figure 7. Damage due to liquefaction and lateral spreading at the Port of Coronel in Chile after the M8.8 Maule earthquake. Port facilities are particularly vulnerable to damage from lateral spreading. Photo: Geotechnical Extreme Events Reconnaissance (GEER).

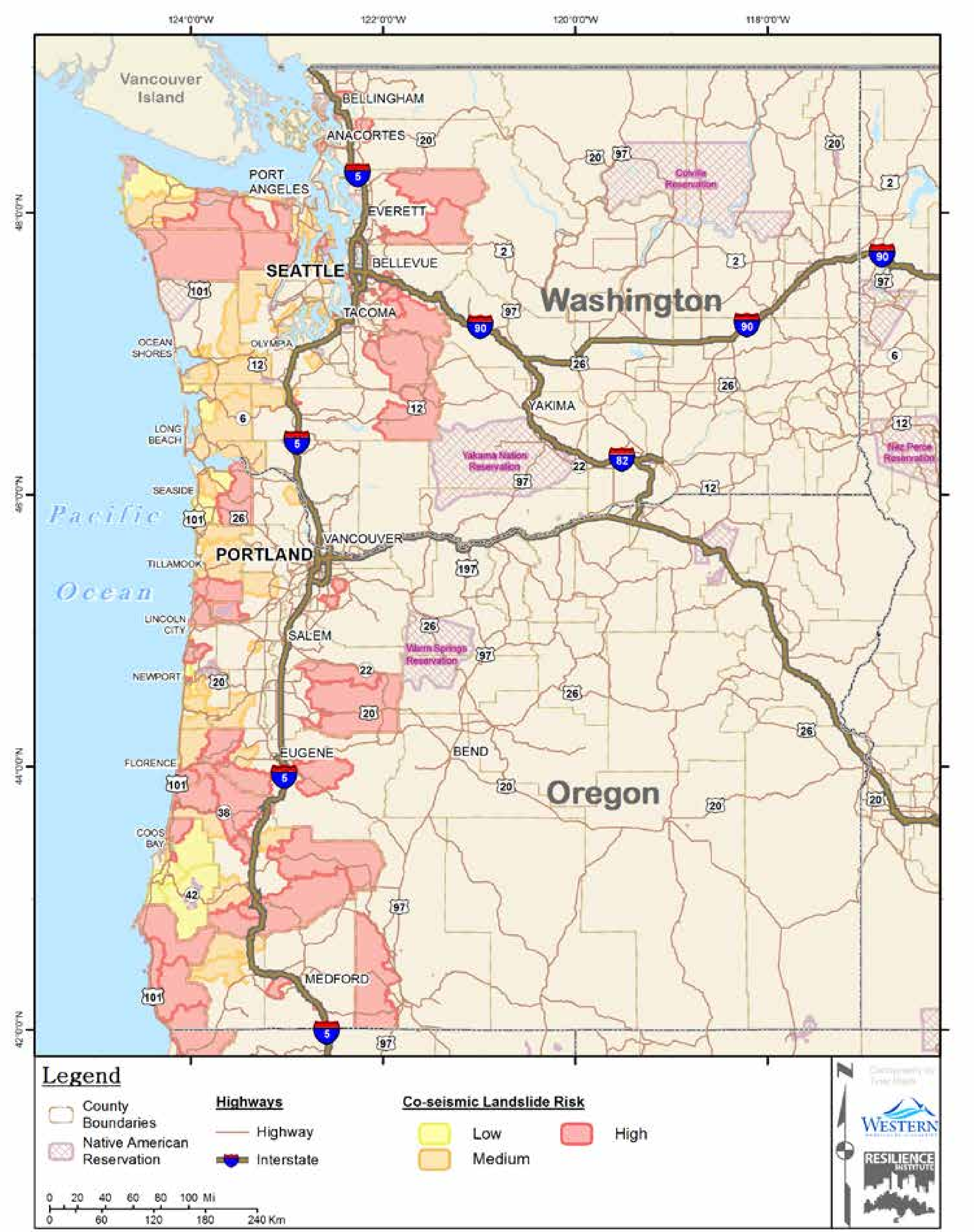

Figure 8. Washington and Oregon areas susceptible to co-seismic land sliding

FUTURE RISK

The evidence for past subduction zone earthquakes of magnitude 9.0 suggests that they recur, on average, every 500 years, but the actual intervals between events are far from predictable—such earthquakes have been separated by as many as 1,000 years and as few as 200. The estimates of the sizes of pre-1700 earthquakes are also uncertain. Cascadia has now been building up strain for over 300 years, so the next great earthquake could happen at any time.

Should the earthquake and tsunami happen tomorrow, it could affect millions of people's lives, property, infrastructure, and environment. The number of deaths could exceed 10,000, and more than 30,000 people could be injured. The economic impacts could also be significant. For Washington and Oregon, the direct economic losses have been estimated at upward of $81 billion. These social and economic impacts could distress the region for years to come.

While the timing cannot be forecast very precisely, great subduction zone earthquakes are inevitable—they are a fundamental consequence of plate tectonics. Whether this type of earthquake is considered alone or in combination with other earthquake sources, the odds that a large, damaging earthquake will occur in the near future in the Cascadia region are very high. The more steps our communities take now to prepare, the more resilient we will be.

CONTINUING RESEARCH: EARTHQUAKE EARLY WARNING SYSTEMS

By detecting the smaller seismic waves that precede the earthquake's destructive waves, an early warning system might provide a few seconds to a few minutes of warning to cities (such as Portland, Seattle, and Vancouver) that are some distance from the Cascadia subduction zone. This would give people time to drop, cover, and hold, and it could be enough time to shut off gas mains, open fire station doors, slow freeway traffic, and clear cars away from potentially dangerous structures (such as bridges and viaducts). The University of Washington, Caltech, and the University of California, Berkeley, with support from the U.S. Geological Survey and the Gordon and Betty Moore Foundation, have begun development of an earthquake early warning system. Japan has already implemented such a system and used it to provide some warning of the Tohoku earthquake on March 11, 2011. While Japan's experience suggests that early warning systems are promising, much still needs to be done to test the usefulness and appropriateness of such a system for the western coast of the United States.

British Columbia is likewise in the process of developing an earthquake early warning system through the cooperation of the Ministry of Transportation, Natural Resources Canada, the University of British Columbia, and Ocean Networks Canada. The project will use offshore sensors in the northern Cascadia Subduction Zone and land-based instruments throughout the province to deliver earthquake warnings.

THE M9 PROJECT

The ground motions and tsunami caused by a magnitude 9 earthquake will depend on many factors. Consequently, it is difficult to predict the resulting landslides, liquefaction, and building response. At the University of Washington, a team of researchers involved in the NSF-funded "M9 Project," are currently working to probabilistically forecast the shaking and earthquake-related effects that cities across the Cascadia region will experience in the wake of a magnitude 9 event.

Several factors will affect the pattern of shaking caused by a magnitude 9 earthquake. The distribution of asperities (i.e., pockets of concentrated strain energy on the fault), the direction that the rupture propagates, and the geology of the Puget Sound basins all influence where the shaking will be strongest. In order to better quantify the potential shaking across the Pacific Northwest, the M9 Project is generating a suite of state-of-the-art 3-D simulations of fault rupture and their resulting ground motions that take into account these variabilities. In addition to stronger shaking, a large magnitude 9 earthquake will also generate more long-period energy and have a longer duration of shaking than smaller earthquakes. The effects of this long-period energy and longer duration of shaking on liquefaction, seismically-induced landslides, and building response is still poorly understood and a target for ongoing M9 Project research.

Similarly, destructive tsunami impacts on the coastal built environment, and the number of fatalities and injuries inflicted, will be strongly dependent on the details of the earthquake ground motion. In particular, tsunamis are generated from the vertical seafloor deformation that occurs during an earthquake, so the severity of tsunami impacts on a given coastal community are critically dependent on its location relative to the magnitude and precisely how the fault slips over the thousands of square kilometers that rupture during the earthquake. In general, a patch of fault surface that slips will spawn a tsunami that will strike the community sooner and with more destructive waves than a patch with relatively little slippage. Therefore, during the same M9 event, individual Washington and Oregon coastal communities could experience different tsunami wave heights up to 30+ feet and arrival times from about 10 to 30 minutes. But adequately detailed predictions of the variability in fault slip for tsunami hazard assessments are not known. For this reason, the M9 project is developing and testing probabilistic tsunami hazard assessment methods, in which the best available science is used to weigh the probability of a large number of distributions that are deemed credible, and the associated tsunami simulations are combined to produce probabilistic tsunami hazard products, including forces on structures. In addition, the M9 project conducts research into the physics of tsunami generation by landslides and the probabilistic characterization of this process.

In the long-term, M9 Project researchers aim to integrate probabilistic hazard scenarios for earthquake shaking, tsunami generation, liquefaction, seismically induced landslides, and building response into the preparation and response plans for earthquake-related hazards in the Pacific Northwest. Further information on The M9 Project can be found at http://m9.ess.washington.edu/public/M9_Home.html.

TSUNAMI IMPACTS

The tsunami inundation zone extends 450 miles along the coast of Washington and Oregon. The majority of the coastline is sparsely populated. Nonetheless, the tsunami wave will likely cause devastating damage and loss of life. Anyone in the tsunami zone when the first wave hits will likely be quickly killed or seriously injured; buildings, roads, bridges, and utility infrastructure in the tsunami inundation zone will likely be severely damaged or completely destroyed, as illustrated in Figure 9.

As tsunami waves travel across the deep ocean, tsunami monitoring equipment may detect the wave. However, warning messages may not reach many coastal communities before the first waves make landfall. With only tens of minutes before the tsunami reaches the coastline in some areas, the only warning these communities receive may come from the earthquake itself.

Some survivors may try to evacuate by car but will likely be stopped by impassable roads or bridges. With limited passable driving routes away from the coast, the movement of people fleeing the coastline will likely result in gridlock. Thus, most survivors will be forced to walk or run to higher ground. However, downed power lines, damaged streets and buildings, and other damage may slow evacuation. Moreover, people who suffer injuries from the earthquake may be unable to move fast enough to reach safety.

Figure 9. The tsunami resulting from the 2011 Tohoku earthquake destroyed the low-lying areas of tsuchi, Japan. Photo: Dylan McCord, U.S. Navy.

Over 86,000 residents live in the tsunami inundation zone that is likely to result from an M9.0 Cascadia Subduction Zone earthquake. Assuming these 86,000 residents are present at the time of the initial earthquake and evacuate the inundation zone at a slow walk, over 20,000 residents will likely be unable to make it to high ground. When the wave hits, as many as 15,000 of these residents could potentially be swept out to sea or crushed in debris entrenched in the tsunami water. The remaining survivors may suffer from crushing, puncture, abrasion, exposure, and other injuries. During certain times, thousands of additional tourists, workers, and commuters may also be in the inundation zone and at risk; at these times, loss of life may be much higher.

Even after the first wave recedes, the danger will not be over. Tsunami waves will continue to surge in and out of inundation zones for up to 24 hours after the earthquake. In the coming days, there will likely be numerous large aftershocks, some of which may have the potential to generate additional tsunami waves.

Survivors in many coastal communities may be stranded for weeks due to damaged ground transportation networks. Air and sea transportation may be the only viable way to access many coastal communities.

WASHINGTON: TSUNAMI IMPACTS

The tsunami inundation zone in Washington is located on the coast of the Pacific Ocean and along the coasts of the Strait of Juan de Fuca. Some inundation is also expected on the coasts of counties in the upper Puget Sound, as illustrated in Figure 12.

Over 50,000 Washingtonians reside in the tsunami inundation zone. After the initial ground shaking, survivors may have 30 to 60 minutes before the first wave makes landfall. At a slow walk, as many as 14,000 of the 50,000 residents may be unable to reach higher ground before the first wave hits. Most of the people who are still in the tsunami zone when the first wave arrives may be swept out to sea or crushed by debris entrenched in the tsunami water. During certain times, as many as 25,000 workers, 17,000 tourists, and thousands of commuters may also be in the inundation zone, increasing the potential for loss of life substantially.

As illustrated in Figures 10 and 11, many towns in Pacific and Grays Harbor Counties are located in the tsunami zone. The tsunami will likely devastate the cities of Aberdeen, Ocean Shores, Westport, Long Beach, Hoquiam, Cosmopolis, and Shoalwater Bay Indian Reservation.

The city of Aberdeen has a high number of residents and infrastructure in the tsunami zone. However, due to its close proximity to higher ground, most people will likely make it to safety before the wave hits. While the tsunami will destroy a significant number of buildings and facilities in Aberdeen, some facilities outside of the inundation zone will likely be available to set up triage and temporary shelters.

Ocean Shores, Long Beach, Westport, Hoquiam, and Shoalwater Bay Indian Reservation are also located in the tsunami zone. However, nearly all of these towns' infrastructure and residential homes may be completely inundated by the tsunami. With everything in these towns potentially destroyed, the remaining survivors may need to be evacuated from these tsunami-inundated areas.

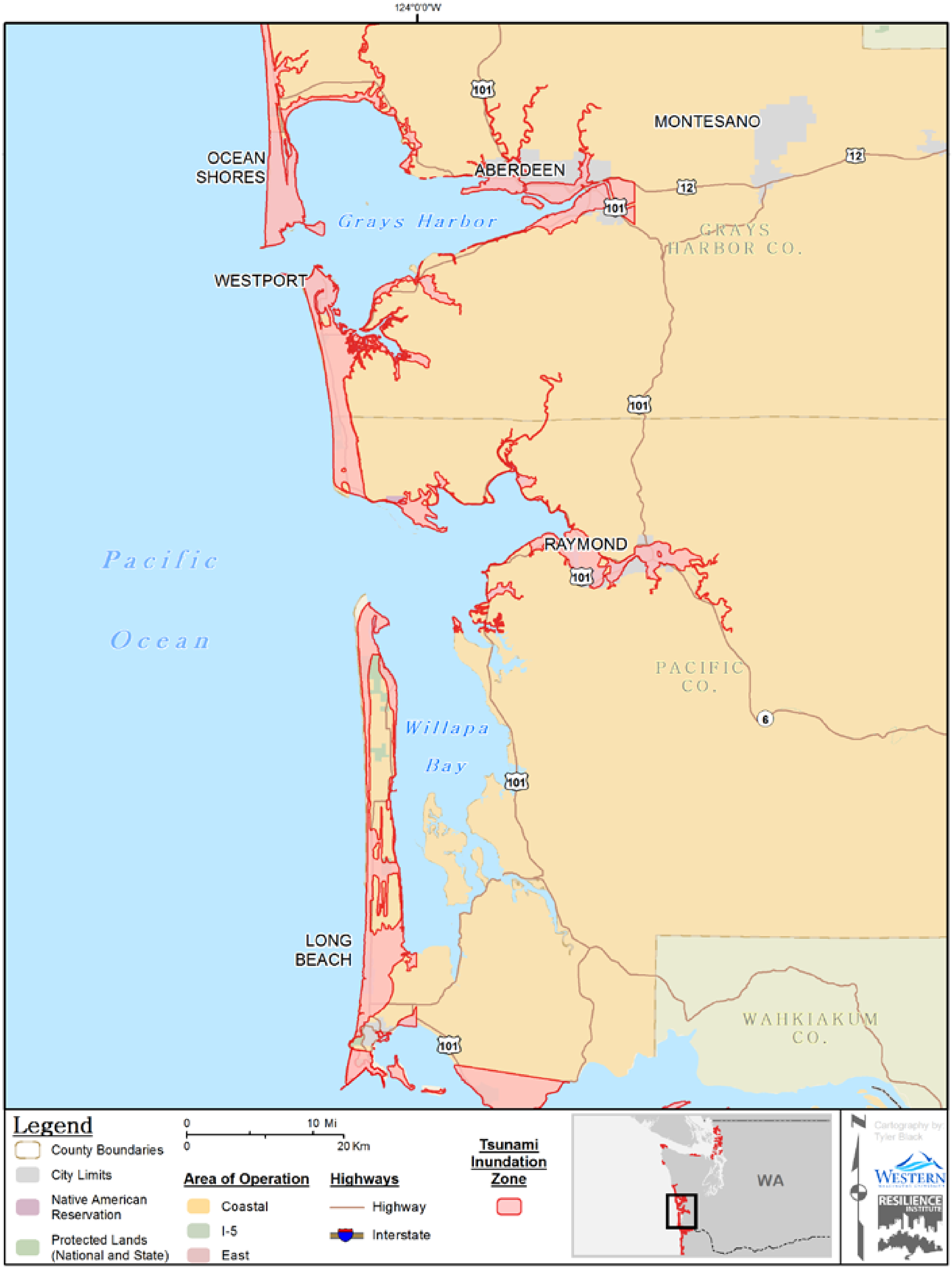

Figure 10. Tsunami inundation zone along the coast of Grays Harbor and Willapa Bay, Washington

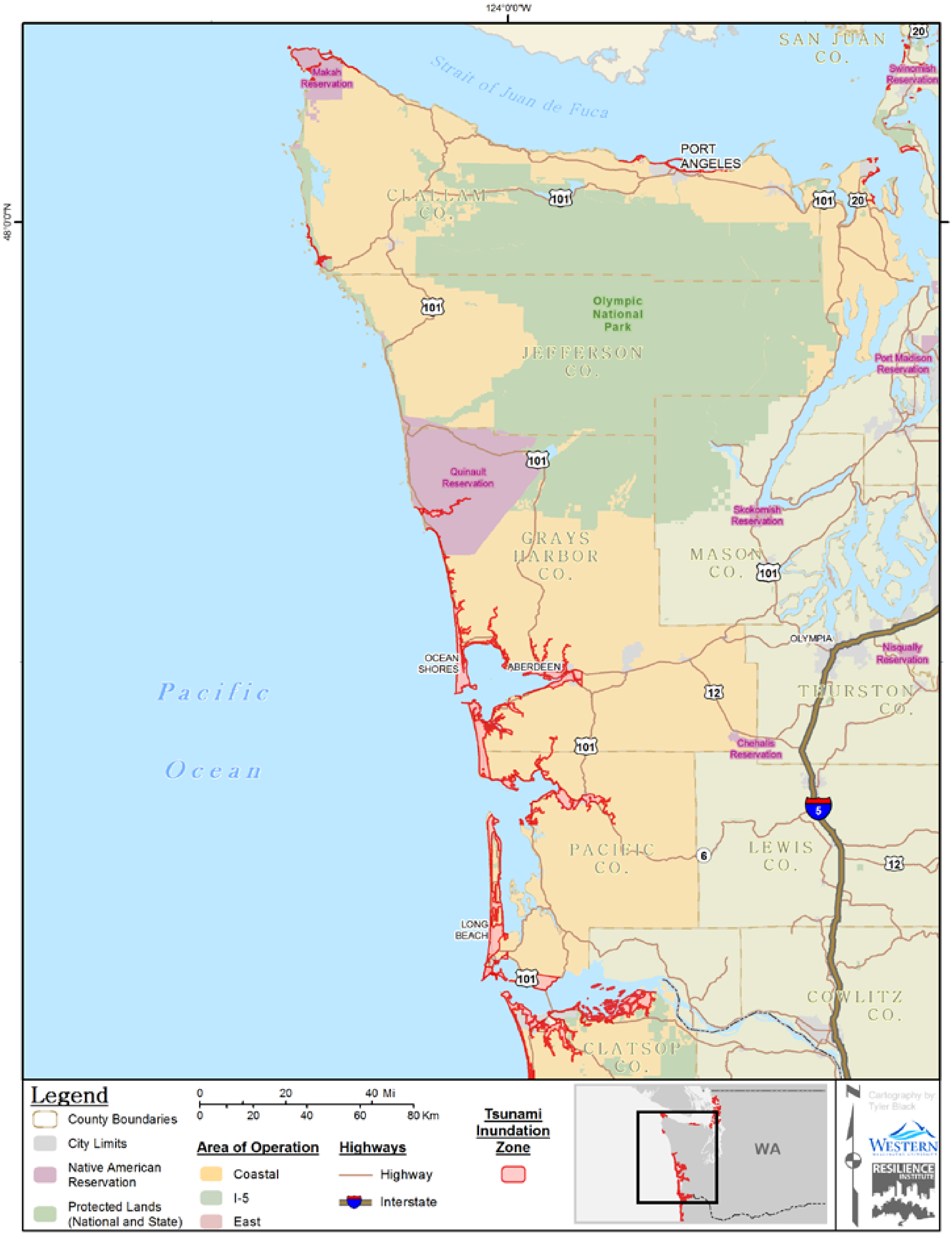

Figure 11. Tsunami inundation zone along the Pacific Coast of Washington

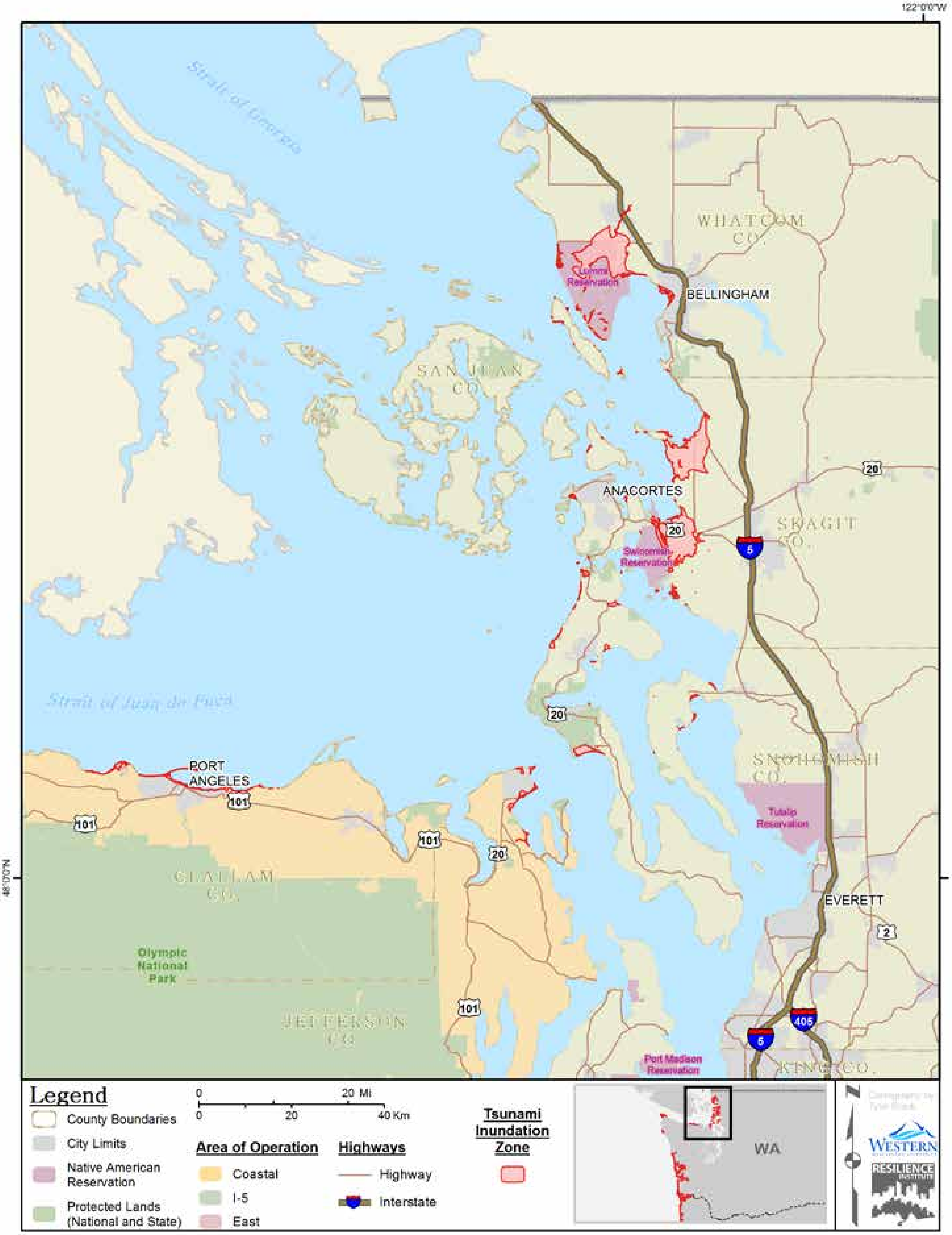

Figure 12. Tsunami inundation zone along the coast of the Puget Sound area of Washington

OREGON: TSUNAMI IMPACTS

Over 30,000 Oregonians live in the tsunami inundation zone that is likely to result from a M9.0 Cascadia Subduction Zone earthquake. After the initial ground shaking, survivors may only have tens of minutes before the first wave makes landfall. Assuming the 30,000 residents are present at the time of the initial earthquake and begin evacuating the tsunami zone at a slow walk, as many as 6,000 residents may be unable reach higher ground before the first wave hits. Most people who are still in the inundation zone may be swept out to sea or crushed by debris entrenched in the tsunami water. During certain times, as many as 50,000 tourists, 15,000 workers and thousands of commuters may also be in this inundation zone, potentially increasing the loss of life substantially.

As illustrated in Figures 13 and 14, many coastal towns and cities are located in the tsunami inundation zone. Nearly all of the city of Seaside's infrastructure and buildings will likely be completely inundated by the tsunami. First responders will likely have no working facilities to set up triage or temporary shelter. The remaining survivors will likely need to be evacuated.

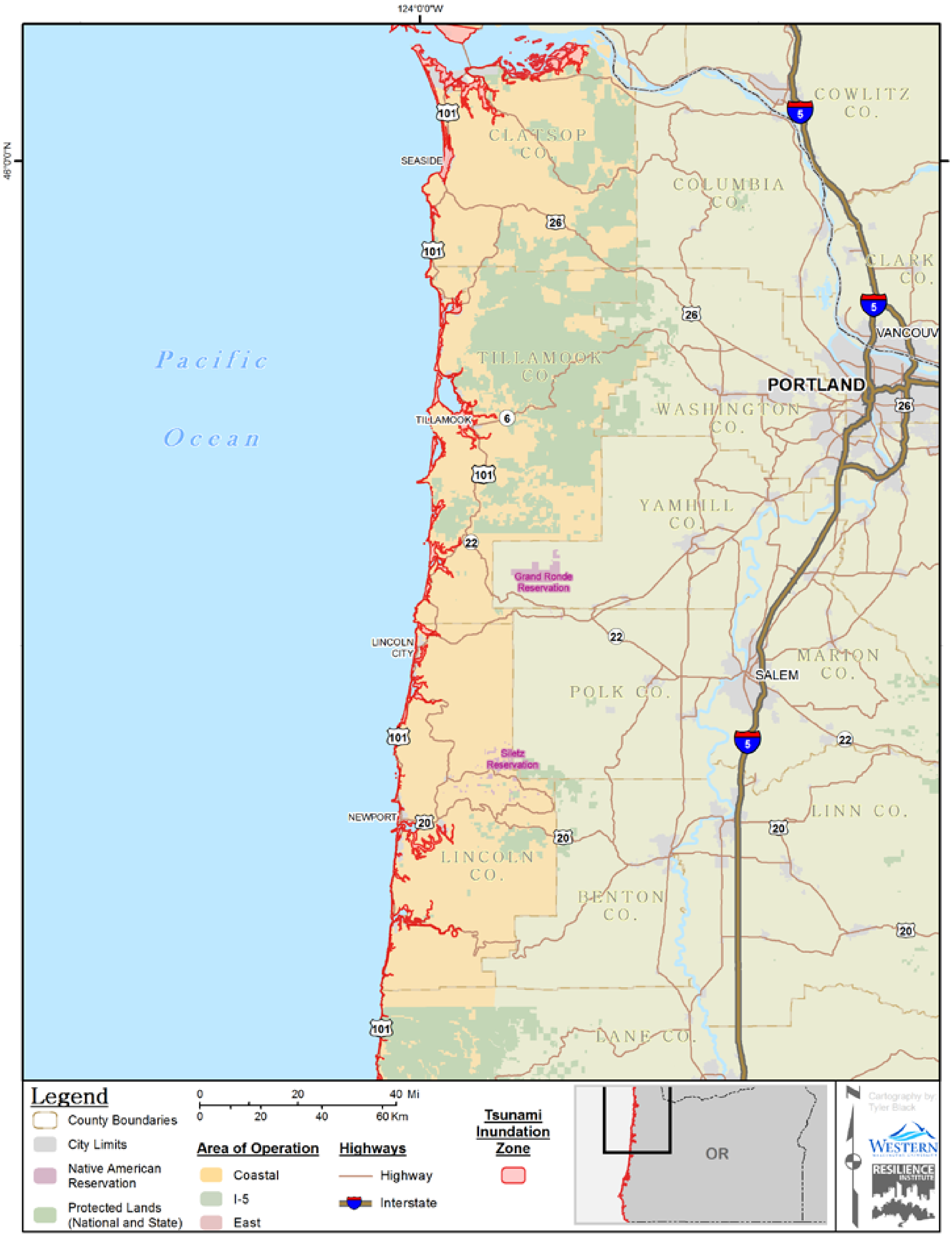

Figure 13. Tsunami inundation zone along the northern Oregon coast

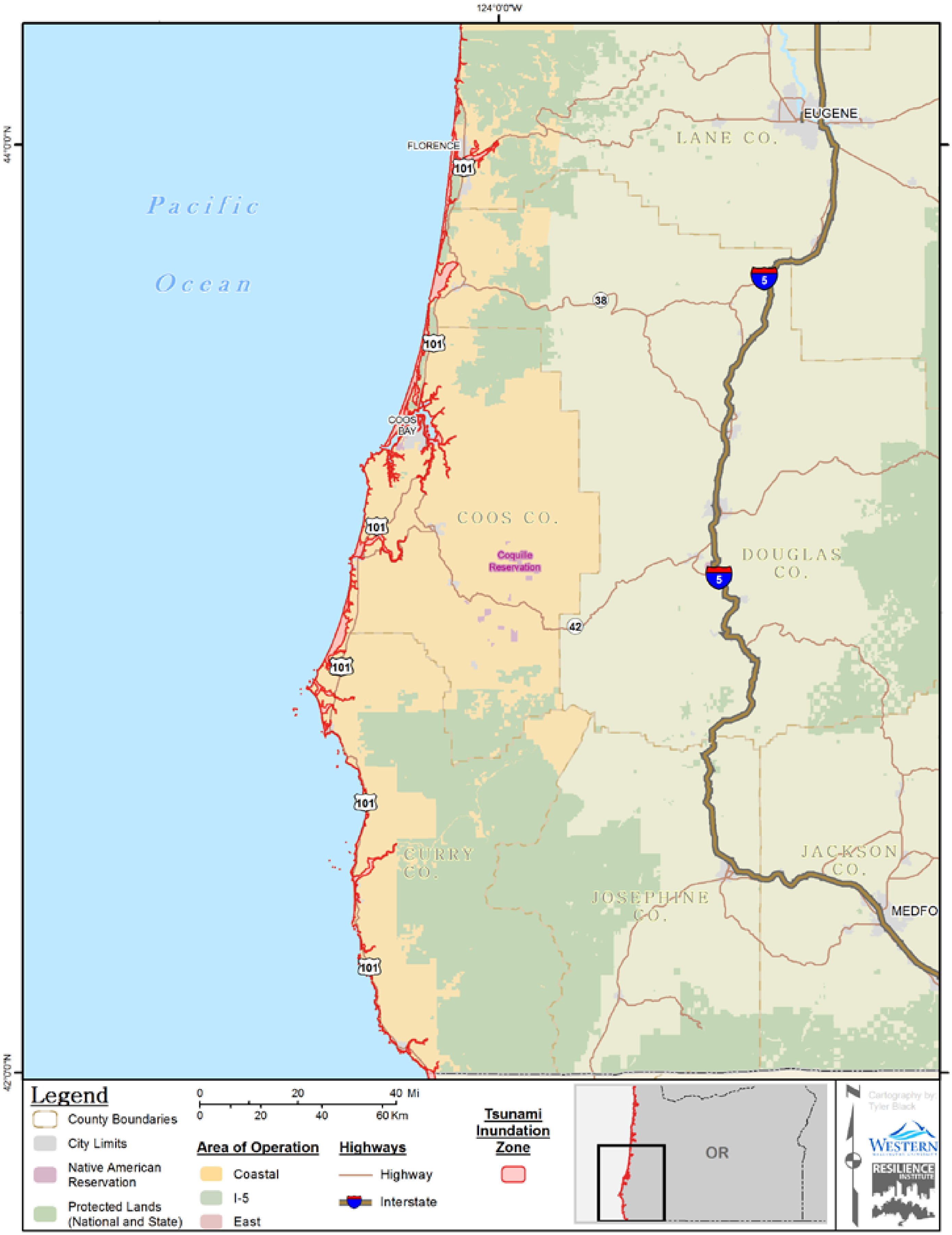

Figure 14. Tsunami inundation zone along the southern Oregon coast

POPULATION IMPACTS

The Cascadia earthquake could be one of the most devastating disasters, not only in Washington and Oregon, but in the history of the United States. As the day of the earthquake arrives, no one suspects that they are about to witness an event that will change their lives forever.

If the earthquake occurs during the day, few people will even notice when the shaking begins. For many people it may feel as if a large semi-truck is passing by; people in cars or near busy roads may not notice the initial tremors. As the shaking becomes more prominent, its jitteriness may catch the attention of people not in a car. However, many people may forget their elementary training of drop, cover, and hold, especially people caught outdoors. Instead, some people may attempt to run to safety, but only make it a few steps before falling. Others may simply stand in place, trying to retain balance and keep from being thrown to the ground. A minute into the earthquake, intense shaking may toss people about. Bookshelves, desks, and other pieces of heavy furniture may begin to move back and forth, causing anything that is not anchored to fall. People in office buildings may notice nearby skyscrapers swaying from side to side. Only a small percentage of people may have gotten under tables, chairs, or anything else that they think will protect them from falling ceiling tiles, utility equipment or furniture. Two minutes into the earthquake, people that were caught outside may notice the ground moving like an ocean wave and everyone inside may feel as if they were on a ship rolling out at sea.

Coastal areas will likely experience the most severe and intense shaking, with shaking intensities of Modified Mercalli Intensity (MMI) scale levels of VII (Severe) extending as far inland as 10 to 60 miles, depending on the location. The shaking may be strong enough to knock over columns and monuments, overturn heavy furniture, knock down walls, and collapse or break chimneys, sending large chunks of brick on to roofs. Even well-built structures may partially collapse after several minutes of this level of intense shaking.

The shaking decreases in intensity going eastward from the coast. The Interstate 5 corridor may experience shaking intensities of MMI VII (Very Strong), with considerable damage incurred in poorly-built or designed structures and in areas with poorer soils.

People living in the eastern half of Oregon and Washington may experience little shaking, simply feeling as if the ground is vibrating. Parked cars may rock and hanging objects may sway slightly. Windows, dishes, and doors may rattle, and buildings with wooden walls and frames may creak during the event.

As the shaking subsides, people may display an array of emotions and reactions. Widespread power outages may make daytime visibility inside large buildings difficult. If the event strikes at night, fallen objects littering the floor may cause people to trip and injure themselves as they try to escape in the dark. In some homes and buildings, heavy pieces of furniture, such as entertainment centers or filing cabinets, may tip over, blocking exits or trapping people under them.

After the shaking, people may begin milling around, uncertain how to respond to the event. Some may gather up belongings and search around in the fallen debris, trying to make sense of what has happened. Many people with access to a phone may try to call or text their loved ones to figure out what has happened and verify their safety. A sense of dread may overcome individuals that are unable to get in touch with their family and friends.

POPULATION IMPACTS (CONT.)

Outside, commuters may get out of their cars and try to figure out what just took place. As they realize that traffic is not moving, and that they may be stuck there for hours, drivers may abandon their cars on roads and bridges, causing backups along transportation routes.

On the coast, the threat of a tsunami has taught many residents to seek out information about the tsunami warning protocols for their area. Longtime local residents may be more efficient in their evacuation process, having prior knowledge of the threat of a tsunami following an earthquake. Visitors and tourists to the region's beautiful coastal towns may largely be unsure of what to do, if they are even aware of the tsunami threat. They may congregate in hotel lobbies and in the streets near vacation houses, seeking direction. In areas where high ground is distant, people may become stuck in traffic jams that slow or even halt evacuation by vehicle. In some areas, people may attempt to evacuate vertically, climbing to upper stories of multi-story buildings. As the tsunami reaches land, those on the ground in the inundation zone may try to outrun the tsunami; very few of them may make it. As the wave knocks them off their feet they may cling to the roofs of buildings or floating debris, but these actions will save very few. Hypothermia or exhaustion may claim many of them.

INJURIES

Following the earthquake and tsunami, thousands of injured survivors may be in need of medical care. They may seek medical treatment for cuts, bruises, and broken bones. Others may suffer from trauma injuries that require acute medical care. The earthquake may injure over 20,000 people across the region. Minutes later, the tsunami may injure several thousand more in the coastal region. More injuries may result from aftershocks, fires, HAZMAT releases, and contaminated water supplies.

In the aftermath of the earthquake and tsunami, thousands of injured survivors may be scattered across hundreds of miles of tsunami inundated coastland. Medical facilities in the region may experience a surge of as many as 30,000 injured survivors seeking medical treatment. Some injured survivors may arrive at the hospital only to find out that it has been damaged beyond use. Others may never make it to the hospital because of impassable roads. Thousands of critically injured people may need to be evacuated by air or sea if they are to be saved.

The number of injured will be affected by the time of the earthquake. Injuries will likely be highest if the shaking occurs during the day - a time when more people are outside or at work and exposed to falling debris, or commuting and exposed to traffic accidents and damaged roadways. If the event were to occur at night, minor and moderate injuries of severity level 1 or 2 may be a half or less than injury estimates during a daytime event. Table 3 describes the injuires expected for each injury severity level.

Table 3. Description of the severity of earthquake-related injuries.

	Injury Severity Level		
	Severity 1	Severity 2	Severity 3
Injury Description	Injuries requiring basic medical aid that could be administered by paraprofessionals. These types of injuries would require bandages or observation, such as sprains, cuts, and minor burns.	Non-life threatening Injuries requiring greater medical care and technology, such as x-rays or surgery. These types of injuries could include large burns, broken bones, and/or loss of consciousness.	Injuries that pose an immediate life threatening condition if not treated adequately and expeditiously, such as uncontrolled bleeding, punctured organs, spinal column injuries, or crush syndrome.

INJURIES (CONT.)

The number of severity level 3 injuries – injuries that are immediately life-threatening if not treated – are most affected by earthquake timing. Severity level 3 injuries will be highest during the day. If the event were to occur during the night, these injuries may be only a quarter or less of the daytime estimates.

If the earthquake were to occur during commuting hours, these severe injury numbers may rise further. During these commuting hours, more people may be leaving or entering buildings, on the streets of high-density downtown business areas, or in retail stores full of unsecured products on high shelves. These individuals may be exposed to falling debris and shattering glass. The many commuters on the road may be more exposed to vehicular injuries, accidents, and damaged roadways. If an event were to happen during these commuting hours, the number of severe injuries could be 20 fold greater, or more, than the number likely to result from a nighttime event.

Figure 16. Rescue workers pull an injured woman from a collapsed building following the 2011 Christchurch, New Zealand earthquake. Photo: Reuters.

FATALITIES

Not all will survive the event. Across the coastal and I-5 corridor regions, the earthquake shaking may claim the lives of over 1,100 residents and visitors. The tsunami that closely follows may claim as many as 13,500 lives on the coast. The scale of fatalities across the coast may overwhelm the resources of local governments. Hospitals and morgues on the coast may also need to manage numerous human remains. Temporary morgues may have to contend with power outages and fuel shortages.

With emergency responders unable to reach many areas, survivors may attempt to manage the remains of community members themselves. The disruptions in communications systems may limit the reach of public messaging and training regarding public health and the safe disposal of deceased humans, farm animals, and pets.

The number of fatalities will also be highly dependent on the time of the event. Fatalities, like injuries, may be lowest during a night time event. They are likely to increase threefold during a daytime event in rural areas and fivefold or more in urban areas, regardless of whether the event occurs during the workday or during a commuting hours.

Figure 16. Morgue overcrowding following the 2011 Tohoku earthquake and tsunami, led workers to create makeshift morgues like this one in gymnasiums and other available facilities. Photo: Damir Sagolj, Reuters.

WASHINGTON: INJURIES AND FATALITIES

With the adoption of increasingly robust building codes with seismic design provisions over the last several decades, much of the newer building stock in Washington has been designed for life safety even in strong shaking. As shown in Table 4, the highest number of earthquake-related injuries and deaths are likely in the urban areas of Seattle, which has many older structures that were not built to these codes and where people are more exposed to collapsing buildings, falling glass, and other objects that may cause injury or death.

The highest number of tsunami-related injuries and deaths will likely be in Grays Harbor County, with as many as 5,000 casualties in Ocean Shores alone. The city of Long Beach in Pacific County may also have a high number of tsunami casualties. It is likely that most residents in these communities will not reach high ground before the tsunami wave hits.

Nearly all of the infrastructure and residential housing in Ocean Shores, Long Beach, Westport, Hoquiam, and Shoalwater Bay Indian Reservation will likely be destroyed by the tsunami. After the water recedes, there may be no remaining buildings to set up triage or temporary shelters. The few remaining survivors in these towns will likely need to be evacuated.

Table 4. Estimated injuries and deaths in Washington resulting from the CSZ earthquake and tsunami

	Injuries			Fatalities		
Area of Operation	Earthquake	Tsunami	Total	Earthquake	Tsunami	Total
Coastal	2,000	3,000	**5,000**	100	9,000	**9,100**
I-5 corridor	7,000	0-400*	**7,000**	300	0-1,300*	**300**
Washington total	9,000	3,000	**12,000**	400	9,000	**9,400**

**Tsunami deaths and injuries in the I-5 corridor represent exposed populations in the upper Puget Sound region, such as coastal communities in San Juan, Island, Skagit and Whatcom counties. However, studies are conflicting as to the fatalities and injuries in these inundation zones. These numbers are not included in state totals.*

Source: FEMA CSZ Response Plan (2013) and Wood - see Methodology section for more detail

OREGON: INJURIES AND FATALITIES

With the adoption of increasingly robust building codes with seismic design provisions over the last several decades, much of the newer building stock in Oregon has been designed for life safety even in strong shaking. As shown in Table 5, the highest number of earthquake-related injuries and deaths are likely in the Portland metropolitan area, which has many older structures that were not built to withstand intense shaking and where people are more exposed to collapsing buildings, falling glass, and other objects that may cause injury or death.

The highest number of tsunami-related injuries and deaths are likely in Clatsop County, with over 4,000 casualties in the city of Seaside alone.

Table 5. Estimated injuries and deaths in Oregon resulting from the CSZ earthquake and tsunami

	Injuries			**Fatalities**		
Area of Operation	**Earthquake**	**Tsunami**	**Total**	**Earthquake**	**Tsunami**	**Total**
Coastal	5,000	1,500	5,500	300	4,500	4,800
I-5 corridor	9,000	0	9,000	400	0	400
Oregon total	14,000	1,500	15,500	700	4,500	5,200

Source: FEMA CSZ Response Plan (2013) and Wood - see Methodology section for more detail

TRANSPORTATION SYSTEMS

The severe shaking and tsunami inundation may cause significant damage to the region's ground, air, and marine transportation systems. The damage may be widespread – affecting approximately 16,000 miles of highway, 7,000 highway bridges, 6,000 miles of rail, 100 rail bridges, 100 airports, and 700 port facilities. Most of the Pacific Northwest's transportation infrastructure was constructed prior to modern seismic design standards. Many bridges, tunnels, and ports have yet to be seismically retrofitted to withstand the shaking. Additionally, many transportation systems are built across liquefiable soils along old landslides that may be set in motion by the earthquake.

The road and highway network is one of the most critical infrastructure systems. If roads are damaged and impassable, inspecting and repairing other infrastructure systems becomes difficult or even impossible. The challenge of restoring transportation networks after a Cascadia event may be compounded by the damages to other interconnected systems, such as fuel, power and communication systems.

ROADS

During the initial response period, widespread road damage may impair rescue operations, access to critical buildings, and the restoration of utilities. In the impacted area of Washington and Oregon, roughly one-third of highways may suffer medium to high damage, with damages ranging from localized, moderate cracking to the complete failure of pavement and subsurface soils supporting the roads.

Table 6 describes road damage for each damage state. This damage is due to ground failure as a result of lateral or vertical displacement, liquefaction, or landslides. The photos in Figures 19-24 illustrate these types of ground failures and corresponding damage states.

Close to half of Interstate 5, running from the southern Oregon border to the U.S.-Canadian border, may suffer medium to high damage and be unusable for long distance travel until road and bridge repairs are made. These repair procedures may be as simple as sealing large cracks or patching up bumps in the pavement, or extensive enough to require the complete removal and replacement of existing pavement and subsurface materials.

Road damage may be particularly severe in coastal areas where the shaking is most intense. Almost the entire stretch of U.S. Highway 101, from the southern Oregon border to the northern tip of the

Table 6. Description of road damage state resulting from permanent ground displacement

	Damage State		
	Low	Medium	High
Permanent ground displacement (inches)	1 - 3	3 - 12	> 12
Summary of damage description	Slight cracking or movement. No interruption of traffic.	Moderate to extensive cracking or movement of pavement surface but not failure of subsurface soils.	Roadway pavement and subsurface soils fail. Roadway surface requires replacement.

ROADS (CONT.)

Olympic Peninsula, may suffer high damage, with the roadway shifting up or down a foot or more in many areas. Low-lying segments of U.S. 101 that survive the shaking will likely be damaged by the rushing waters of the tsunami or landslides. Figure 17 illustrates roadways destroyed by a tsunami.

Most of the roads connecting coastal communities to the I-5 corridor may also suffer high damage due to extensive ground settlement. With few drivable routes from the coast to the I-5 corridor, coastal communities along U.S. 101 may be unable to self-evacuate. Emergency responders may also find it nearly impossible to deliver emergency supplies of food, water, fuel, and materials by ground until sufficient road repairs are made, which could take several months. However, the coast may still be accessible by sea or air. Figures 20-21 shows the type of high damage to expect on segments of coastal highway.

In urban areas, damage to roadways may cause heavy traffic congestion as commuters attempt to drive from work to home or as individuals seek to drive toward loved ones. While some degree of movement may be possible via alternate routes, motorists may need to expect longer travel times and heavy congestion.

Roads connecting major urban areas in the I-5 corridor with infrastructure in eastern Oregon and eastern Washington, may suffer little structural

Figure 17. The 2011 Tohoku tsunami caused high damage to roadways, shifting parts of the road up or down by more than a foot. Photo: Japan Red Cross Society, published in the New York Times March 24, 2011.

Figure 18. The 2010 M7.1 Canterbury, New Zealand earthquake caused low to medium damage to roadways, with two to five inches of permanent ground displacement. Photo: Martin Luff.

ROADS (CONT.)

damage to the roads themselves. However, there are only a handful of eastbound routes that run through the steep, mountainous terrain of the Cascades and many of these routes cross pre-existing landslides. The earthquake could trigger landslides that block or endanger these mountain passes. With only two major interstate highways, a handful of U.S. and state routes, and two rail lines crossing the Cascades, even a few landslide events or damaged bridges on these routes may cripple the movement of supplies from the eastern side of Washington and Oregon into the I-5 corridor and coastal regions.

Figure 19. A M7.0 earthquake in California caused medium damage to roadways, with three to twelve inches of vertical displacement dissecting the road. This type of damage can be patched with an asphalt concrete overlay. Photo: Karl V. Steinbrugge, HITRAC.

Figure 20. The 2011 M6.3 Christchurch, New Zealand earthquake caused high damage to roadways as a result of ground failure due to liquefaction. This type of damage may require the removal and replacement of existing pavement. Photo: David Hallett, HITRAC.

Figure 21. The 2007 Niigata earthquake in Japan triggered landslides that took out portions of roads. Some critical roadways in Oregon and Washington were built atop preexisting landslides, which could be triggered again during the earthquake. Source, CREW.

WASHINGTON: ROADS

Over a quarter of Washington's road infrastructure may suffer medium to high damage, with damages ranging from large cracks and ground settlement to complete failure of pavement structure and subsurface materials. The high damage road segments may be completely unusable until major repairs are made.

Washington's portion of the I-5 interstate stretches some 250 miles from the Canadian border to the southern border with Oregon. Roughly two-thirds may suffer medium or greater damage, with large cracks and major settlement across many segments of roadway. Damage may be particularly severe in the Seattle-Tacoma region, as shown in Figure 22.

Roadway damage may be extensive throughout the coast and coastal mountain chain. As shown in Table 7, 75 percent of the roadways may suffer high damage, including over 12 inches of ground displacement resulting in the failure of pavement and subsurface materials. Nearly the full extent of U.S. 101 may suffer high structural damage, with landslide debris blocking segments of road near Chinook, Hoquiam, Port Angeles, and Shelton.

Most of the primary and secondary roads between the coast and the I-5 corridor may be unusable for long-distance travel due to high structural damage caused by the initial earthquake. Alternative routes along tertiary roads may exist. However, landslide debris may render these roads inaccessible or unusable.

When the tsunami waves make landfall, parts of as many as eight major coastal highways will likely be destroyed by the force of the waves. Coastal communities will likely be completely isolated for a couple of weeks. Restoration of ground transportation infrastructure connecting coastal communities to the interior of the states may take several months.

Table 7. Distribution of damage states for highways in Washington state, by areas of operation

	Damage State			
Area of Operation	**None**	**Low**	**Medium**	**High**
Coastal	14%	6%	5%	75%
I-5 corridor	65%	5%	8%	22%
East	33%	66%	0%	0%
Summary of damage description	No damage.	1 - 3 inches ground displacement. Slight cracking or movement. No interruption of traffic.	3 - 12 inches ground displacement. Moderate to extensive cracking or movement of pavement surface but not failure of subsurface soils.	Over 12 inches ground displacement. Roadway pavement and subsurface soils fail. Roadway surface requires replacement.

Figure 22. Washington state road and tunnel damage caused by the initial earthquake

OREGON: ROADS

In Oregon, the I-5 highway stretches over 300 miles from the Washington border to the southern border with California. Roughly half of the interstate may suffer high structural damage from the initial earthquake, with large cracks and major settlement across many segments of roadway. Mountainous terrain in the southern part of Oregon and ongoing slope instability in areas around Portland may cause high damage to much of I-5 from Eugene to Portland. Large cracks, loose soil, and landslide debris may occur along this stretch of highway.

Roadway damage may be extensive throughout the coastal region, as shown in Figure 23. As shown in Table 8, ninety-one percent of the roadways in the coastal corridor may suffer high damage, including over 12 inches of ground displacement resulting in the failure of pavement and subsurface materials. Nearly the full extent of U.S. Highway 101 in Oregon may be completely destroyed by the initial earthquake.

Most of the primary and secondary roads connecting coastal roads to the I-5 corridor may also suffer high damage and be unusable for long-distance travel. Along U.S. 20 from Corvallis to Newport, damage may be especially heavy, with up to three feet of settlement across segments of roadway. Oregon state highways 38, 126, 34, 20, 18, 22, and U.S. 26 may suffer high damage along their full extent.

Oregon highways 4, 6, 8, 105, 109, and 112, as well as U.S. 12 may have large cracks and major settlement across many segments of roadway. Loose soil and landslide debris may block access to segments along Oregon 42, U.S. 199 and U.S. 30. Many of these roadways may be closed for several weeks to several months. Travel up and down the coast and into the valley will be difficult. Alternative routes along tertiary roads may exist. However, landslide debris may render these roads inaccessible or unusable.

When the tsunami waves make landfall, as many as twenty-five major coastal highways may be partially or fully destroyed by the force of the waves.

Table 8. Distribution of damage states for highways in Oregon, by areas of operation.

	Damage State			
Area of Operation	**None**	**Low**	**Medium**	**High**
Coastal	6%	1%	2%	91%
I-5 corridor	35%	10%	8%	46%
East	100%	0%	0%	0%
Summary of damage description	No damage.	1 - 3 inches ground displacement. Slight cracking or movement. No interruption of traffic.	3 - 12 inches ground displacement. Moderate to extensive cracking or movement of pavement surface but not failure of subsurface soils.	Over 12 inches ground displacement. Roadway pavement and subsurface soils fail. Roadway surface requires replacement.

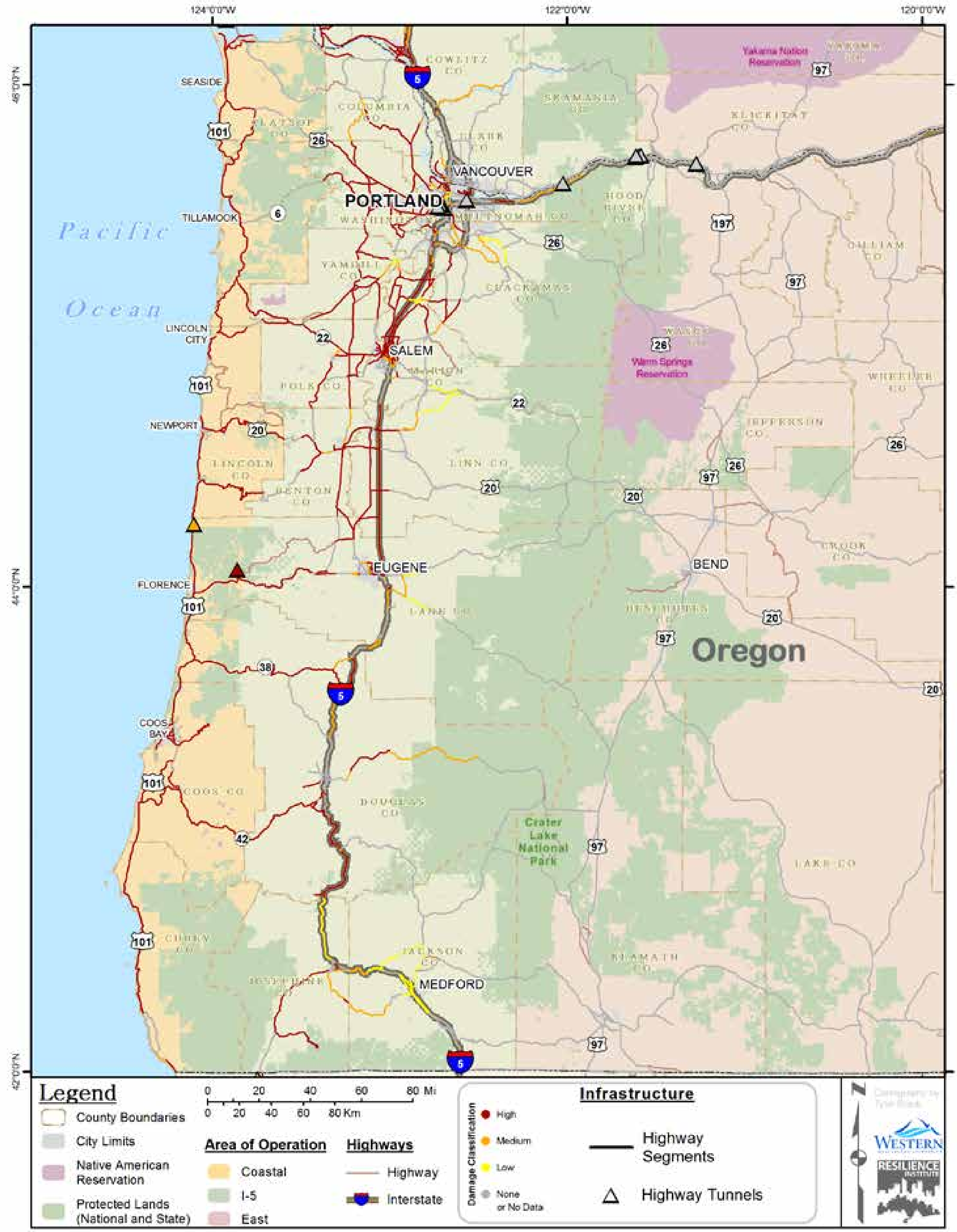

Figure 23. Oregon road and tunnel damage caused by the initial earthquake

ROAD BRIDGES

As seismic waves move across the region, over 9,000 bridges that tie our transportation network together will be put to the test. Seismic waves are amplified when they move across the deep, soft soils that support many of our bridges. Amplified waves may send destructive, resonate vibrations across long bridges, causing them to twist, swing, and pull away from their abutments. As the shaking subsides, two-thirds of the region's road bridges may be damaged to some degree. Table 9 describes bridge damage for each damage state. Figures 24-27 provide examples of these damage states from past earthquakes and tsunamis. This damage is due to ground failure as a result of lateral or vertical displacement, liquefaction, or landslides.

The majority of these damaged bridges may withstand the shaking well, experiencing minor cracking of decks and abutments, and some sloughing-off of concrete protective layers on bridge piers. These cosmetic damages may not interrupt traffic, and may require only minor repairs.

Some 2,000 bridges may suffer moderate levels of damage and may not be able to support even reduced vehicular traffic until temporary supports

Table 9. Description of damage levels for road bridges

	Damage state		
	Low	**Medium**	**High**
Bridge damage description	Minor cracking or sloughing off of the outer layer of concrete columns or walls supporting bridges or to bridge decks. These damages require only minor, cosmetic repairs, but the bridges can support traffic even before these repairs are made.	Moderate damage requiring repairs before use, but not requiring demolition of bridges. These moderate damages may include extensive cracking of support columns, up to two inches of movement in bridge columns alignment, or extensive damage to the connections between a bridge and its support columns or walls. Bridges may not support heavy loads and will likely require engineering assessments before deemed safe for traffic.	Bridge collapse or damages so severe as to require demolition and complete replacement of the entire bridge. This damage may include collapse of bridge deck or any column supporting the bridge, or tilting of the bridge due to foundation failure. Bridges likely impassable to traffic.

ROAD BRIDGES (CONT.)

are put in place. Later, they may need extensive repair to be fully functional again. However, nearly 20 percent of the bridges in the region – over 1,000 bridges – may either completely collapse or be damaged enough as to require the replacement of the entire bridge. Aftershocks may continue to impact transportation systems in the response and recovery phases, worsening damage to moderately and heavily damaged bridges.

Figure 24. The 1989 M6.9 Loma Priesta earthquake in California caused medium damage to the support column of a bridge. The shaking caused the concrete to break up and shift the bridge column alignment. Photo: H.G. Wilshire, USGS.

Bridges along the coastal highways from Southern Oregon to the northern tip of the Olympic Peninsula may suffer the highest level of damage, especially bridges carrying U.S. 101. Several bridges that survived the earthquake may be washed away by the tsunami. Additionally, debris from bridge collapse and tsunami inundation will block access to critical transportation infrastructure.

With direct shaking damage to bridges and land sliding onto highways or bridges, traditional ground access from the I-5 corridor west to the coast may be completely cut off. Due to the rugged terrain upon which these highways were built, detouring traffic around bridge collapses may not be possible in all locations.

Figure 25. The 1994 M6.7 Northridge Earthquake caused low damage to a California highway bridge, shifting sections of the bridge and breaking a guard rail. Bridges with low damage should be operational and require only minor repair later. Photo: Mark Aschheim.

ROAD BRIDGES (CONT.)

Access to the east-west corridor will be critical for people trying to evacuate the tsunami. Due to transportation impacts, many survivors in coastal communities may be unable to self-evacuate out of the most heavily impacted areas. In the immediate aftermath, coastal survivors may remain scattered across hundreds of miles of coastline in isolated tsunami-inundated communities. With heavily damaged bridges and degraded roadways, delivering emergency supplies may be impossible using traditional ground transportation.

Figure 26. Tsunami waves following the 2011 Tohoku earthquake in Japan slammed into a pier supporting a rail bridge. The force of the tsunami waves washed away the bridge spans and heavily damaged the pier. Photo: Shideh Dashti.

Figure 27. Following the 1994 M6.7 Northridge Earthquake in California, several freeway bridges such as this post-tensioned north to south connector ramp, completely collapsed. Heavily damaged and collapse of bridges that have not been seismically retrofitted may severely disrupt transportation and take years to demolish and rebuild. Photo: Guillermo Santana.

WASHINGTON: ROAD BRIDGES

Many of the bridges in Washington may withstand the shaking well and may not interrupt transportation. However, as many as 30 percent of bridges may suffer moderate levels of damage and may not be able to support even reduced vehicular traffic until temporary supports are put in place. Roughly 20 percent of bridges – over 700 - may either completely collapse or be in imminent danger of collapse.

Over a dozen bridges holding I-5 may suffer irreparable damage from the earthquake, and several may collapse. Many of the recently seismically retrofitted I-5 overpasses from south of Everett to Joint Base Lewis-McChord may only suffer minor damage. However, the on/off ramps to those overpasses may have damage. Figures 28 and 29 show the locations of damaged bridges in Washington State.

As shown in Table 10, half of the bridges in coastal corridor may sustain high damage. This damage may be extensive enough to require the complete replacement of the entire bridge. Within minutes of the earthquake, the resulting tsunami may send waves of water and debris that inundate several more coastal bridges.

BRIDGE RETROFITTING IN WASHINGTON STATE

Most of western Washington's bridges are located in high to moderate seismic zones and were designed prior to modern standards. To address this, the Washington State Department of Transportation (WSDOT) has invested more than $166 million since the early 1990s to retrofit existing bridges.

To date, 284 bridges in the program have been retrofitted, 34 are currently being retrofitted and 595 still require work. Each bridge is evaluated based on capacity and needs using nationally adopted guidelines. From July 2013 to July 2017, WSDOT will spend $26 million to shore up bridges. To complete all of the bridges in the program will require approximately $1.4 billion.

WSDOT, federal, and local officials have prioritized some of the retrofitting to create a resilient bridge "life line" through the Puget Sound. The goal is to create a north-south route between Joint Base Lewis-McChord south of Tacoma and Paine Field in Everett that can be used to transport emergency supplies after a major earthquake.

WASHINGTON: ROAD BRIDGES (CONT.)

Table 10. Distribution of damage states for Washington state road bridges, by areas of operation

	Damage State			
Area of Operation	**None**	**Low**	**Medium**	**High**
Coastal	16%	12%	23%	50%
I-5 corridor	53%	7%	27%	13%
East	100%	0%	0%	0%
Summary of damage description	No damage.	Slight damage requiring only minor, cosmetic repairs, but the bridges can support traffic even before these repairs are made.	Moderate damage requiring repairs before use, but not requiring demolition of bridges. Bridges may not support heavy loads and will likely require engineering assessments before deemed safe for traffic.	Bridge collapse or damages so severe as to require demolition and complete replacement of the entire bridge. Bridge likely impassable to traffic.

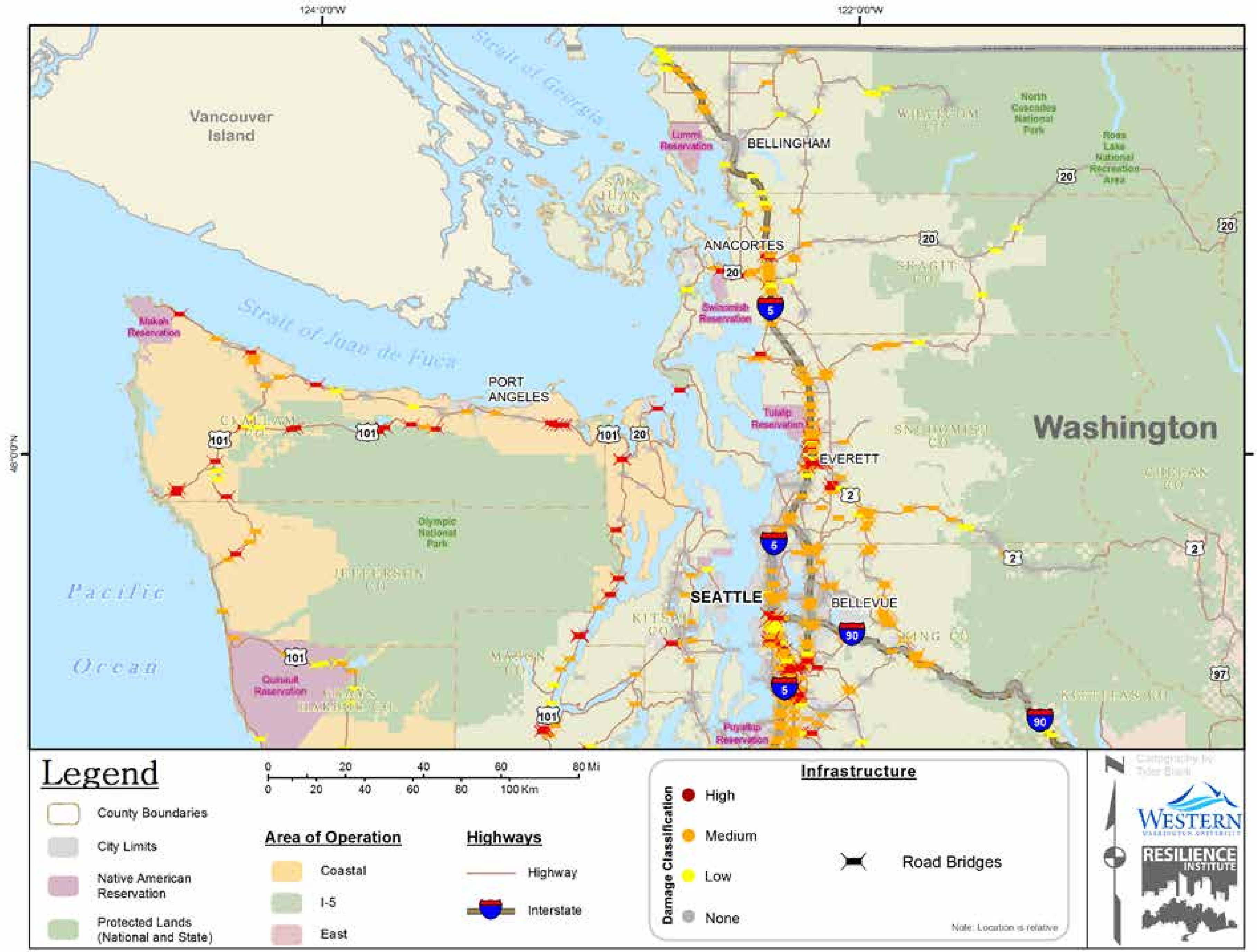

Figure 28. Bridge damage on major highways in northern Washington caused by the initial earthquake

Figure 29. Bridge damage on major highways in southern Washington caused by the initial earthquake

SEATTLE METRO: ROADS AND BRIDGES

Road and bridge damage may significantly disrupt traffic in Washington's population centers, as shown in Figures 30 and 31. Most of the high damage road segments may be concentrated between Seattle and Tacoma. Large cracks, loose soil, and landslide debris may make this stretch of I-5 impassible until major repairs are made. Congested surface streets and other alternate routes may make some movement possible, but may add to already lengthy travel times. Repair of the urban road system may take months to years to complete.

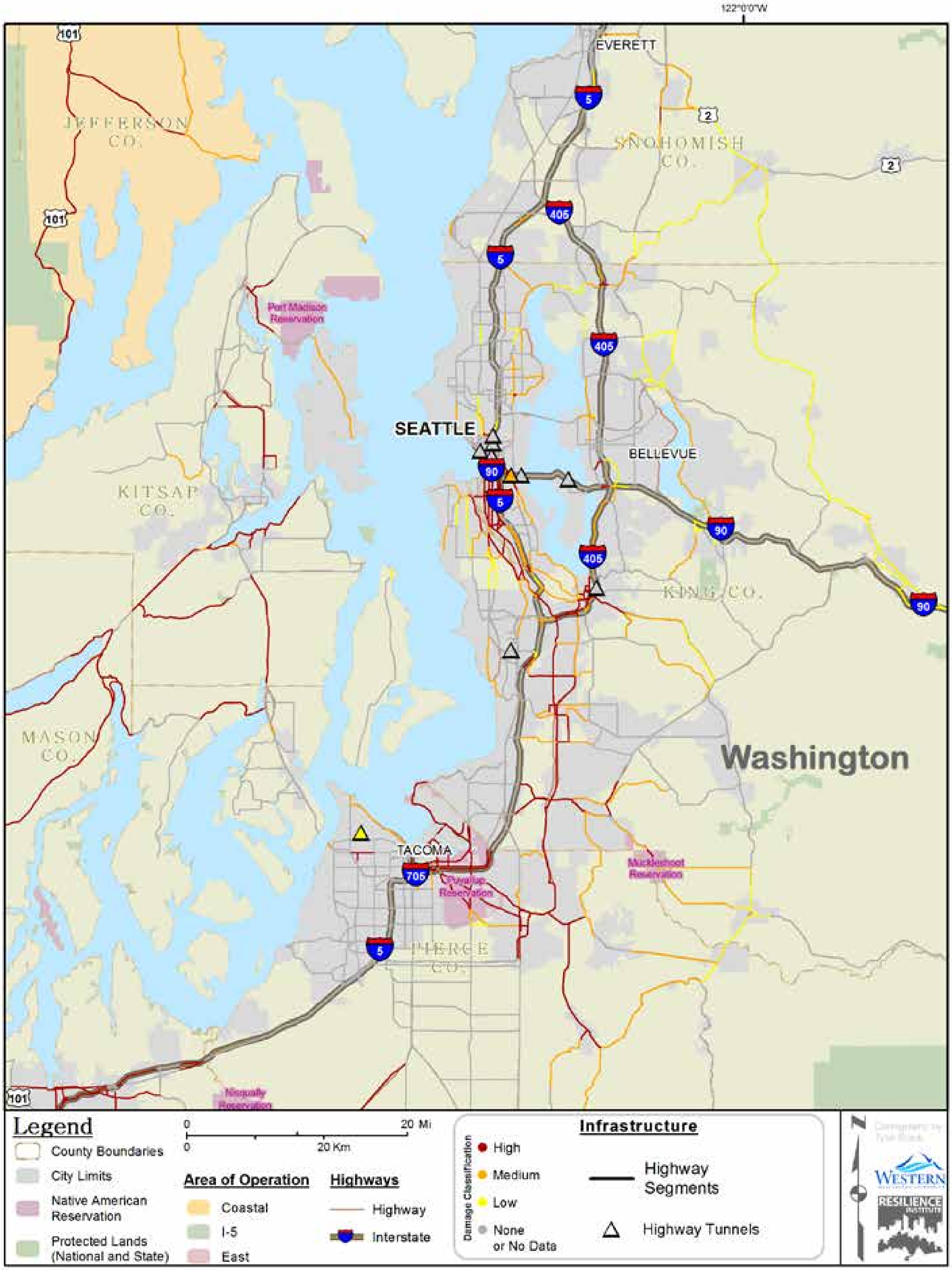

Figure 30. Road and tunnel damage on major highways in the Seattle metropolitan area of Washington

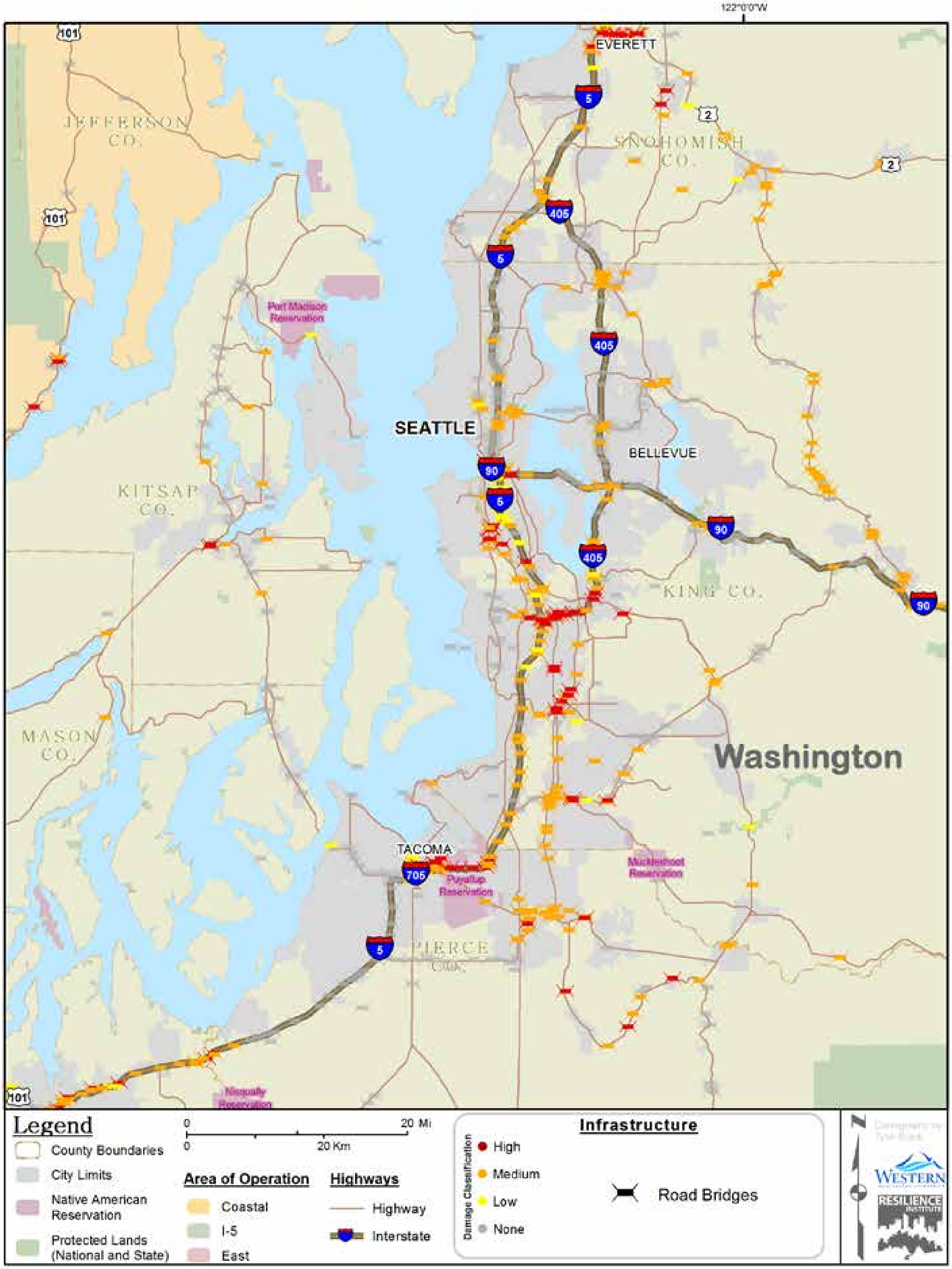

Figure 31. Bridge damage on major highways in the Seattle metropolitan area of Washington

OREGON: ROAD BRIDGES

Roughly half of the bridges in Oregon may withstand the shaking fairly well and may not interrupt transportation. However, over 20 percent of bridges may suffer moderate levels of damage and may not be able to support even reduced vehicular traffic until temporary supports are put in place; and over 20 percent of bridges – as many as 700 – may either completely collapse or be in imminent danger of collapse. This damage may be extensive enough as to require the complete replacement of the entire bridge. General locations of damaged bridges are shown in Figures 32 and 33.

Dozens of bridges along the I-5 corridor may suffer irreparable damage from the earthquake, and several may collapse. The violent shaking along the coast may destroy many coastal bridges, especially those holding U.S. 101. As shown in Table 11, fifty-five percent of the bridges in the coastal corridor may suffer high damage. This damage may be extensive enough to require the complete replacement of the entire bridge. Of the 135 bridges holding U.S. 101, as many as one-third may be so heavily damaged as to be impassable immediately after the quake. Within minutes of the earthquake, the resulting tsunami may send waves of water and debris that may inundate a dozen or more coastal bridges.

The overall condition of east-west bridges between the coast and the Willamette Valley may be only marginally better than those on U.S. 101. Each major connecting highway may have at least one collapsed or irreparable bridge.

Bridge damage may significantly impact all of Oregon's major commercial centers – Portland, Salem, Eugene, Corvallis, and Albany – all of which are bisected by the Willamette River. In some places, bridges spanning rivers may collapse into the river, temporarily disrupting shipping channels along sections of the Columbia and lower Willamette River, preventing the movement of fuels and essential recovery equipment by water.

OREGON: ROAD BRIDGES (CONT.)

Table 11. Distribution of damage states for Oregon road bridges, by areas of operation

	Damage State			
Area of Operation	**None**	**Low**	**Medium**	**High**
Coastal	10%	11%	24%	55%
I-5 corridor	32%	6%	42%	20%
East	94%	6%	0%	0%
Summary of damage description	No damage.	Slight damage requiring only minor, cosmetic repairs, but the bridges can support traffic even before these repairs are made.	Moderate damage requiring repairs before use, but not requiring demolition of bridges. Bridges may not support heavy loads and will likely require engineering assessments before deemed safe for traffic.	Bridge collapse or damages so severe as to require demolition and complete replacement of the entire bridge. Bridge likely impassable to traffic.

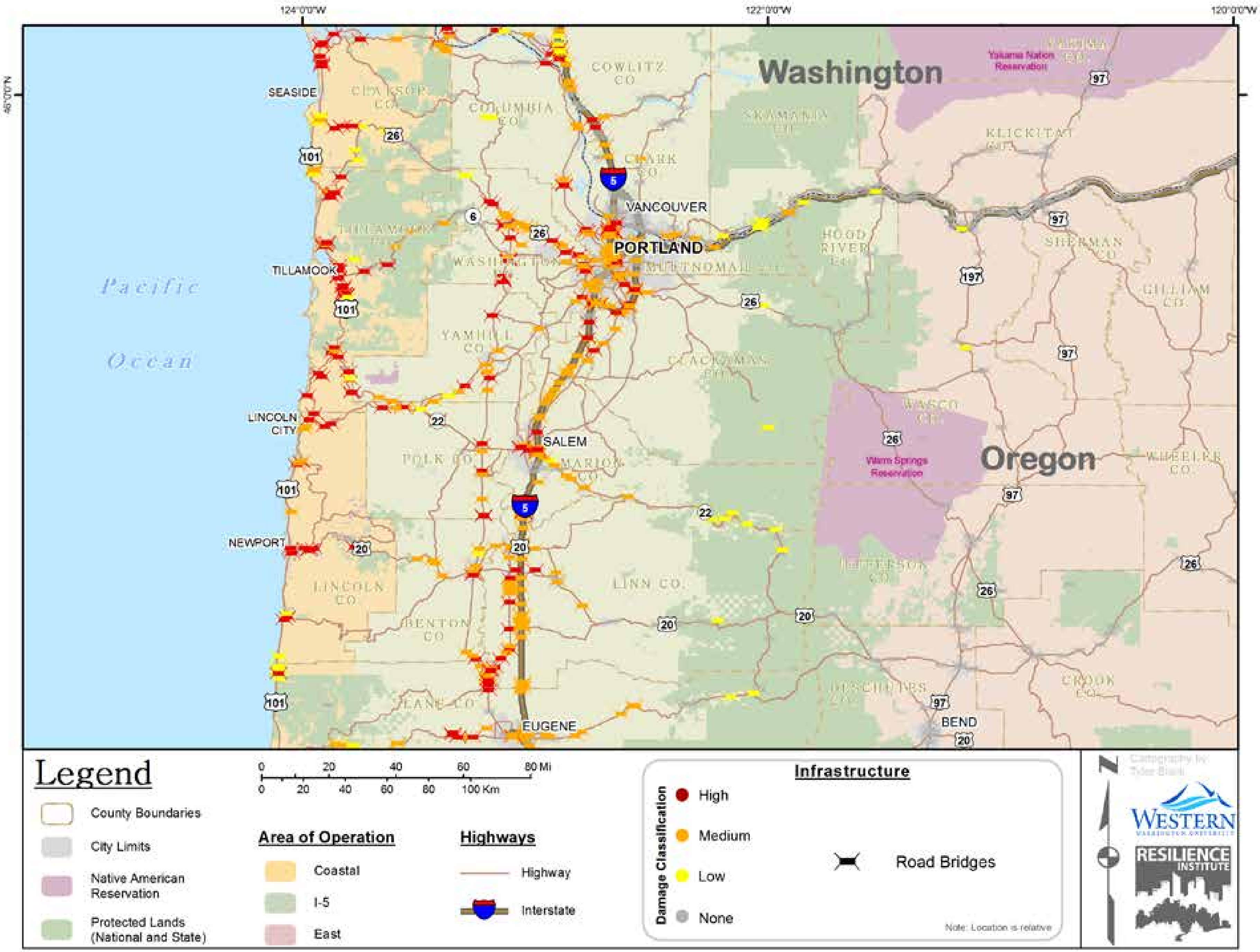

Figure 32. Bridge damage on major highways in northern Oregon

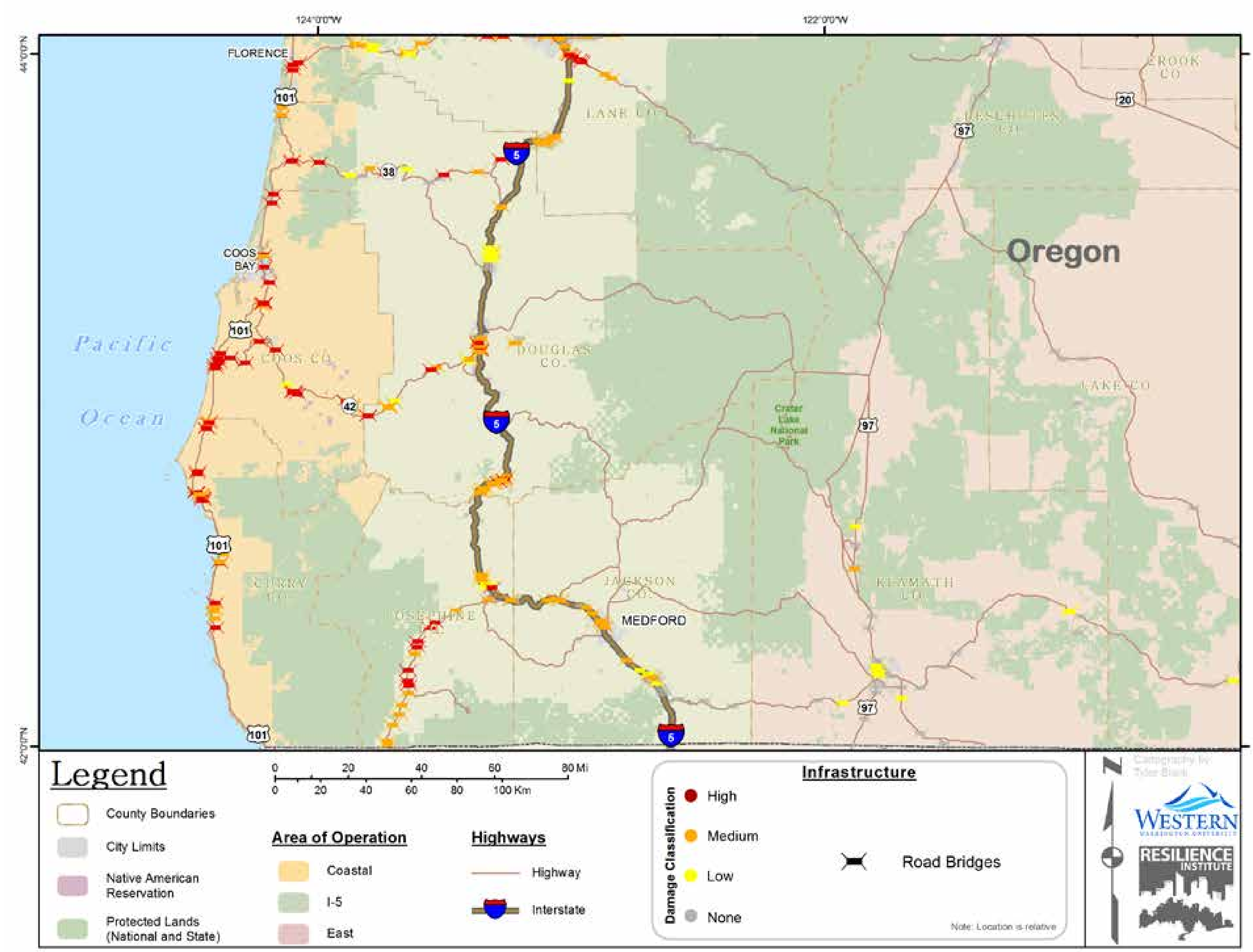

Figure 33. Bridge damage on major highways in southern Oregon

PORTLAND METRO: ROADS AND BRIDGES

Road and bridge damage may significantly disrupt traffic flow in downtown Portland, as shown in Figures 34 and 35. Bridges outside of the downtown core, such as St. Johns, Fremont, Broadway, Steel, Burnside, Morrison, Hawthorne, Ross Island, and Sellwood — may need to be inspected before they are passable. In the immediate hours after the earthquake, many of the workers in the downtown core of Portland may struggle to get home if they live east of the Willamette River.

Workers who live on the west side of town may also have problems getting home. One or more tunnels on Highway 26, a major transportation artery between Portland and its west-side suburbs, may not be passable. Many workers may be stranded in the downtown area until bridges and tunnels are cleared. Congested surface streets and other alternate routes may make some movement possible, but may add to already lengthy travel times. Repair of the urban road system may take months to years to complete.

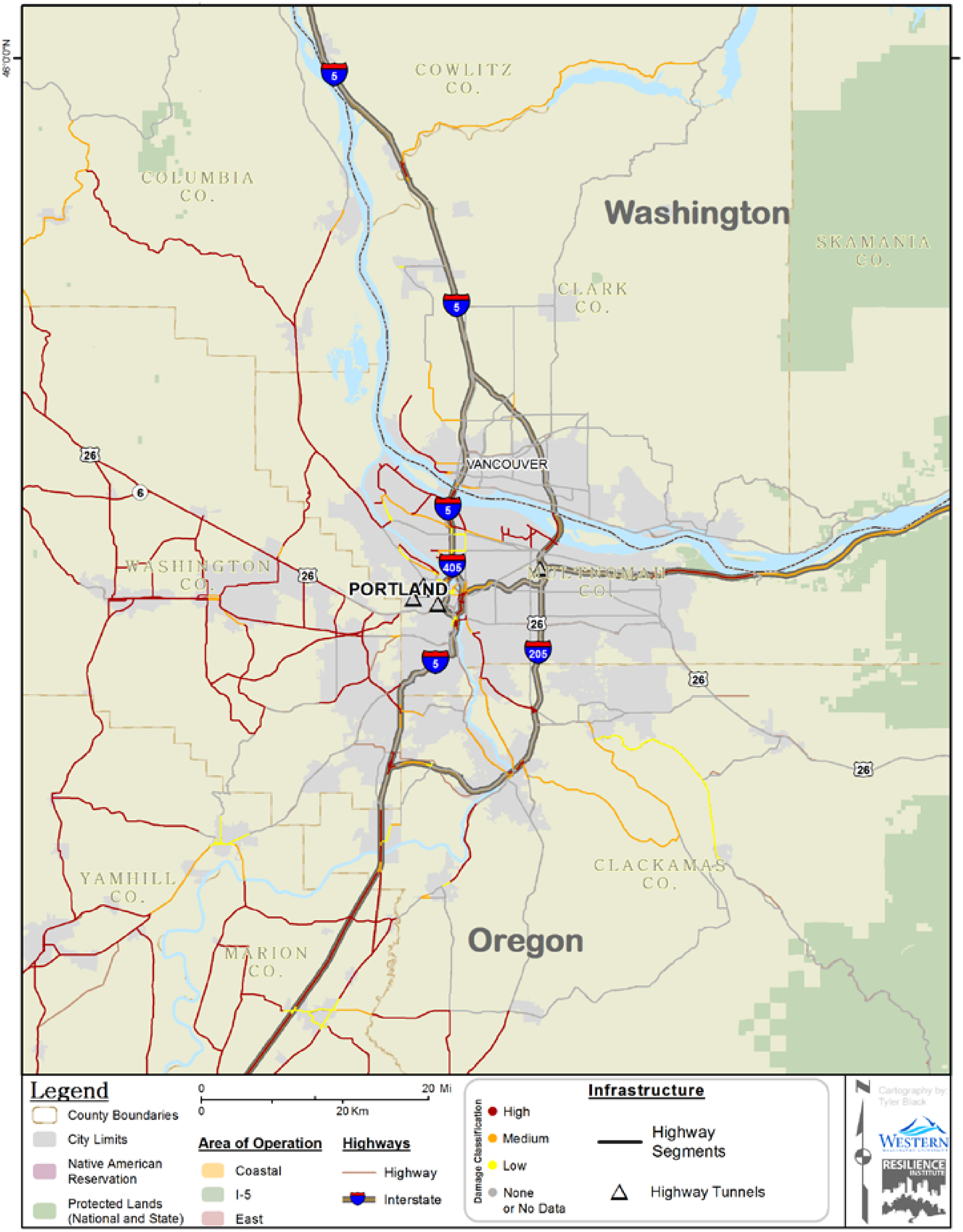

Figure 34. Road and tunnel damage on major highways in the Portland metropolitan area

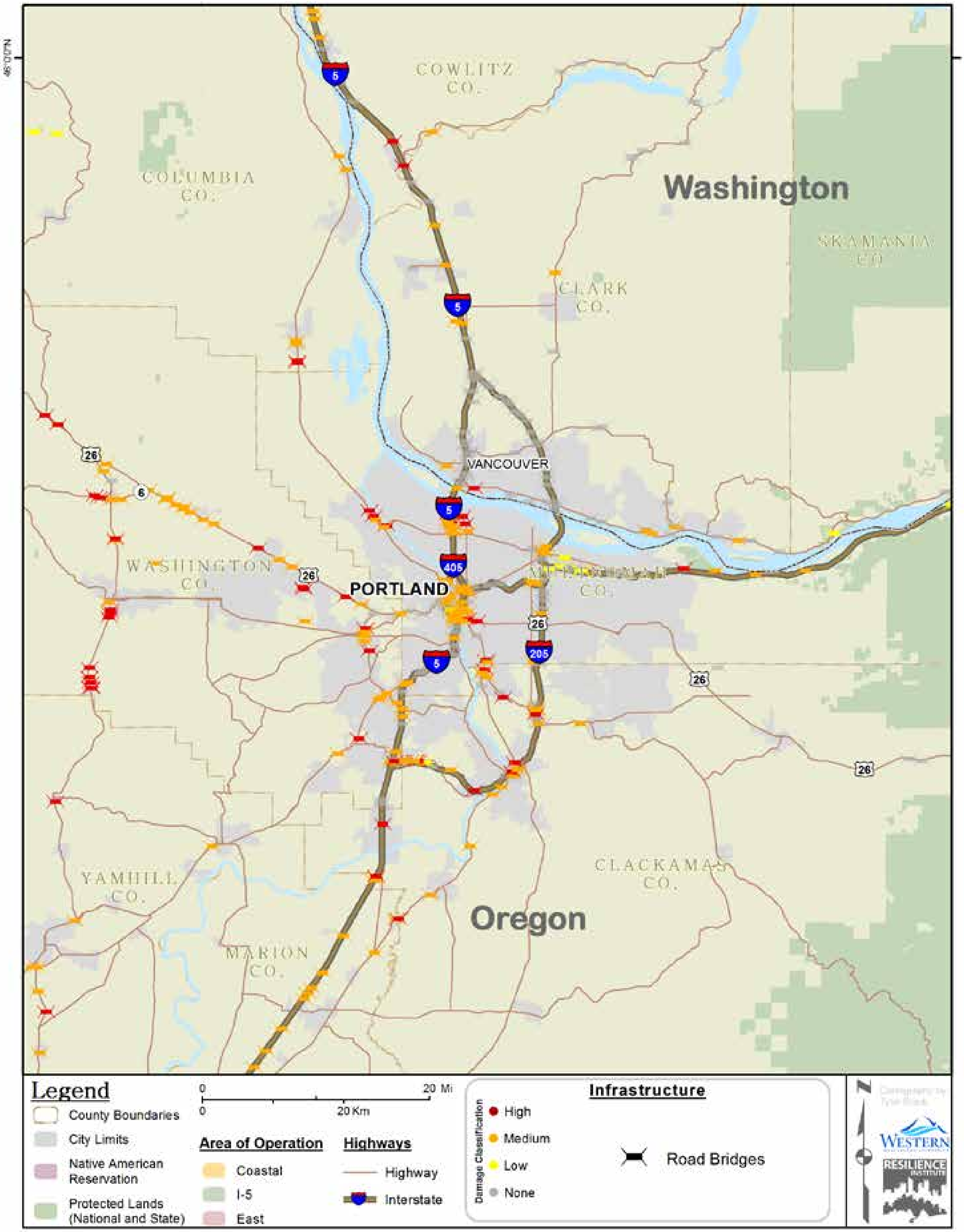

Figure 35. Bridge damage on major highways in the Portland metropolitan area

AIR TRANSPORTATION

Definition: Airport facilities include terminal buildings, fuel facilities, and control towers. These, combined with the runways, make up airport transportation infrastructure.

In the immediate aftermath of the earthquake, air transportation may be the only viable means to evacuate residents and deliver supplies to areas impacted by the earthquake. However, damaged airport facilities and runways may impede emergency transport to and from the impacted areas.

Of the 100 airports in the impacted area of Washington and Oregon, roughly two-thirds may suffer medium or greater structural damage from the initial earthquake. This damage may be extensive enough as to temporarily halt all air traffic in and out of these airports. Control towers and terminal buildings at high-damage airports may sustain structural damage severe enough to cause reinforced-steel structures to collapse or put the structure in imminent damager of collapse, as illustrated in Figure 36.

Figure 36.The Great Alaskan Earthquake in 1964 caused this reinforced concrete-framed control tower to collapse at the Anchorage International Airport. Photo: Karl V. Steinbrugge.

Figure 37. In 2014, a M6.9 earthquake near Greece caused nonstructural damage to airport at Lemnos International Airport in Lemnos, Greece. Photo: Ayis Theos.

In addition to structural damage, terminals and control towers may suffer extensive nonstructural damage. The shaking could cause unanchored electrical equipment to fall, breaking connections to wire piping and ducts, or it could cause suspended ceilings to collapse and some light fixtures to fall, as shown in Figure 37. In control towers, this damage may obstruct air control and monitoring capabilities. These airports may require a portable controlling facility to operate at a very limited capacity.

In addition, navigation aids may be downed in many areas, affecting air transportation.

Although damage to airports may hamper commercial travel, these damages may not necessarily prevent emergency air transport operations. As long as runways remain intact and useable, responders can carry out these operations regardless of whether the airport itself is functional.

AIR TRANSPORTATION (CONT.)

Figure 38. The M7.9 Denali earthquake in 2002 caused significant damage to the only runway at the Northway, Alaska airport. The runway was temporarily replaced with a gravel surface before permanent repairs. Photo: Unknown.

Roughly 80 percent of runways may suffer only minor to no damage; most of these are in the I-5 corridor. With appropriate air traffic support, pilots may access these runways to carry out emergency response operations. Undamaged runways may be a critical resource for high-impact areas, especially runways long enough to accommodate the type of fixed-wing aircrafts typically needed to stage emergency response operations. In Washington and Oregon, 76 of these longer runways exist, but half may be damaged beyond use. On the coast, only a few of these runways may be used to support response operations.

In the tsunami inundation zones, some smaller runways that have enough usable open pavement to support helicopters may be functional once the water has receded. While helicopters can typically land on any level clearing, they are slower and generally have a lower carrying capacity than heavier fixed-winged aircraft.

Figure 39.Tsunami waves resulting from the 2011 Tohoku earthquake, inundated the first floor and parts of the second floor of the terminal at Sendai Airport and littered runways and tarmac with debris. Photo: Staff Sgt. Samuel Morse, U.S. Air Force.

WASHINGTON: AIR TRANSPORTATION

Many of the runways in the I-5 corridor of Washington may sustain little or no damage, with only minor cracking and heaving of the pavement. Among the surviving runways, several runways capable of handling C-130 aircraft may be operational within hours of the event.

The terminals and control tower at Seattle-Tacoma International Airport (SeaTac) may sustain some structural damage, including minor cracking to support beams and columns. While this damage may not disrupt air traffic, extensive nonstructural damage may result in a temporary closure. Runways at SeaTac may suffer little damage. However, damaged roads and bridges adjacent to SeaTac may impede ground access. If jet fuel shortages occur because of damage to the pipelines that deliver this fuel, air transport out of SeaTac and surrounding airports may be more difficult.

The most significant damage may be reported at airport facilities along the coast, where soil liquefaction may cause large breaks across runway pavement and ground settling that collapses control towers. As shown in Table 12, 55 percent of the airport facilities in the coastal corridor may suffer high damage. This damage may render many of these facilities unusable by fixed-wing aircraft. However, some runways may have enough usable open pavement to support helicopters. The location of airport facilities is shown in Figure 40.

Table 12. Distribution of damage states for Washington state airport facilities, by areas of operation

	Damage State			
Area of Operation	**None**	**Low**	**Medium**	**High**
Coastal	0%	0%	45%	55%
I-5 corridor	0%	30%	32%	8%
East	27%	73%	0%	0%
Summary of damage description	No structural damage. Possible non-structural damage.	Minor structural damage, with some beams and columns exhibit hairline cracks near joints or within joints. Some nonstructural damage.	Most beams and columns exhibit cracks. Some frame elements have reached yield capacity, which may result in partial collapse. Damage may obstruct air control and monitoring capabilities.	Structure is collapsed or in imminent danger of collapse.

Figure 40. Washington airports in relation to shaking intensity and landslide potential

OREGON: AIR TRANSPORTATION

Most of the runways in the I-5 corridor of Oregon may sustain light damage, with only minor cracking and heaving of the pavement. Among the surviving runways, over a dozen runways capable of handling C-130 aircraft are expected to be operational within hours of the event. The Redmond Municipal Airport, east of the Cascade Mountains, may be able to accept fixed-winged aircraft up to Class 1. However, road and bridge damage may limit ground access to many airports.

The terminals and facilities at Portland International Airport (PDX) may suffer some damage, with most support beams and columns exhibiting minor cracks and some showing larger stress cracks. Even with only minor damage to the airport structures, unsecured equipment in the airport facilities may topple over and break, requiring cleanup and replacement prior to reopening the facilities. The airport runways may suffer damages due to liquefaction and levees protecting the airport along the Columbia River may fail resulting in possible flooding of the airport. Moreover, damage to the pipelines carrying liquid jet fuel from Oregon's critical energy infrastructure (CEI) hub may cause jet fuel shortages and limit flights out of PDX and surrounding airports.

The most significant damage may be reported at airport facilities along the coast, where soil liquefaction may cause large breaks across runway pavement and ground settling that collapses control towers. As shown in Table 13, all of the airport facilities in the coastal corridor may suffer high damage. This damage may render many of these facilities unusable by fixed-wing aircraft. However, some runways may have enough usable open pavement to support helicopters. The location of airport facilies in Oregon is shown in Figure 41.

Within minutes of the earthquake, North Bend and Astoria airports may be inundated with water from the resulting tsunami.

Table 13. Distribution of damage states for Oregon airport facilities, by areas of operation

	Damage State			
Area of Operation	**None**	**Low**	**Medium**	**High**
Coastal	0%	0%	0%	100%
I-5 corridor	0%	0%	30%	70%
East	100%	0%	0%	0%
Summary of damage description	No structural damage. Possible non-structural damage.	Minor structural damage, with some beams and columns exhibit hairline cracks near joints or within joints. Some nonstructural damage.	Most beams and columns exhibit cracks. Some frame elements have reached yield capacity, which may result in partial collapse. Damage may obstruct air control and monitoring capabilities.	Structure is collapsed or in imminent danger of collapse.

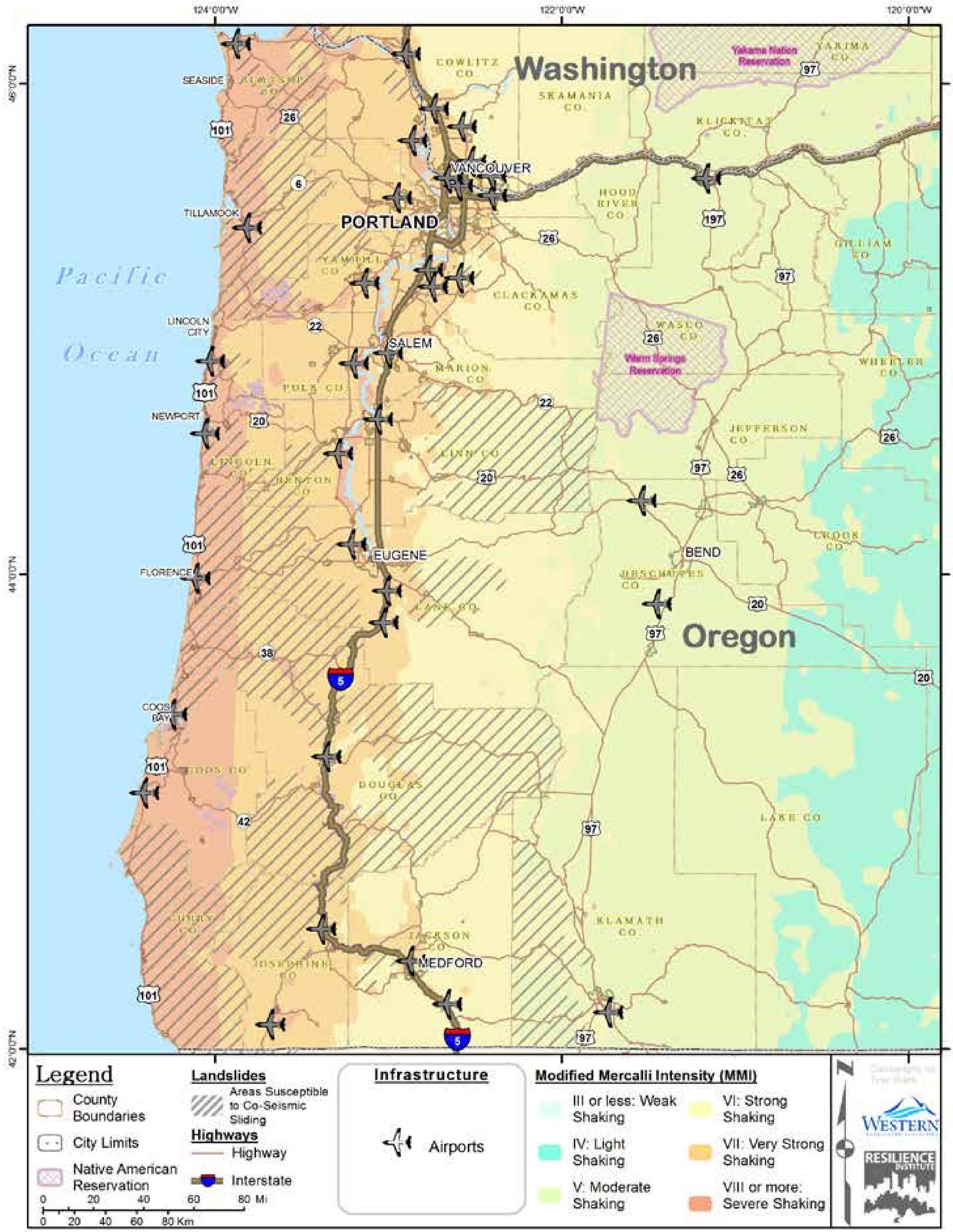

Figure 41. Oregon airports in relation to shaking intensity and landslide potential

RAIL TRANSPORTATION SYSTEMS

Definition: The rail transportation system consists of tracks/roadbeds, bridges, tunnels, urban stations, maintenance facilities, fuel facilities, and dispatch facilities.

Rail damage may be more disruptive than road damage due to the lack of alternative routes. Rail systems rely on continual clearance up and down the line. Moderate, localized earthquake and landslide damage may result in bottlenecks in the rail network. This is especially severe in the case of damage to railway bridges. Unlike track repair, which could be completed within a month, rail bridges may take several months to a year to repair. Table 14 describes railway track and bridge damage for each damage level.

Figure 42. The M 7.4 earthquake in Turkey caused localized bending of the rail tracks. Photo: Turkish State Railways.

Table 14. Railway track and bridge damage state description

	Damage State		
Infrastructure Component	**Low**	**Medium**	**High**
Railway tracks	Localized bending of tracks horizontally or vertically, possibly requiring minor repair before reopening track.	Considerable bending of track requiring repair.	Major bending of track due to settlement of railway bed or shifting of the ground surface over extended lengths of track.
Railway bridges	Slight damage requiring only minor, cosmetic repairs. Bridges can support rail traffic even before these repairs are made.	Moderate damage requiring repairs before use, but not requiring demolition of bridges. Bridges may not support heavy loads and will likely require engineering assessments before being deemed safe for traffic.	Bridge collapse or damages so severe as to make rail transport impossible without extensive repairs or demolition and rebuilding.

RAIL TRANSPORTATION SYSTEMS (CONT.)

The majority of rail facilities – such as train stations, dispatch facilities, and fuel facilities – are located along the I-5 corridor. Over three-quarters of these facilities may suffer moderate or greater damage which may significantly hinder the ability to perform essential dispatch and switching control. However, rail facilities can be replaced or relocated relatively quickly and with few resources.

Most of the railway spurs running west from the I-5 corridor may suffer high damage and may be completely unusable until the entire spur has been checked for damage and repairs made. The majority of rail tracks along the I-5 corridor may suffer enough damage to require repair before they are useable, hindering transport of export goods, industrial components, commuters, or other goods again. Rail tracks running east of the Cascades from Oregon and Washington may not suffer damage from the initial earthquake. However, railway tracks that survive the shaking may be damaged by landslides immediately after the earthquake or in the weeks and months following the event.

Figure 43. The 2011 M 9 Tohoku earthquake caused considerable bending of the Hitachinaka Railway tracks. Photo: Toshinoei Baba.

Figure 44. The M9.2 Great Alaska Earthquake of 1964 damaged extended lengths of track due to ground failure as a result of lateral displacement. This type of ground failure can tear rails from their ties and caused them to buckle. Photo: USGS.

Five or more mechanical bridges between Portland, Oregon and Marysville, Washington may be severely damaged by the earthquake. The loss of these bridges may have the biggest impact on rail shipments along the I-5 corridor. These bridges may be out of commission for six to twelve months while repairs are made. The loss of these bridges, coupled with damaged track segments up and down the line, may result in a complete shutdown of rail traffic along I-5 and to the west.

Until bridge and track repairs are made, communities between Seattle and Portland, and south of Portland, may not have access to rail service of any kind.

WASHINGTON: RAIL DAMAGES

In Washington's I-5 corridor, roughly half of railway track segments may suffer some damage, ranging from minor, localized bending of the track to major bending over extensive lengths (see Table 15). A few segments in the Tacoma area may suffer high damage from major ground settlement under rail tracks.

As shown in Figure 45, several railway bridges between Seattle and Olympia, as well as the main railway bridge spanning the Columbia River, may suffer extensive damage. The loss of these critical bridges may halt all rail traffic along the I-5 corridor. Eastbound rail lines may suffer little damage and may be used to reroute rail traffic in and out of Seattle. However, some of these routes may suffer damage from landslides. Until bridge repairs are made, which may take six months to a year, communities south of Seattle may be isolated from rail service.

WASHINGTON: RAIL DAMAGES (CONT.)

Table 15. Washington rail facilities in relation to shaking intensity and landslide potential

	Damage State			
Area of Operation	**None**	**Low**	**Medium**	**High**
		Railway Tracks		
Coastal	25%	2%	2%	71%
I-5 corridor	49%	6%	42%	3%
East	100%	0%	0%	0%
Summary of damage description	No damage.	Localized bending of tracks horizontally or vertically, possibly requiring minor repair before reopening track.	Considerable bending of track requiring repair.	Major bending of track due to settlement of railway bed or shifting of the ground surface over extended lengths of track.
		Railway Bridges		
Coastal	0%	0%	0%	0%
I-5 corridor	66%	0%	6%	28%
East	100%	0%	0%	0%
Summary of damage description	No damage.	Slight damage requiring only minor, cosmetic repairs, but the bridges can support rail traffic even before these repairs are made.	Moderate damage requiring repairs before use, but not requiring demolition of bridges. Bridges may not support heavy loads and will likely require engineering assessments before deemed safe for traffic.	Bridge collapse or damages so severe as to make rail transport impossible without extensive repairs or demolition and repair.

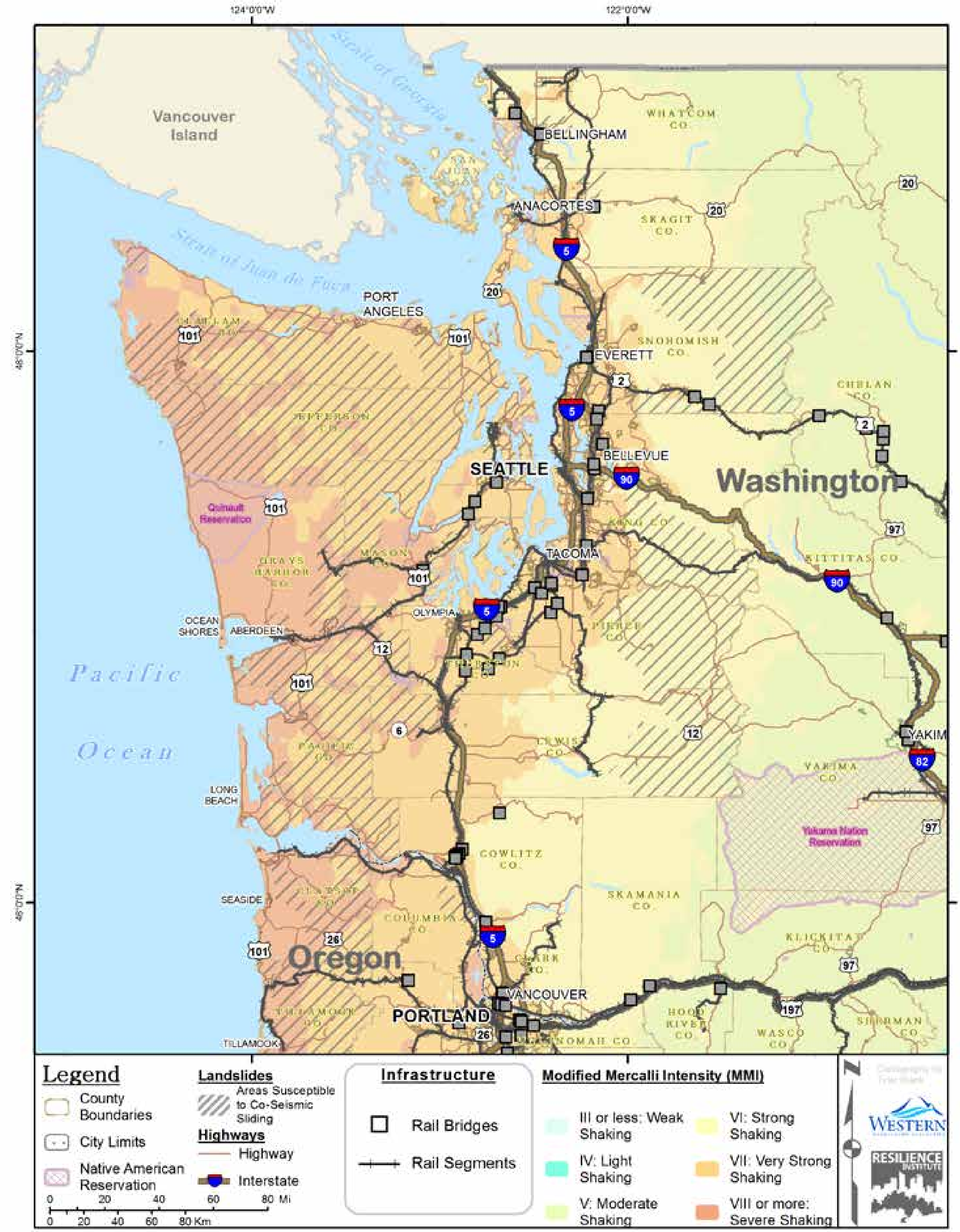

Figure 45. Washington railway track and bridges in relation to shaking intensity and landslide potential

OREGON: RAIL DAMAGES

In Oregon's I-5 corridor, most railway track segments may suffer some damage, ranging from minor, localized bending of the track to major bending over extensive lengths (see Table 16). Rail segments along the Willamette Valley between Portland and Eugene may suffer high damage from major ground settlement under the rail tracks.

As shown in Figure 46, the main rail bridge that crosses the Columbia River and several bridges in downtown Portland may suffer damages so severe as to make rail transport impossible without extensive repairs or demolition and rebuilding. Eastbound rail lines may suffer little damage and be used to reroute rail traffic in and out of Portland. However, some of these routes may suffer damage from landslides. Until bridge and track repairs are made, communities and businesses north and south of Portland may be completely isolated from rail service.

OREGON: RAIL DAMAGES (CONT.)

Table 16. Distribution of damage states for Oregon rail tracks and bridges, by areas of operation

	Damage State			
Area of Operation	**None**	**Low**	**Medium**	**High**
		Railway Tracks		
Coastal	13%	2%	10%	75%
I-5 corridor	37%	8%	32%	23%
East	100%	0%	0%	0%
Summary of damage description	No damage.	Localized bending of tracks horizontally or vertically, possibly requiring minor repair before reopening track.	Considerable bending of track requiring repair.	Major bending of track due to settlement of railway bed or shifting of the ground surface over extended lengths of track.
		Railway Bridges		
Coastal	0%	0%	0%	0%
I-5 corridor	88%	0%	0%	13%
East	0%	0%	0%	0%
Summary of damage description	No damage.	Slight damage requiring only minor, cosmetic repairs, but the bridges can support rail traffic even before these repairs are made.	Moderate damage requiring repairs before use, but not requiring demolition of bridges. Bridges may not support heavy loads and will likely require engineering assessments before deemed safe for traffic.	Bridge collapse or damages so severe as to make rail transport impossible without extensive repairs or demolition and repair.

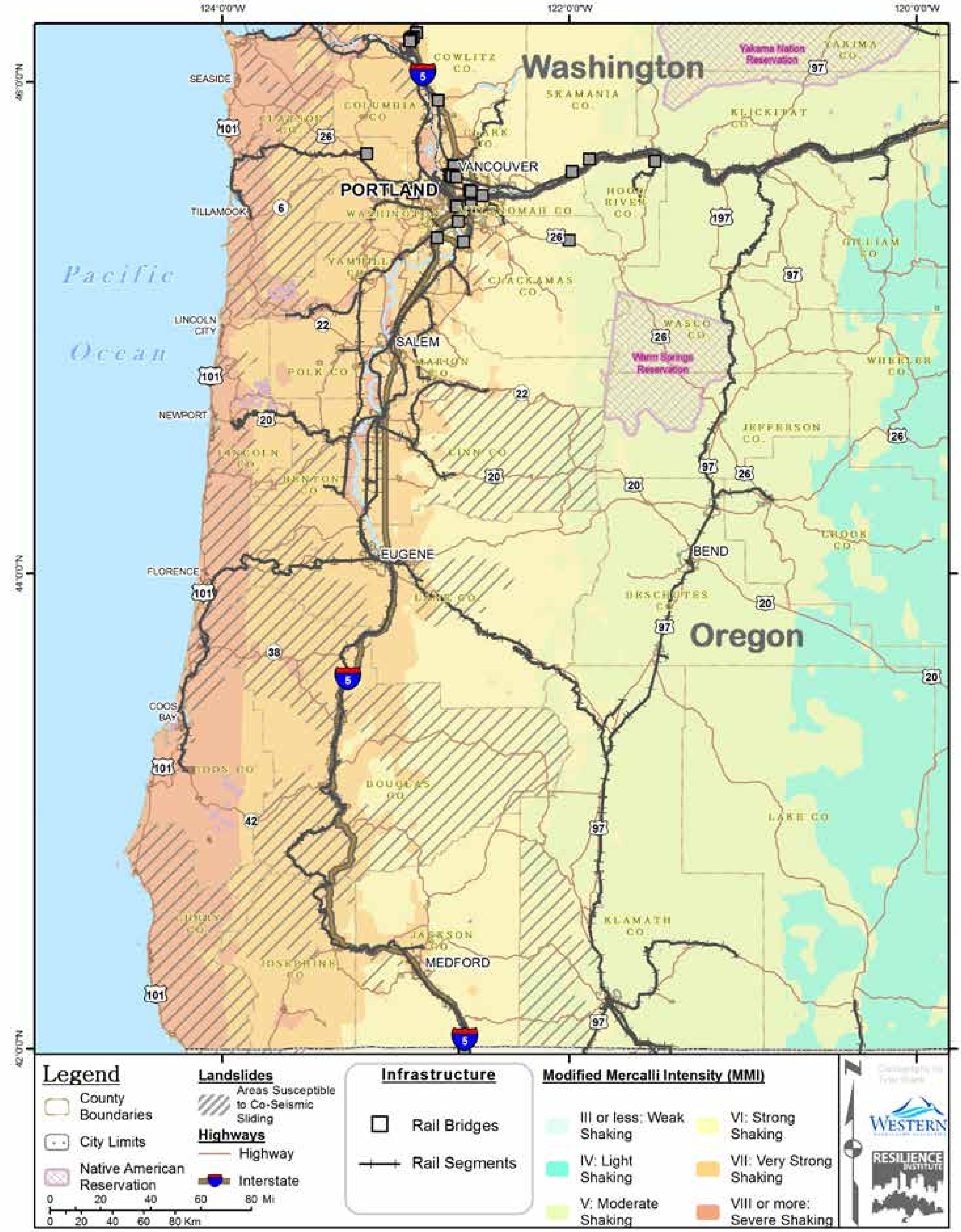

Figure 46. Oregon track and bridges in relation to shaking intensity and landslide potential

SEAPORTS

Definition: Port facilities include waterfront structures (e.g., wharfs, piers and seawalls), cranes and cargo handling equipment, fuel facilities, warehouses, and port infrastructure, such as transportation systems and utility systems. Intermodal transfer from ships onto trucks and trains, or into bulk storage, is required for the port to function.

In many cases, port facilities were constructed prior to widespread use of engineered fills. Consequently, port structures are prone to damage, due to slope failure or lateral spreading from liquefaction. Liquefaction-induced soil movement can damage piers, wharfs, and seawalls by exerting pressure against the retaining structure, causing it to tilt or slide toward the water. This outward movement can form deep depressions behind retaining walls and damage structures on the ground surface, as illustrated in Figure 47. These large soil movements can derail cranes and warehouses and compromise access to shipping terminals. Until the retaining structure is repaired, use of areas behind them may be limited to light loads.

Seaports have a complex web of links to other elements of the overall transportation system. If immediate rail and road access is not available, ports will not be able to distribute goods to surrounding areas. Tarmacs, access roads, and other paved surfaces may experience differential settlement of

Figure 47. Liquefaction resulting from 1995 M 6.9 Kobe earthquake caused high damage to facilities at the Port of Kobe. The liquefied soil pushed against a major retaining wall causing it to slide five to ten feet toward the water. This movement caused settlement of the retained soils and destroyed structures supported by these soils. Photo: Koji Sasahara, AP.

SEAPORTS (CONT.)

Table 17. Port facility damage level description

	Damage state		
	Low	**Medium**	**High**
Waterfront structures (e.g., wharfs, piers and seawalls)	Slight ground settlement causing minor cracking of pavement and sliding of piers. Minor repairs may be required.	Considerable ground settlement causing cracking of pavement with many piles supporting piers/seawalls broken and/or damaged.	Failure of most piles, extensive sliding of piers, and significant ground settlement causing extensive cracking of pavements. Extensive damage is widespread at the port facility.
Cranes/cargo-handling equipment	Slight ground settlement, causing minor damage to cranes and handling equipment. Minor repair may be required.	Derailment due to differential displacement of parallel track. Toppled cranes likely to occur. Rail repair and some repair to structural members required.	Considerable damage to equipment. Totally derailed cranes likely to occur. Replacement of structural members required.
Warehouse	Slight ground settlement, causing minor damage to warehouses. Minor repair may be required.	Considerable derailment due to differential settlement or offset of the ground. Rail repair is required.	Major differential settlement of the ground resulting in potential derailment over extended length.

several feet or more due to liquefaction. Until these surfaces are regraded and resurfaced, marine terminals may only operate at a very limited capacity.

Table 17 lists the physical components of port facilities and provides a description of the damage that correlates to low, medium, and high damage states. The photos below illustrate port facility damage and corresponding damage states.

Figure 48. The 2010 Haitian earthquake caused medium damage to surrounding facilities, causing shipping containers to tumble and warehouses to derail. Ships were unable to deliver supplies and aid until repairs were made. Photo: U.S. Coast Guard.

Of the 700 individual port facilities within Oregon and Washington, as many as 90 percent may be moderately or highly damaged from the initial earthquake. This damage may be as minimal as cracked decks above piers, slight derailment of cranes, or minor displacement of decks in warehouses, or as great as to require complete replacement of the facility.

Damaged navigation channels may also affect marine terminal viability. The Columbia River navigation channel is an engineered structure designed to accommodate deep-water vessels. The channel extends 100 miles upstream to the ports of Kalama, Longview, Portland, and Vancouver. During the earthquake, the lateral spreading of channel banks and underground landslides may shift sediment into navigation channels, trapping deep-water vessels in transit in waterways. Bridge or dam failure may block access to the channel for an extended period of time.

Figure 49. The 2010 M7 Haitian earthquake caused high damage to the main port terminal in Port-au-Prince. Seismically induced lateral spreading caused a shipping-container crane to tilt toward the harbor. Photo: Daniel C. Pearson, U.S. Navy.

SEAPORTS (CONT.)

When the tsunami arrives, it is likely that debris entrained in the waves will scour the navigational channels and destroy port facilities along the outer coast and mouth of the Columbia River. Navigation may be extremely difficult from the mouth of the Columbia River to the Portland/Vancouver area. The channel may need to be dredged and cleared of silt and bridge debris before navigability is restored. The lower reaches of the Columbia River may be inaccessible for up to a month due to changes in navigability. The location of port facilities on the Columbia River are shown in Figure 52.

Figure 50. A tsunami resulting from the 1965 M9.2 earthquake in Alaska caused significant damage to facilities at Seward Port. In addition to infrastructure damage, tsunami currents could drastically modify the underwater topography near ports, making it difficult or even impossible for vessels to navigate. Photo: Mildred Kirkpatrick.

Figure 51. The 1996 M6.6 Kobe earthquake in Japan caused damage to pavement supporting tanks and other facilities. Some of Washington and Oregon's port fuel facilities, such as fuel tanks and terminals, are situated on liquefiable soil. These facilities could spill or rupture during the earthquake, posing serious fire and explosion threats. Photo: HITRAC.

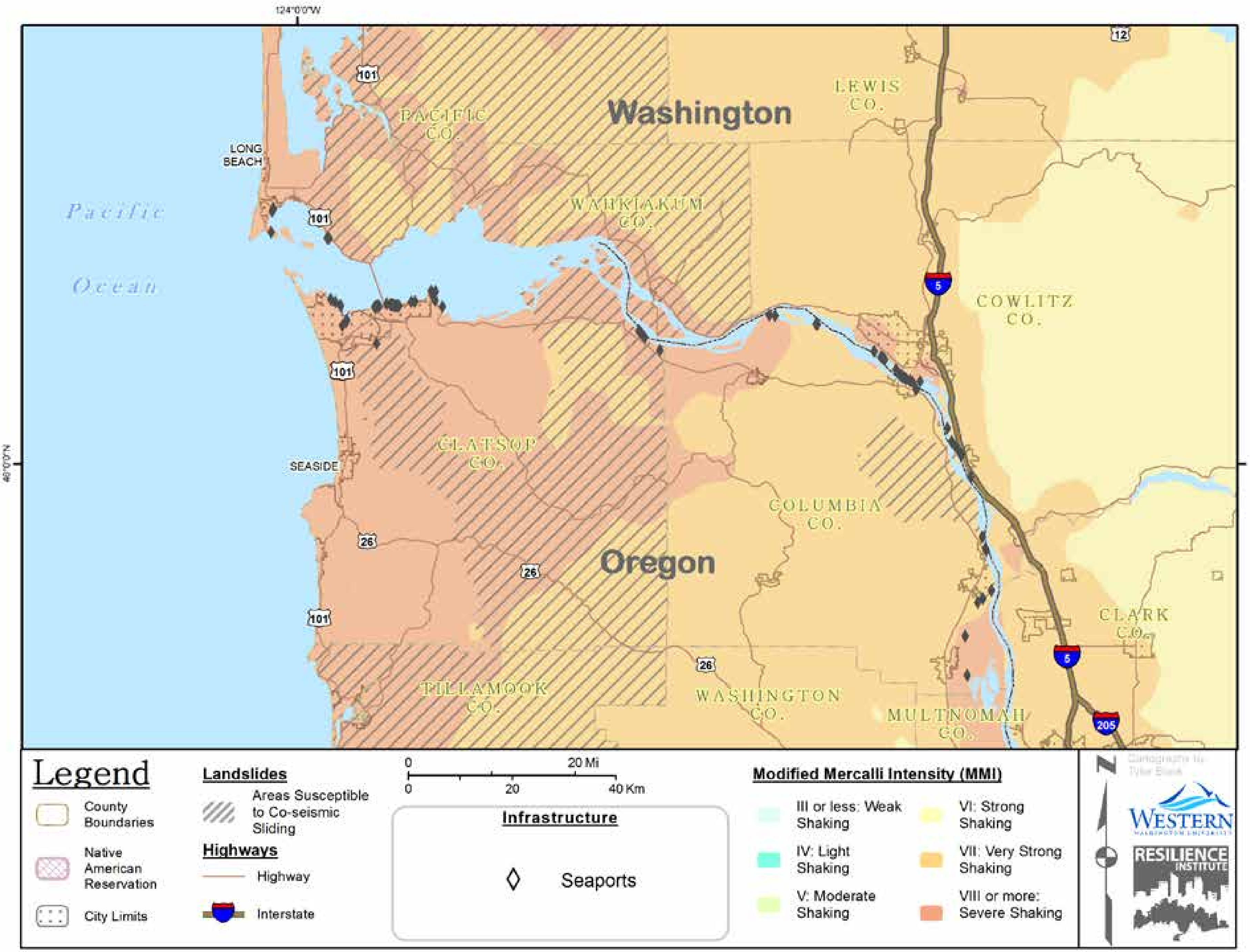

Figure 52. Columbia River ports in relation to shaking intensity and landslide potential

WASHINGTON: SEAPORTS

In the aftermath of the earthquake, Washington's major international seaports – Seattle and Tacoma – may suffer damage from ground failure as a result of liquefaction. Locations of these ports are shown in Figure 53. Ports north of Seattle, such as the ports of Bellingham and Anacortes may suffer the least amount of damage and may be used to support response operations. The most significant port facility damage may be along the coast, where the shaking is expected to be most intense. As shown in Table 18, as much as 78 percent of port facilities in the coastal region may suffer high damage. These damaged facilities will likely need to be reconstructed.

Within minutes of the earthquake, the resulting tsunami will send waves of water and debris that will also likely destroy port facilities along the outer coast and mouth of the Columbia River. Although the tsunami wave heights may decrease in the inner Puget Sound, severe currents may damage ships and piers in these inland harbors. If waves get stuck in a small port or harbor, heightened currents could last for three to four days.

The earthquake and tsunami may significantly modify navigation at the mouth of the Columbia River such that vessels may be unable to navigate the river to the upstream ports of Kalama, Longview, Portland, and Vancouver. Because of damage to shipping channels, marine transport of petroleum from Puget Sound to Portland and other points along the Columbia River may be difficult immediately following the earthquake and tsunami. The lower reaches of the Columbia River may be inaccessible for up to a month and may need to be dredged and cleared of silt and bridge debris before navigability is restored. The loss of critical maritime infrastructure across the lower reaches of the Columbia River, and in Grays Harbor, may greatly impact commercial shipping.

WASHINGTON STATE FERRY SYSTEM

The Cascadia Region is home to a robust ferry transportation system that will be uniquely impacted by a major CSZ earthquake. The Washington Department of Transportation operates the nation's largest ferry system by fleet size and passenger volume. Twenty two vessels carry approximately 22 million people and 10 million vehicles to and from twenty ferry terminals annually. The system operates both domestic and international routes, serving destinations throughout Northwest Washington State and Southwest British Columbia. Full or partial failure of this system after a CSZ earthquake would create significant response challenges for island communities only accessible, or most easily accessible, by existing ferry routes.

Figure 53. The 1995 M6.6 Kobe earthquake damaged a loading ramp structure at Higashi-Kobe ferry pier, along with other port infrastructure in the area. Damage to ferry facilities could isolate island populations in the San Juan Islands and slow transportation across the Puget Sound. Photo: unknown.

WASHINGTON: SEAPORTS (CONT.)

In addition to ports, 50 ferry facilities serve coastal communities and communities along Puget Sound in Washington. Ferries serving coastal communities in Grays Harbor and Port Angeles may suffer high damage from the initial earthquake and may be destroyed by the tsunami waves and strong currents. Most of the ferry facilities in central and southern Puget Sound may suffer damage from liquefaction and lateral spreading of soil. These facilities may need extensive repairs before they can be used. The ferry system in the San Juan Islands may suffer only minor damage. Until repairs are made, island populations may be isolated because of the combination of damage to ferry facilities, roads, and bridges.

Table 18. Distribution of damage states for Washington state port facilities, by areas of operation

	Damage State			
Area of Operation	**None**	**Low**	**Medium**	**High**
Coastal	0%	0%	22%	78%
I-5 corridor	0%	18%	73%	9%
East	33%	67%	0%	0%
Summary of damage description	Port facility is fully functional.	Slight ground settlement causing minor cracking of pavement and sliding of piers. Minor repairs may be required.	Broken and damaged piles supporting piers/seawalls. Considerable crane and warehouse derailment, with some toppled cranes. Rail repair and some repair to structural members required.	Extensive damage is widespread at the port facility. Failure of most piles and extensive sliding of piers. Potential for totally derailed cranes and derailment of warehouses over extended length Replacement of structural members required.

Figure 54. Washington seaports in relation to shaking intensity and landslide potential

OREGON: SEAPORTS

In the aftermath of the earthquake, Oregon's waterborne transportation infrastructure may suffer severe damage from ground failure as a result of liquefaction. As shown in Table 19, as much as ninety-seven percent port facilities in the coastal region may suffer high damage. These damaged facilities will likely need to be reconstructed. The location of port facilities are shown in Figure 55.

Within minutes of the earthquake, the resulting tsunami will send waves of water and debris that will likely destroy port facilities along the outer coast and mouth of the Columbia River. The earthquake and tsunami may significantly modify navigation at the mouth of the Columbia River such that vessels may be unable to navigate the river to upstream ports. Because of damage to shipping channels, marine transport of petroleum from Puget Sound to Portland and other points along the Columbia River may be difficult immediately following the earthquake and tsunami. The lower reaches of the Columbia River may be inaccessible for up to a month, and may need to be dredged and cleared of silt and bridge debris before navigability is restored.

Table 19. Distribution of damage states for Oregon port facilities, by areas of operation

	Damage State			
Area of Operation	**None**	**Low**	**Medium**	**High**
Coastal	0%	0%	3%	97%
I-5 corridor	0%	4%	31%	65%
East	14%	86%	0%	0%
Summary of damage description	Port facility is fully functional.	Slight ground settlement causing minor cracking of pavement and sliding of piers. Minor repairs may be required.	Broken and damaged piles supporting piers/seawalls. Considerable crane and warehouse derailment, with some toppled cranes. Rail repair and some repair to structural members required.	Extensive damage is widespread at the port facility. Failure of most piles and extensive sliding of piers. Potential for totally derailed cranes and derailment of warehouses over extended length Replacement of structural members required.

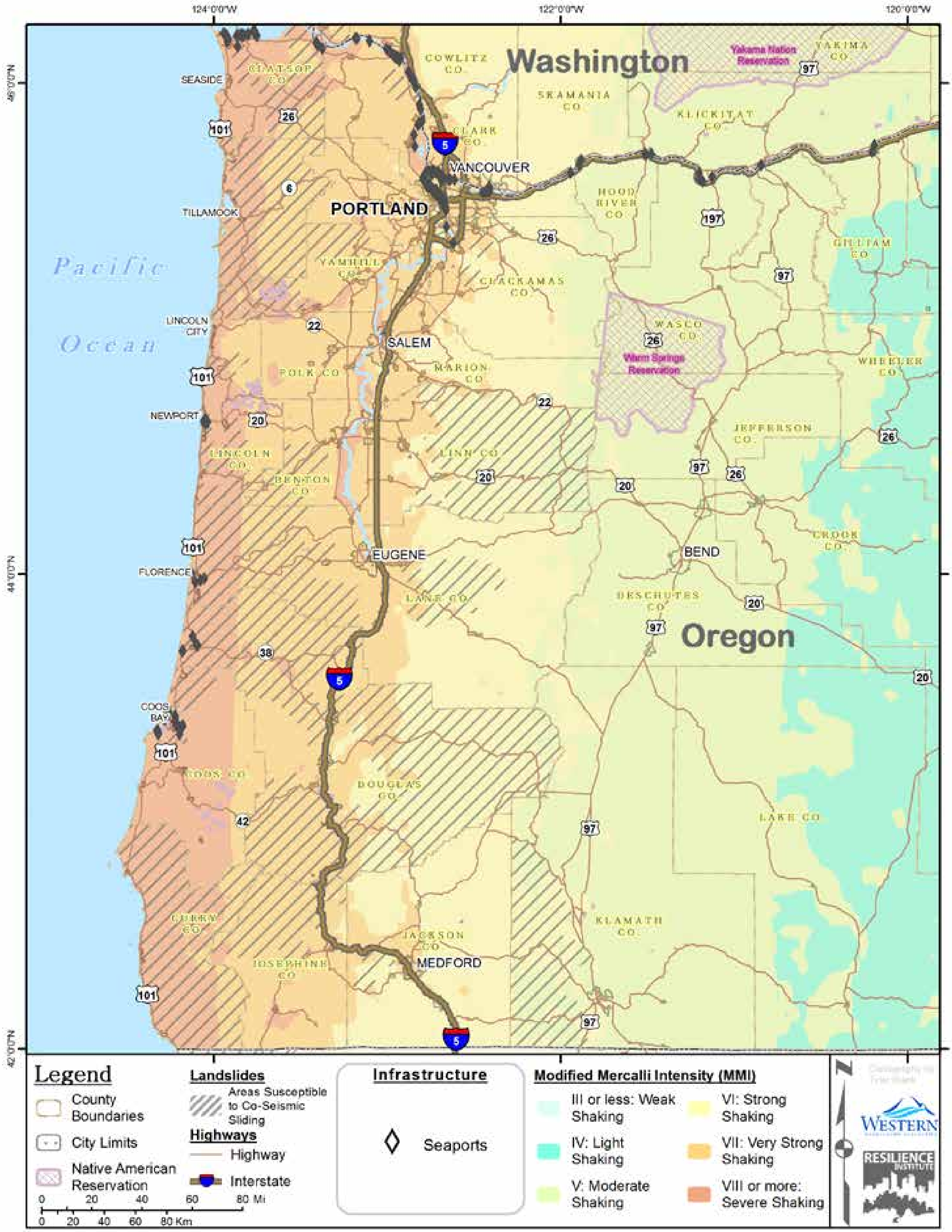

Figure 55. Oregon ports in relation to shaking intensity and landslide potential

WATER RESOURCE INFRASTRUCTURE

Water is a critical resource for human consumption, agriculture, transportation, power generation, and environmental sustainment throughout the Cascadia Region. Water resources are naturally formed, but collected and used through a complex system of physical infrastructure designed to store, redirect, and move water where it is needed, or to mitigate flooding events. This infrastructure includes, but is not limited to, the following:

- Water control facilities and systems:
    - o Dams and reservoirs (water storage, power generation, flood control benefits, and recreation
    - o Canals (navigation, irrigation)
    - o Levees, canals, and channels (flood control, navigation)
    - o Locks (navigation)
- Water utilities:
    - o Water distribution systems
    - o Storm and sewage drainage systems
    - o Water treatment facilities (drinking and wastewater)

Ownership of water resources infrastructure depends on the development history of the area and is not based on any systematic or consistent interstate approach. Federal agency control alongside private ownership of infrastructure (e.g. dams) on the same river is not uncommon. For example, dams on the Columbia River are owned and operated by Federal agencies, private corporations, public utilities, and individuals in two nations. Thus, it can be difficult to identify who is responsible for which specific piece of infrastructure, and what their roles and responsibilities are.

A Cascadia Subduction Zone earthquake and tsunami will have direct and indirect impacts on the region's water infrastructure. Water utilities are similar to other utilities in this regard as the loss of power and other local damages will disrupt service until repairs can be completed. Those services can be replaced temporarily through various means (e.g. bottled water, portable toilets, etc.). Water control facilities and systems differ in that they feed water to utilities and may have additional direct impacts on populated areas that are not easily mitigated. These impacts include, but are not limited to, the following:

- An increased risk of failure resulting from a loss of structural integrity, requiring the piece of infrastructure to be shut down or operated at minimum levels until assessments and/or repairs are completed.

- Structural failure, possibly resulting in catastrophic flooding, and loss of benefits until the project or system is rebuilt.

- Loss of baseline power generation for the entire region until repairs can be made, resulting in considerable economic impacts.

- Loss of transportation and navigation infrastructure until repairs are completed due to flooding of roads, damaged locks, blocked navigation channels, etc.

DAMS AND LEVEES

The potential for flood-induced damage from the failure of a single dam or levee could result in large losses, and significantly compromise rescue and recovery efforts. Catastrophic failure of dams managed by the U.S. Army Corp of Engineers is not expected to occur. However, any federal, state, or privately owned dam or levee may sustain damage and will require immediate assessment. Damage sustained by a dam or levee from the initial seismic event will make the structure significantly more vulnerable to aftershocks.

Slumping and settlement of embankments caused by liquefaction are among the most common causes of dam damage. If the dam is full, landslides in reservoirs could cause water to overtop the dam, resulting in dam failure. Finally, damage to spillway gates could lead to an unexpected water release resulting in significant flooding.

Seismic failure of levees during non-flood conditions does not pose an inundation hazard. However, flooding is possible if heavy rains occur and levees are weakened by ground shaking.

Dams and locks are a vital component for navigation along the Columbia River system. Redundancy does not exist for these dams and locks. Failure of a dam or a lock would significantly compromise river navigation for an extended period of time. In addition, a collapsed bridge obstructing the river channel would also impede navigation. Moreover, Portland International Airport (PDX) is located adjacent to the Columbia River and is protected by a levee system. The airport could be impacted by levee failure and liquefaction along the Columbia River.

ELECTRIC POWER SYSTEMS

Definition: Generation facilities are the main supply components of electric power infrastructure systems. A transmission network of circuits, structures, and conductors transmit high-voltage power from generating plants to substations where the voltage is lowered. Substations, which house transformers, high voltage switches, circuit breakers, and other critical electrical equipment, then allocate energy supply to a local distribution area. Electric power must always be in balance between the supply and the demand (called the load).

The electric power network supports almost every aspect of life in the region. This vast network provides the basic infrastructure to light and heat homes, run cash registers and keep items cold at the local grocer, power equipment at hospitals and businesses, pump water and wastewater at municipal treatment plants and gasoline at commercial gas stations, amongst many other activities. The fragility of some of the electric power network's components and their interconnectedness means this network is vulnerable to damages that could cut electricity to large portions of the region after a Cascadia event.

Much of the region's electric power network was not initially built to withstand earthquakes. At the region's gas, hydroelectric, nuclear, and other generating plants, the strong shaking may cause instruments and racks to chatter and unanchored equipment to slide around before crashing to the ground. Landslides, liquefaction, and lateral spreading may occur across the region's electric power grid network, which may cause distribution infrastructure and transmission tower failures. Fires may be ignited from fallen electrical lines throughout the region. At substations, seismically vulnerable equipment may fail and control buildings may be damaged.

Over half of the region's electric facilities may suffer medium to high damage, resulting in a significant loss in load capacity. A description of these damage states is provided in Table 20. One thousand substations or more may be damaged by the earthquake and unable to provide service. Most electrical power assets on the coast may suffer damage severe enough as to render the equipment and structures irreparable.

Electric facilities in the I-5 corridor may suffer considerable damage to generation plants, and many distribution circuits and substations may fail, resulting in a loss of over half of the systems load capacity. When electric facilities fail, power is rerouted to neighboring segments of the network. Protective relays may sense the overload and shut down. The loss of load capacity from each switch may cause cascading blackouts extending much further than the impacted area. Within minutes of the initial shaking, vast regions of Washington and Oregon may experience a complete blackout.

Figure 56. Earthquake damage to substation equipment. Photo: BPA Energy

ELECTRIC POWER SYSTEMS (CONT.)

Table 20. Description of damage state levels for electric facilities

Damage State		
Low	**Medium**	**High**
Light damage to generation plants, substation equipment, and buildings. No transformer damage. Repairs completed in a few hours to days. Temporary outage period, if any.	Considerable damage to generation plants, substation equipment, and buildings. Up to 10% of the generation plants have critical equipment damage. Up to 25% of critical substation equipment is damaged. Relays tripped in 50% of the substations. Up to 5% of the regional power transformers are damaged and non-functional. Many distribution circuits are damaged, and a few transmission lines are non-functional. Up to 10% of the substation control buildings are damaged and repairs are needed to regain functionality. Restoring power to meet 90% of demand may take weeks to months.	Extensive damage to generation plants, substations, and buildings. Up to 20% of the generation plants have critical equipment damage. Up to 50% of critical substation equipment is damaged. Relays tripped in 75% of the substations. Up to 15% of the regional power transformers are damaged and non-functional. A significant number of distribution circuits are damaged and a large number of transmission lines are non-functional. Up to 20% of the substation control buildings are damaged and repairs are needed to regain functionality. Restoring power to meet 90% demand may take months to one year.

WASHINGTON: ELECTRIC POWER

In the immediate aftermath of the earthquake, Seattle, Tacoma, and cities within 100 miles of the Pacific coastline may experience partial or complete blackouts. Sixty-six percent of the electric facilities in the I-5 corridor may suffer considerable damage to generation plants, and many distribution circuits and substations may fail, resulting in a loss of over half of the systems load capacity (see Table 21). Most electrical power assets on the coast may suffer damage severe enough as to render the equipment and structures irreparable. Some isolated areas may experience outages even if the distribution systems and substations in the area are undamaged.

Restoration timelines largely depend on the number of utility personnel and contractors available, and upon road conditions. Emergency damage repairs to the transmission line system in western Washington may take weeks to months. In areas where collapsed bridges, landslides, and damaged roadways have degraded the transportation network, or where fuel shortages hamper the ability to send out sufficient repair teams, power restoration may be even slower. Isolated areas of power outages east of the Cascades, where transportation networks are immediately functional, may be restored relatively quickly. The location of electric facilities is shown in Figures 57 and 58.

Table 21. Distribution of damage states for Washington electric facilities, by areas of operation

	Damage State			
Area of Operation	**None**	**Low**	**Medium**	**High**
Coastal	0%	0%	60%	40%
I-5 corridor	0%	22%	66%	12%
East	31%	69%	0%	0%
Summary of damage description	No damage to distribution systems and substations.	Light damage to generation plants, substation equipment, and buildings. No transformer damage. Repairs completed in a few hours to days. Temporary outage period, if any.	Considerable damage to generation plants, substation equipment, and buildings. Repairs are needed to regain functionality. Restoring power to meet 90% of demand may take weeks to months.	Extensive damage to generation plants, substations, and buildings. Repairs are needed to regain functionality. Restoring power to meet 90% of demand may take months to one year.

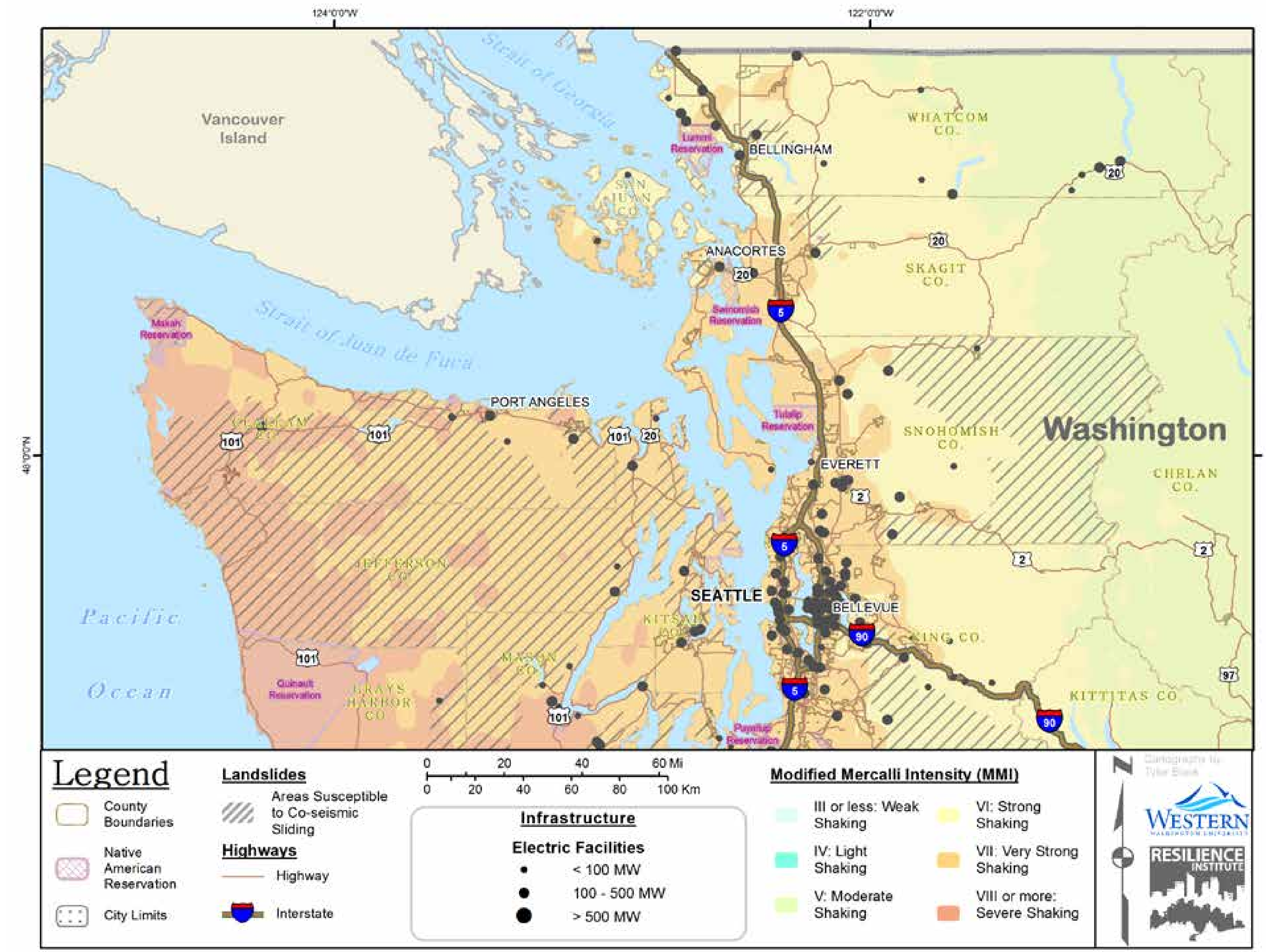

Figure 57. Location of electrical facilities in Northern Washington

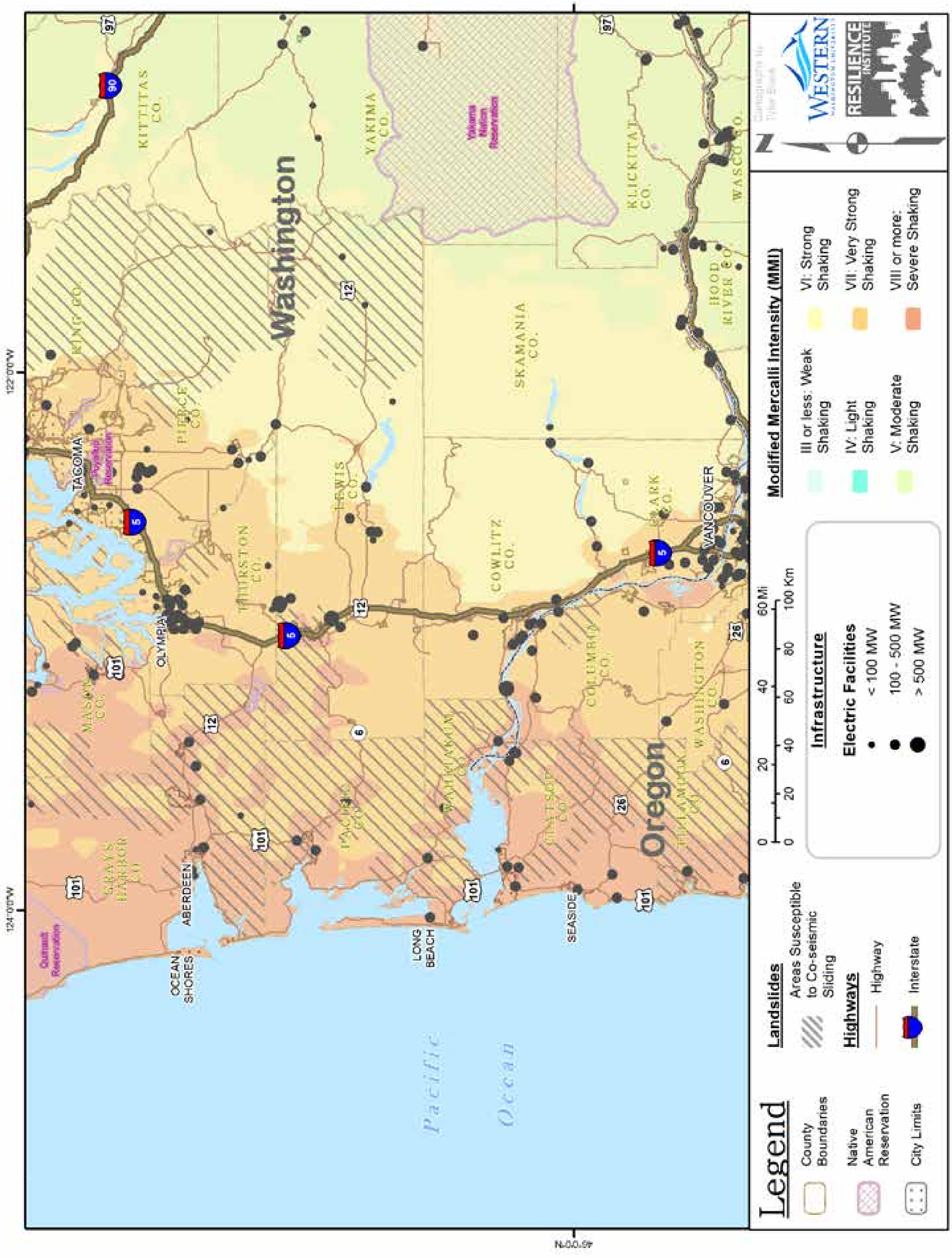

Figure 58. Location of electrical facilities in Southern Washington

OREGON: ELECTRIC POWER

In the immediate aftermath of the earthquake, cities within 100 miles of the Pacific coastline may experience partial or complete blackout. Seventy percent of the electric facilities in the I-5 corridor may suffer considerable damage to generation plants, and many distribution circuits and substations may fail, resulting in a loss of over half of the systems load capacity (see Table 22). Most electrical power assets on the coast may suffer damage severe enough as to render the equipment and structures irreparable. Some isolated areas may experience outages even if the distribution systems and substations in the area are undamaged.

Restoration timelines depend largely on the number of utility personnel and contractors available and road conditions. Emergency damage repairs to the transmission line system in western Oregon may take weeks to months. In areas where collapsed bridges, landslides, and damaged roadways have degraded the transportation network, or where fuel shortages hamper the ability to send out sufficient repair teams, power restoration may be even slower. Isolated areas of power outages east of the Cascades, where transportation networks are immediately functional, may be restored relatively quickly. Figures 59 and 60 show the location of electric facilities in Oregon.

Table 22. Distribution of damage states for Oregon electric facilities, by areas of operation

	Damage State			
Area of Operation	**None**	**Low**	**Medium**	**High**
Coastal	0%	0%	39%	61%
I-5 corridor	0%	0%	30%	70%
East	100%	0%	0%	0%
Summary of damage description	No damage to distribution systems and substations.	Light damage to generation plants, substation equipment, and buildings. No transformer damage. Repairs completed in a few hours to days. Temporary outage period, if any.	Considerable damage to generation plants, substation equipment, and buildings. Repairs are needed to regain functionality. Restoring power to meet 90% of demand may take weeks to months.	Extensive damage to generation plants, substations, and buildings. Repairs are needed to regain functionality. Restoring power to meet 90% of demand may take months to one year.

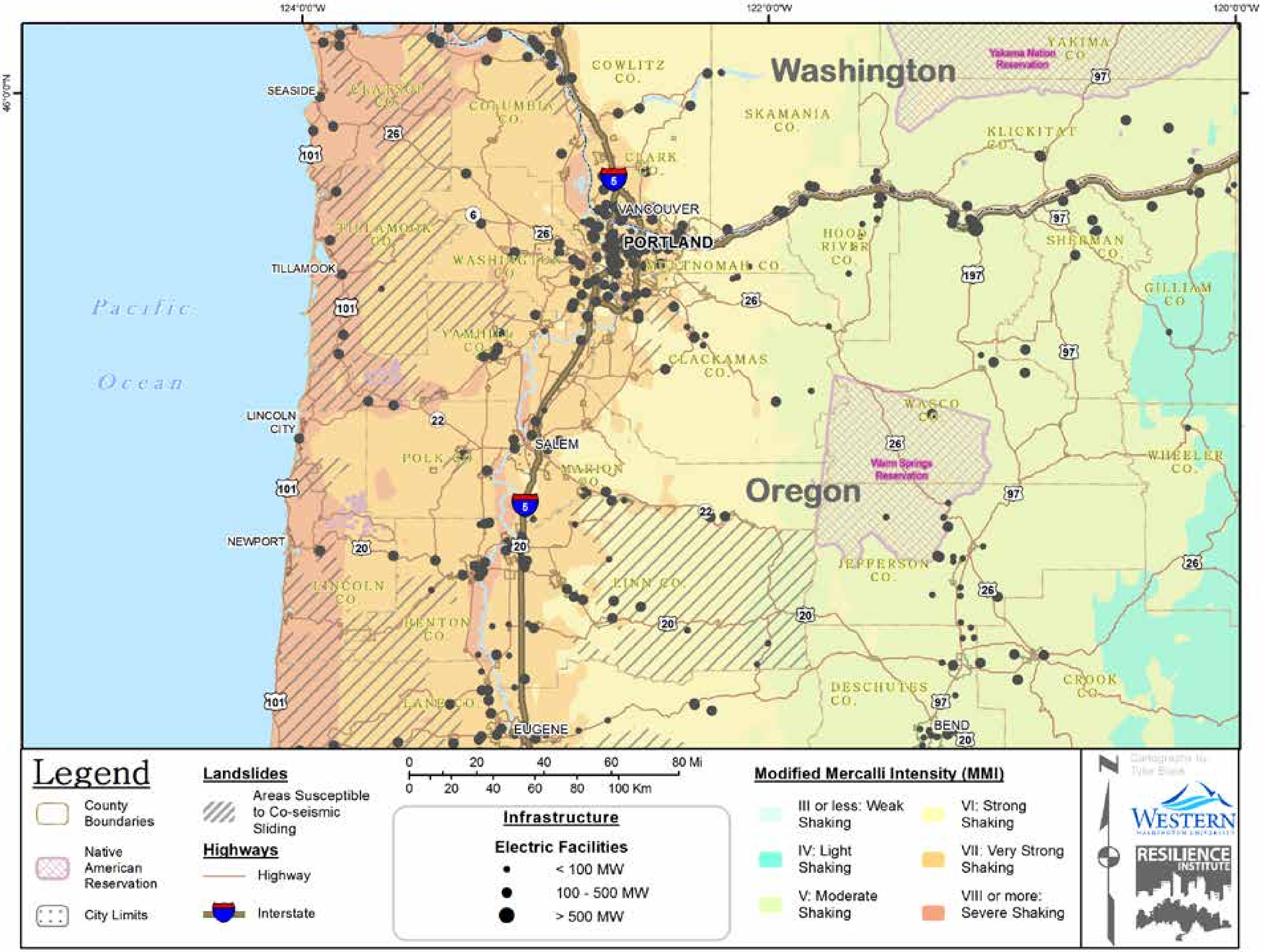

Figure 59. North Oregon electric facilities in relation to shaking intensity and landslide potential

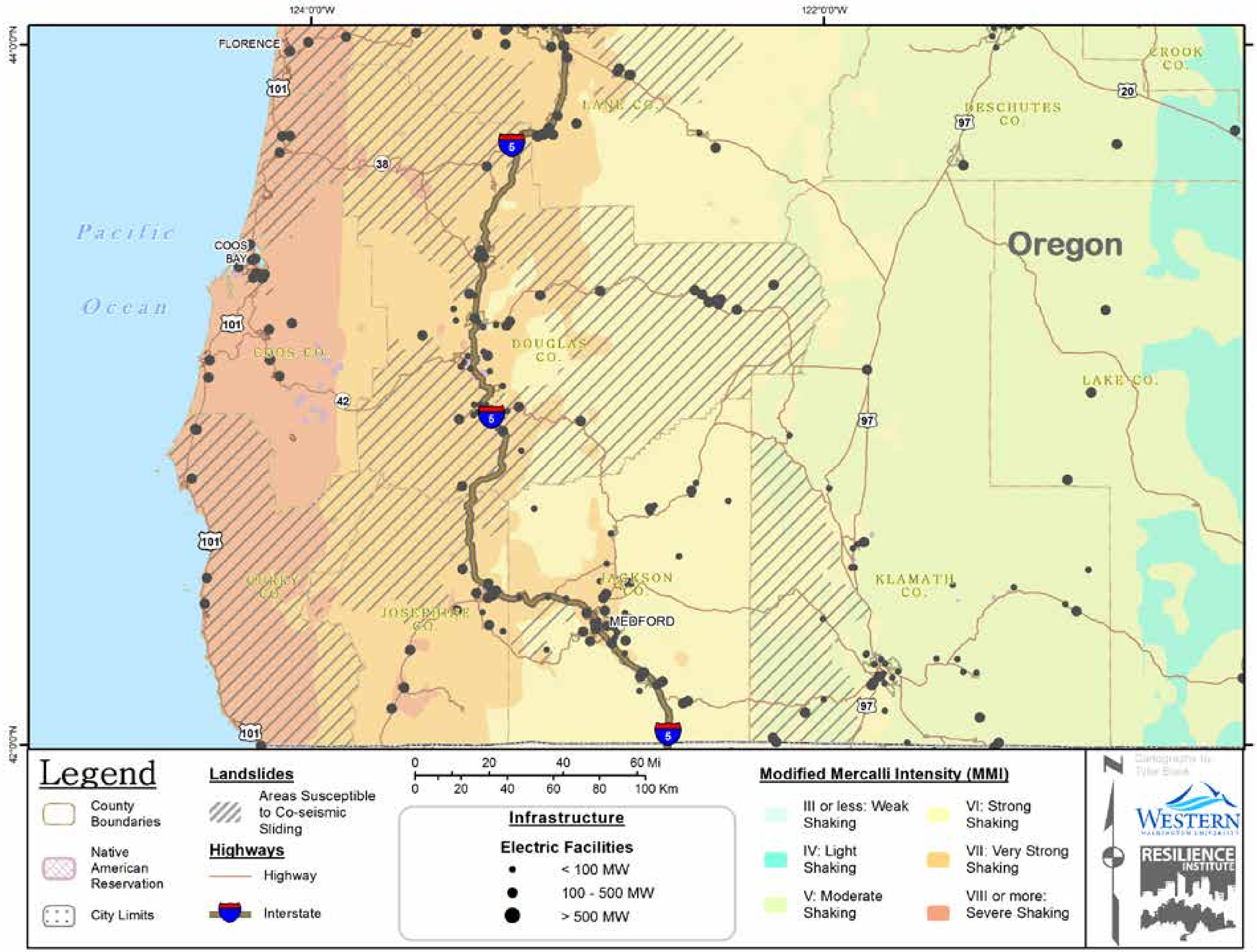

Figure 60. South Oregon electric facilities in relation to shaking intensity and landslide potential

NATURAL GAS SYSTEMS

Definition: The region's natural gas system consists of compressor stations and buried/elevated pipelines.

The natural gas pipeline network is composed of one primary natural gas transmission pipeline – The Northwest Pipeline – that connects to a network of smaller distribution pipelines.

The Cascadia earthquake may damage portions of over 500 miles of natural gas pipeline. Segments of the Northwest Pipeline may be inoperable due to numerous leaks and breaks along its route from the northern Washington border to southwestern Oregon.

Natural gas facilities that maintain the flow of these pipelines may also sustain damage from the earthquake. Roughly three-quarters of natural gas facilities in the impacted area of Washington and Oregon may suffer medium to high damage, including substantial building, mechanical, and electrical equipment damage.

In areas where there are a large number of breaks in the distribution network, local distribution companies may have to shut down the entire local network while repairs are made. The process may leave the majority of customers in western Washington and western Oregon without service. Restoration timelines for natural gas depend on location and road conditions. Some inland areas may have services restored in days. In coastal areas, it may take weeks to months to restore services.

WASHINGTON: NATURAL GAS SYSTEMS

The northern segment of the Northwest Pipeline extends from the Canadian border, at Sumas, Washington, south to the Washougal Station at the Columbia River Gorge. This segment of pipeline may experience multiple breaks and leaks, resulting in over 150 miles of damaged pipeline.

As shown in Table 23, nearly all of the natural gas facilities serving these pipelines may suffer medium to high damage, including damaged compressor station buildings and electrical equipment. As a result, most impacted communities in western Washington may lose natural gas service. Figure 61 shows the location of natural gas facilities in Washington.

Table 23. Distribution of damage states for Washington state natural gas facilities, by areas of operation

	Damage State			
Area of Operation	**None**	**Low**	**Medium**	**High**
Coastal	0%	0%	0%	100%
I-5 corridor	1%	4%	75%	20%
East	100%	0%	0%	0%
Summary of damage description	No damage.	Slight damage to compressor building.	Extensive damage to building, mechanical and electrical equipment. Damage may be irreparable.	Compressor building collapse or imminent danger of collapse.

Figure 61. Washington natural gas facilities and pipelines in relation to shaking intensity and landslide potential

OREGON: NATURAL GAS SYSTEMS

The southern segment of the Northwest Pipeline serving Oregon, begins at the Washougal Station on the Columbia River Gorge and terminating in southwest Oregon. The earthquake may cause numerous leaks and breaks along this route and other segments of pipeline, possibly resulting in over 300 miles of inoperable natural gas pipeline segments. Dozens of natural gas facilities serving these pipelines may suffer medium to high damage, including damaged compressor station buildings and electrical equipment (see Table 24).

The east-west pipeline connecting to the Northwest Pipeline in Portland may only suffer minor damage. After repairs are made to distribution facilities, this pipeline may be used to resupply natural gas to communities in Oregon. Figure 62 shows the location of natural gas facilities in Oregon.

Table 24. Distribution of damage states for Oregon natural gas facilities, by areas of operation

	Damage State			
Area of Operation	**None**	**Low**	**Medium**	**High**
Coastal	0%	0%	0%	100%
I-5 corridor	0%	0%	30%	70%
East	100%	0%	0%	0%
Summary of damage description	No damage.	Slight damage to compressor building.	Extensive damage to building, mechanical and electrical equipment. Damage may be irreparable.	Compressor building collapse or imminent danger of collapse.

Figure 62. Oregon natural gas facilities and pipelines in relation to shaking intensity and landslide potential

REFINED FUEL SYSTEMS

Definition: Refined fuel systems consist of pipelines and facilities, including refining centers, ports, pump stations, terminals, and storage tanks.

The region's five oil refineries are located along the Puget Sound in northwest Washington. These refineries receive most of their crude oil feedstock by waterborne shipments from Alaska. Shipments are also received by rail from the Bakken formation and other foreign sources. The remaining crude oil is transported by a trans-mountain pipeline that runs from the U.S. – Canada border to Mount Vernon, Washington. This pipeline supplies approximately 10 percent of crude feedstock for northwest Washington refineries.

Refined fuel products (e.g., gasoline, diesel, aviation fuel, etc.) produced at the five Washington refineries are distributed throughout the Pacific Northwest by ship, truck, and through the Olympic Pipeline. Ships carry refined product from terminals in the Seattle area to terminals in Portland and along the Columbia and Snake Rivers. The Olympic Pipeline network along the I-5 corridor from Ferndale, Washington to Eugene, Oregon. Some refined product is taken from the pipeline system at the Columbia River and shipped by barge to inland Washington and Idaho.

The Olympic pipeline network is serviced by several pump stations. These pump stations maintain the flow of refined fuel products from Washington refineries to terminals along the 350-mile route to southern Oregon. Refined product terminals store and distribute refined product to meet local demand.

In the impacted area of Washington and Oregon, over 400 miles of refined fuel pipeline may be inoperable due to numerous breaks and leaks caused by the initial earthquake. In addition, segments of the crude oil pipeline running from Canada to Mount Vernon in northwest Washington may also be inoperable due to a number of breaks and leaks along the length of the pipeline.

Many petroleum facilities, including refining centers, ports, pump stations, terminals, and storage tanks may suffer medium to high damage. A description of this damage is listed in Table 25. Until major repairs are made, these facilities may not be operational for several months.

REFINED FUEL SYSTEMS (CONT.)

Table 25. Lists of refined fuel components and corresponding damage state description

	Damage state	
Infrastructure components	**Medium**	**High**
Refineries	Malfunction of plant for a week or so due to loss of power, with damage to equipment or tanks. Refineries will not function until power is restored.	Extensive damage to or failure of tanks, stacks or elevated pipes.
Port - fuel facilities	Damage to tanks, pumping buildings, or loss of power, including backup power, for at least a few days.	Damage to tanks, pumping buildings, or loss of power, including backup power, for at least a few days.
Pumping stations	Considerable damage to mechanical and electrical equipment, or buildings housing them	Extensive damage to buildings or to pumps rendering them inoperable until repaired.
Terminals and storage tanks	Malfunction of tank farm for a week or so due to loss of backup power, extensive damage to various equipment, or considerable damage to tanks.	Complete failure of all elevated pipes, or collapse of tanks.

Major ports along the petroleum supply chain may suffer damage, including ports along Puget Sound that feed refineries, and ports that receive refined products. The earthquake and tsunami may block access to inland ports by modifying the Columbia River navigation channel's shape. Other navigable waterways may be closed to river traffic in places where oil products are contaminating waterways.

The loss of waterborne transportation may disrupt petroleum distribution systems beyond the damage zone. Shortages in western Oregon may cause disruptions as far east as Spokane, Washington.

Restoration times depend on the number of repair crews available. Fuel distribution infrastructure may be inoperable for weeks to months. After gas stations run out of supplies, finding petroleum to operate vehicles, generators, air transportation, or other equipment may become increasingly difficult.

WASHINGTON: REFINED FUELS

Washington's oil refineries may suffer damages from the initial earthquake. A few refineries may malfunction due to loss of electricity and backup power, or from damage to various equipment. Two may suffer damage severe enough to disrupt operations for months.

As shown in Table 20, over half of Washington's refined fuel system may suffer high damage. As much as 200 miles of pipeline segments, and as many as 50 facilities, may be damaged. The refined product pipeline running from northern Washington to the Columbia River may suffer numerous breaks, especially in areas where the pipeline traverses liquefaction zones. These are predominately located in the state's extensive floodplains.

All of the pump stations in Washington, the location of which are shown in Figure 63, of may experience damage to pumps or to the buildings housing pumps and mechanical equipment. Of the dozen plus terminals in Washington located along the Olympic Pipeline, nearly all may suffer damages, including heavily damaged tanks and broken elevated pipes. These terminals may be unable to receive and store petroleum from pipelines and ships. However, refined product may be trucked directly from the refineries to local distributors, but such distribution would be dependent on the viability of the road and bridge network.

Table 26. Distribution of damage states for Washington state refined fuels facilities, by areas of operation

	Damage State			
Area of Operation	**None**	**Low**	**Medium**	**High**
Coastal	N/A	N/A	N/A	N/A
I-5 corridor	0%	0%	44%	56%
East	N/A	N/A	N/A	N/A
Summary of damage description	No damage.	Loss of power resulting in malfunction for less than three days.	Malfunction of refinery for a week or so due to loss of power, with damage to equipment or tanks. Considerable damage to mechanical and electrical equipment, or buildings housing them.	Extensive damage to refinery or failure of tanks, stacks, or elevated pipes. Extensive damage to buildings or to pumps, rendering them inoperable until repaired.

Figure 63. Washington refined fuel facilities and pipelines in relation to shaking intensity and landslide potential

OREGON: REFINED FUELS

Almost all of Oregon's refined fuel products are supplied by refineries in the Puget Sound region of Oregon. Refined fuel passes through Oregon's Critical Energy Infrastructure (CEI) hub outside of Portland. The CEI hub receives refined fuels, either by pipeline or by ship, before the product is distributed throughout Oregon. The refined product pipeline system serving the CEI may suffer damage, with numerous breaks and leaks along its extent, which may result in total loss of refined fuels supply from the Olympic Pipeline. Moreover, ships may be unable to deliver refined fuels due to the closure of the Columbia River navigation channel. The location of Oregon petroleum facilities are shown in Figure 64.

As shown in Table 27, over half of Oregon's refined fuel systems may suffer high damage. Aside from the loss of supplies from pipeline and ship, Oregon may be unable to store and distribute fuels locally, due to the loss of refined fuel terminals. As a result, western Oregon may experience significant shortages in fuel supplies. With the CEI out of commission, petroleum distribution systems may not be functional until major repairs are made.

Table 27. Distribution of damage states for Oregon refined fuels facilities, by areas of operation

	Damage State			
Area of Operation	**None**	**Low**	**Medium**	**High**
Coastal	0%	0%	0%	100%
I-5 corridor	0%	0%	44%	56%
East	N/A	N/A	N/A	N/A
Summary of damage description	No damage.	Loss of power resulting in malfunction for less than three days.	Considerable damage to mechanical and electrical equipment, or building housing them.	Extensive damage to buildings or to pumps rendering them inoperable until repaired.

Figure 64. Oregon refined fuel facilities and pipelines in relation to shaking intensity and landslide potential

CRITICAL PUBLIC SAFETY FACILITIES

Definition: Critical Public Safety Facilities are those structures necessary for emergency response to, and recovery from, a disaster. These facilities include Emergency Operation Centers, 9-1-1 dispatch centers, fire stations, and police stations.

In the immediate aftermath of the earthquake, police, fire, and other emergency personnel will begin their response to an event of massive scale. Yet, nearly half of all police, fire, and ambulance facilities in the impact area of Washington and Oregon may suffer moderate or greater damage, compromising response capabilities.

On the coast, most of the critical public safety facilities and the vehicles housed at the facilities, may suffer high damage from the violent shaking. Those facilities on the coastal plain that survive the earthquake may be inundated by tsunami waves moments later. The loss of these critical facilities' services may put pressure on critical facilities in surrounding communities, further complicating response operational coordination.

Damaged facilities may lose access to basic services, such as power, water, and sewer (though most facilities have emergency back-up power). A description of damage states in terms of building damage and functionality, is provided in Table 28.

Figure 65. EOCs will activate following the earthquake, but challenges in maintaining staffing coupled with facility damages may hinder operational coordination. Photo: Unknown.

Disruptions in communications may be a widespread problem throughout emergency response operations. Local-emergency response facilities may be overwhelmed by the high volume of emergency calls, causing cellular and 9-1-1 phone systems to crash. Widespread damage to roadways and bridges may limit access to many critical facilities along the coast. Emergency-response personnel may struggle to access those injured in the event and may even have trouble reporting to work. Some critical facilities may need to run on backup generators due to electric power outages.

CRITICAL PUBLIC SAFETY FACILITIES (CONT.)

Table 28. Description of critical facility building damage for each damage state

	Damage state		
	Low	Medium	High
Building damage description	Visible cracks in walls and windows.	Large cracks in walls, columns and partial ceiling collapse, loss of power and utilities.	Building shifted off of foundation, collapsed or in imminent danger of collapse.
Functionality	Facility is structurally sound and able to be occupied, though damage to interior contents may make immediate use more difficult.	Facility is damaged and may need repair before full occupation is possible.	Facility is not accessible.

EMERGENCY OPERATION CENTERS

As emergency operation centers activate across the region, the capabilities of state, tribal, and local Emergency Operation/Coordination Centers (EOC/ECCs) to provide situational awareness may be limited due to power outages and disruptions in communications across the region. Some EOCs may need to run on backup generators. Over time, as battery life fades and fuel shortages occur, key EOCs may experience failure of some backup supporting and communications systems. Emergency-response personnel may have to develop alternative ways to distribute public messages directing survivors to their support areas.

PUBLIC SAFETY ANSWERING POINTS (PSAPS)

Washington and Oregon have a network of Public Safety Answering Point (PSAP) facilities that operate as 9-1-1 call centers and are sometimes co-located with county or municipal EOCs. PSAPs receive notifications and calls for service from the public, dispatch (via radio and/or computer) the needed public safety field units (police, fire, etc.), and respond to requests from the public safety field units themselves. Residents also frequently utilize the PSAP system to report power outages, natural gas leaks, water main breaks, etc.; the information is then relayed to the appropriate utility.

If after a CSZ earthquake event, cell towers are rendered inoperable, telephone lines are down, "repeater" stations are impaired, or the PSAP communication infrastructure is overloaded, damaged or otherwise compromised, critical gaps in this public safety resource will be created. Not only will PSAPs be unable to communicate with citizens and field units, but emergency response personnel will not be able to communicate with one another. Disruption in PSAP service would create a situation of extreme danger to the public, law enforcement and firefighting personnel, and other first responders. Additionally, PSAPs that remain structurally intact after a CSZ earthquake may experience limited operations, if staff members cannot reach the facility because of transportation system damage.

FIRE STATIONS

Numerous fires may ignite from downed electric lines and broken natural gas pipelines caused by the earthquake. Fire stations across the region may experience high emergency incident volumes but the disruptions in communications may make it challenging to estimate the scope and severity of the situation. Estimates indicate that roughly 40 percent of fire service facilities may suffer medium to high structural building damage from the initial CSZ earthquake. Many of these facilities may need repair before they can be occupied.

Additionally, damage to water supply pipelines, plants, and pumps, may render most fire hydrants useless. This combination of direct damage to fire facilities and potential water shortages, combined with limited road access and disruptions in emergency communications systems, may significantly compromise the ability of local fire departments to respond. Firefighters may have to draft water from lakes, rivers, and reserves to fight fires in urban and suburban areas, or rely on tankers to move water.

Figure 66. Liquefaction from the 2011 M6.3 earthquake in Christchurch, New Zealand trapped a fire engine in silt. Unnavigable road conditions could hinder emergency response efforts throughout Washington and Oregon.

WASHINGTON: FIRE STATIONS

The majority of fire stations in the I-5 corridor may sustain only low structural damage from the initial earthquake. Jammed overhead doors and other non-structural damage may impede immediate access to fire trucks and equipment. With minor repair, these facilities may be usable shortly after the earthquake.

As shown in Table 29, 58 percent of fire facilities in the coastal corridor may suffer high damage, and may not be accessible for an extended period of time. Their locations are shown in Figures 67-69. Facilities in the tsunami inundation zone that survive the earthquake could potentially be destroyed by incoming waves. Nearly half of the fire stations serving Grays Harbor County may be inundated by tsunami waters.

Table 29. Distribution of damage states for Washington fire stations, by areas of operation

	Damage State			
Area of Operation	**None**	**Low**	**Medium**	**High**
Coastal	0%	12%	30%	58%
I-5 corridor	18%	53%	7%	22%
East	100%	0%	0%	0%
Summary of damage description	Facility is fully functional.	Facility is structurally sound and able to be occupied, though damage to interior contents may make immediate use more difficult.	Facility is damaged and may need repair before full occupation.	Facility is not accessible.

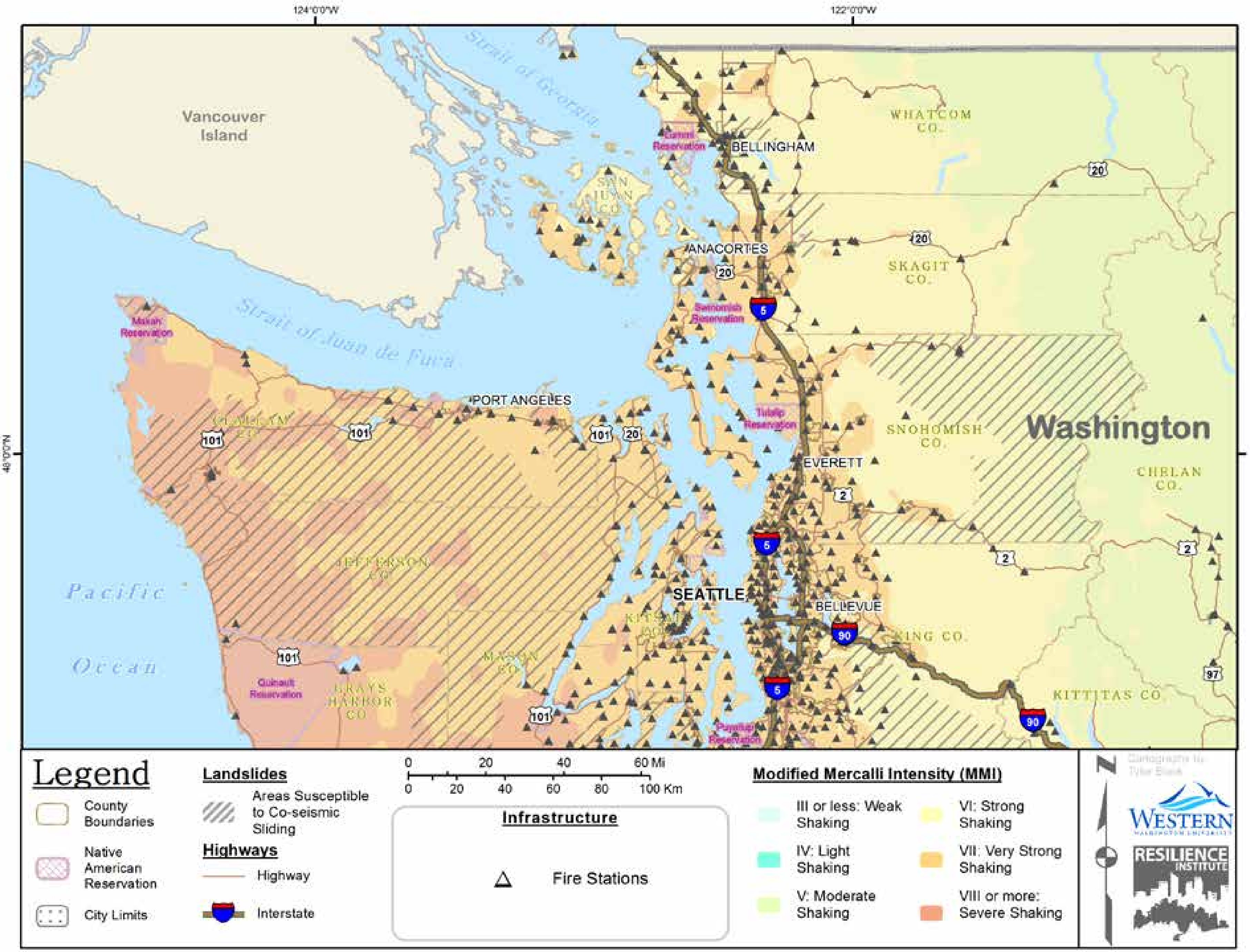

Figure 67. North Washington fire stations in relation to shaking intensity

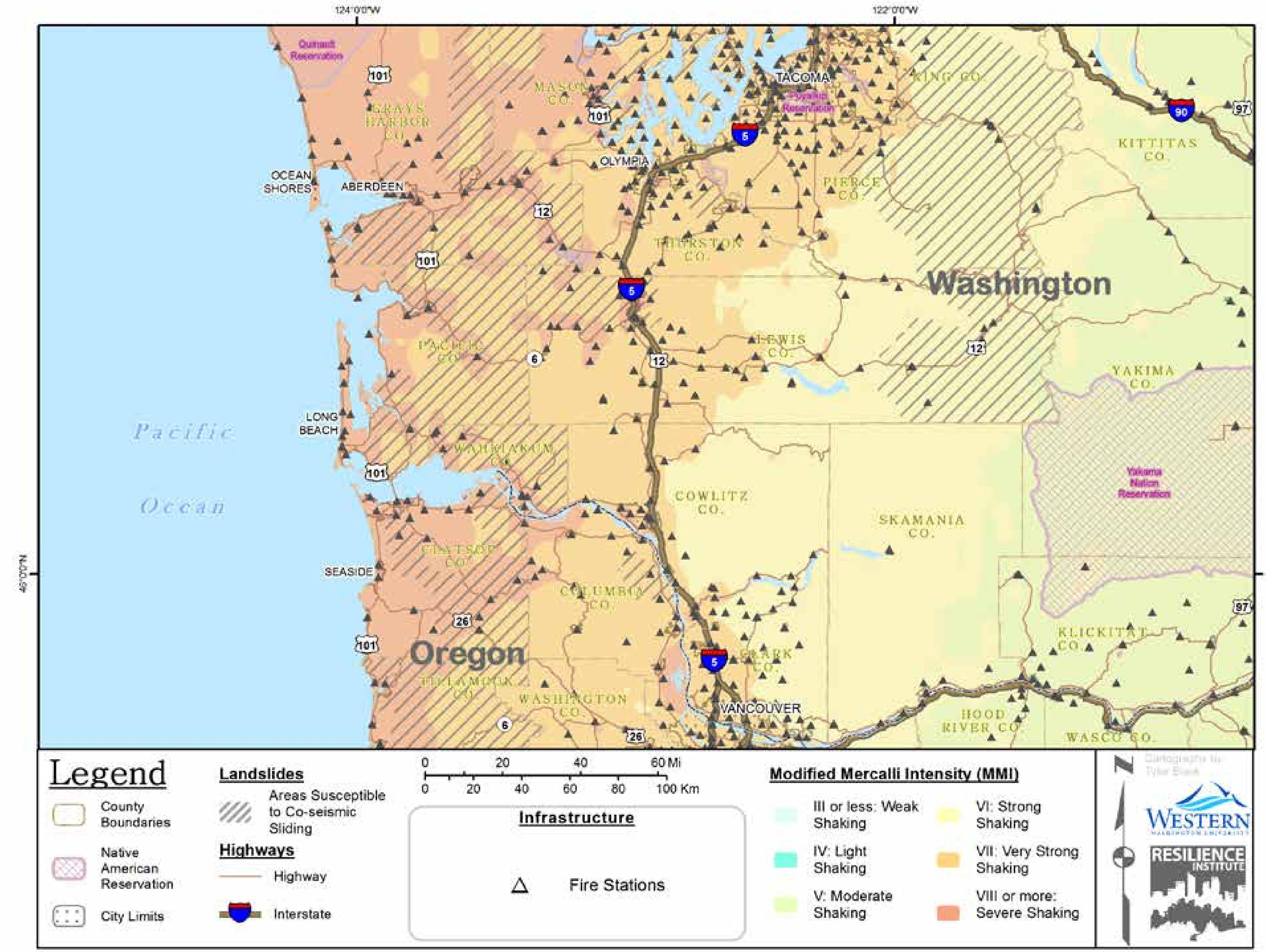

Figure 68. South Washington fire stations in relation to shaking intensity

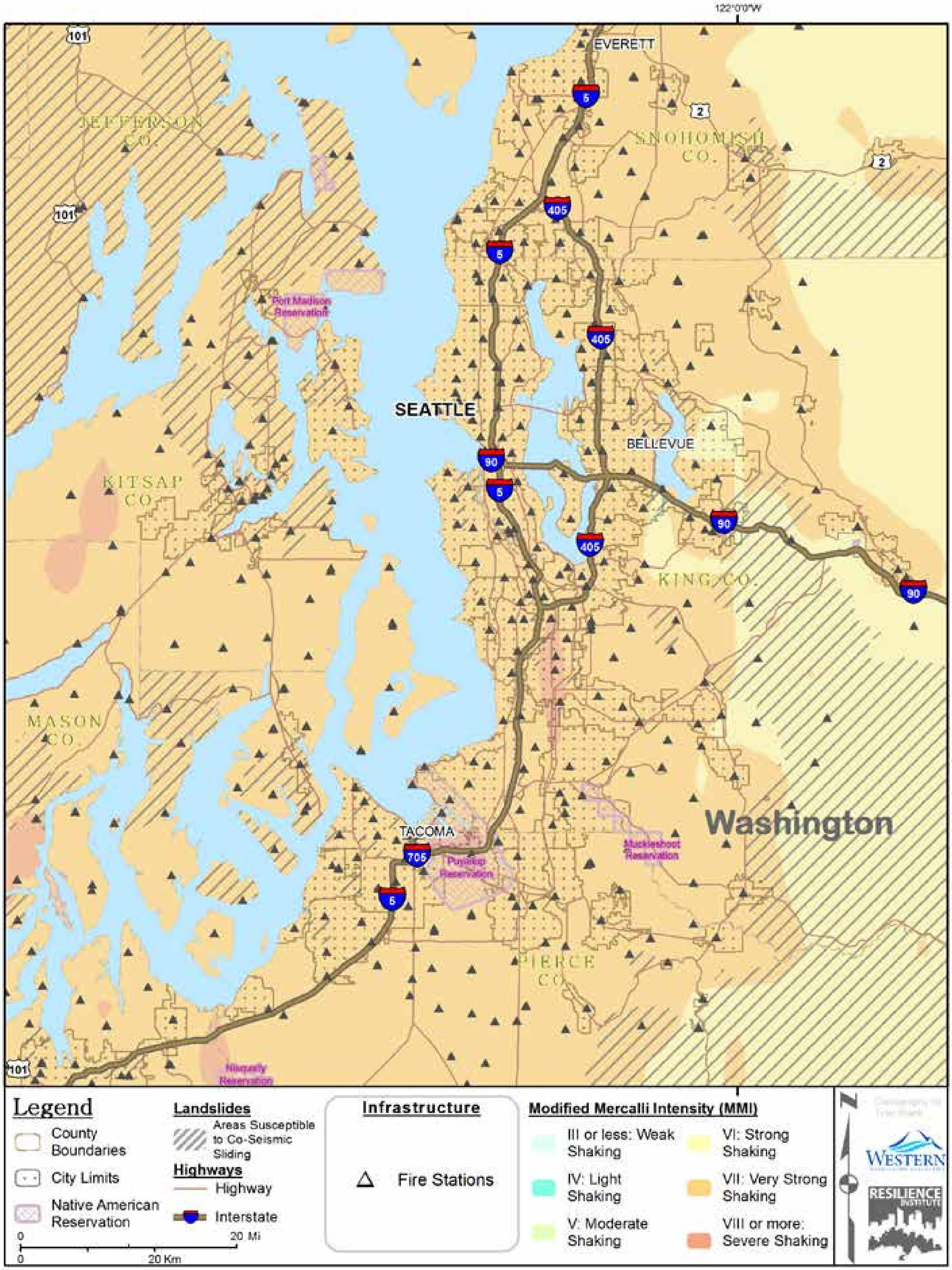

Figure 69. Seattle-Tacoma metro region fire stations in relation to shaking intensity and landslide potential

OREGON: FIRE STATIONS

The majority of fire stations in the I-5 corridor may suffer high structural damage from the initial earthquake. Some fire stations around Portland may still be functional immediately after the earthquake. However, jammed overhead doors and other non-structural damage may impede immediate access to fire trucks and equipment

As shown in Table 30, 85 percent of fire facilities in the coastal corridor may suffer high damage from the initial earthquake and may not be accessible for an extended period of time. Some of the facilities within the inundation zone that survive the earthquake could potentially be destroyed by incoming waves. The location of fire stations in Oregon is shown in Figures 70-72.

Table 30. Distribution of damage states for Oregon fire stations, by areas of operation

	Damage State			
Area of Operation	**None**	**Low**	**Medium**	**High**
Coastal	0%	5%	15%	85%
I-5 corridor	17%	28%	1%	54%
East	100%	0%	0%	0%
Summary of damage description	Facility is fully functional.	Facility is structurally sound and able to be occupied, though damage to interior contents may make immediate use more difficult.	Facility is damaged and may need repair before full occupation.	Facility is not accessible.

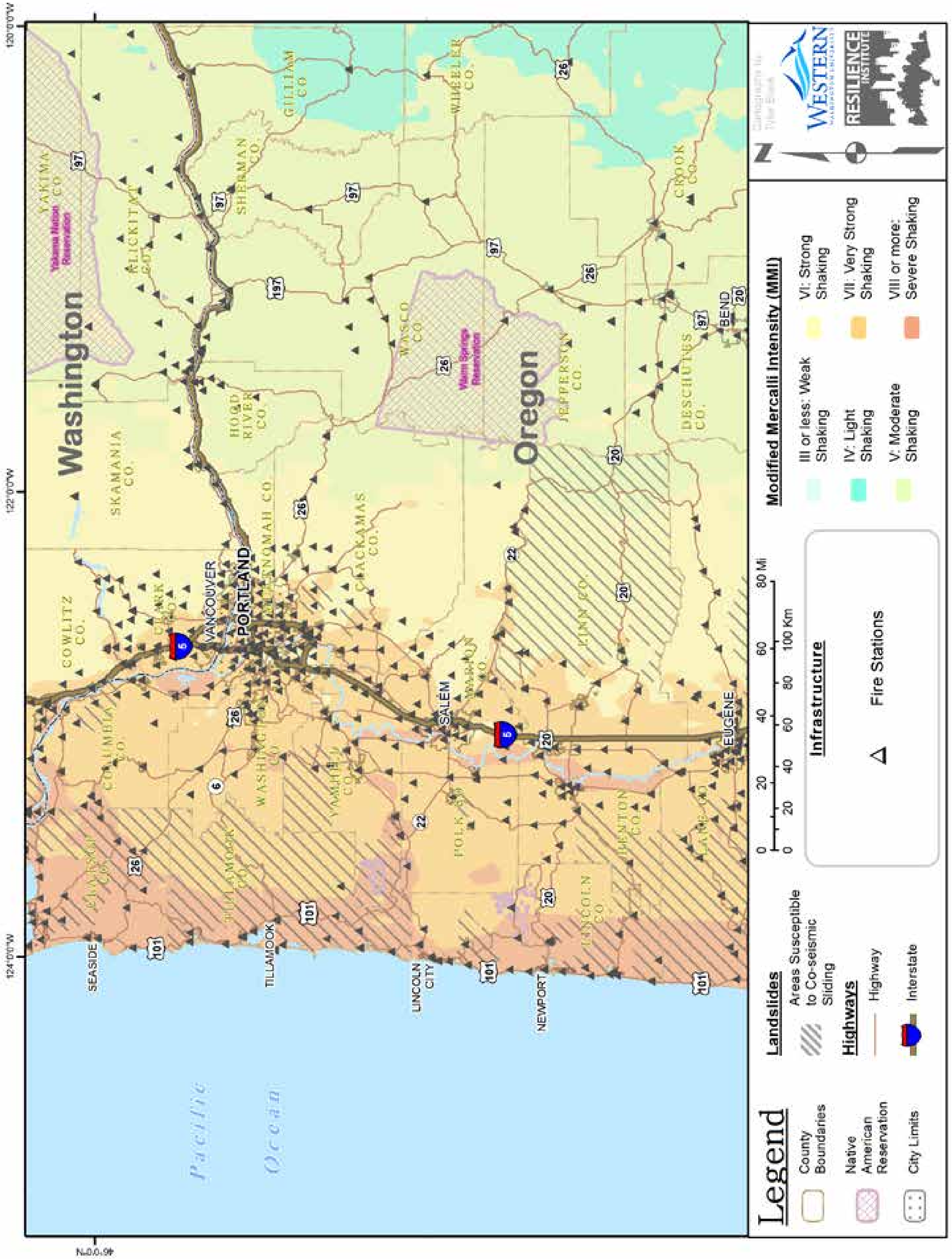

Figure 70. North Oregon fire stations in relation to shaking intensity and landslide potential

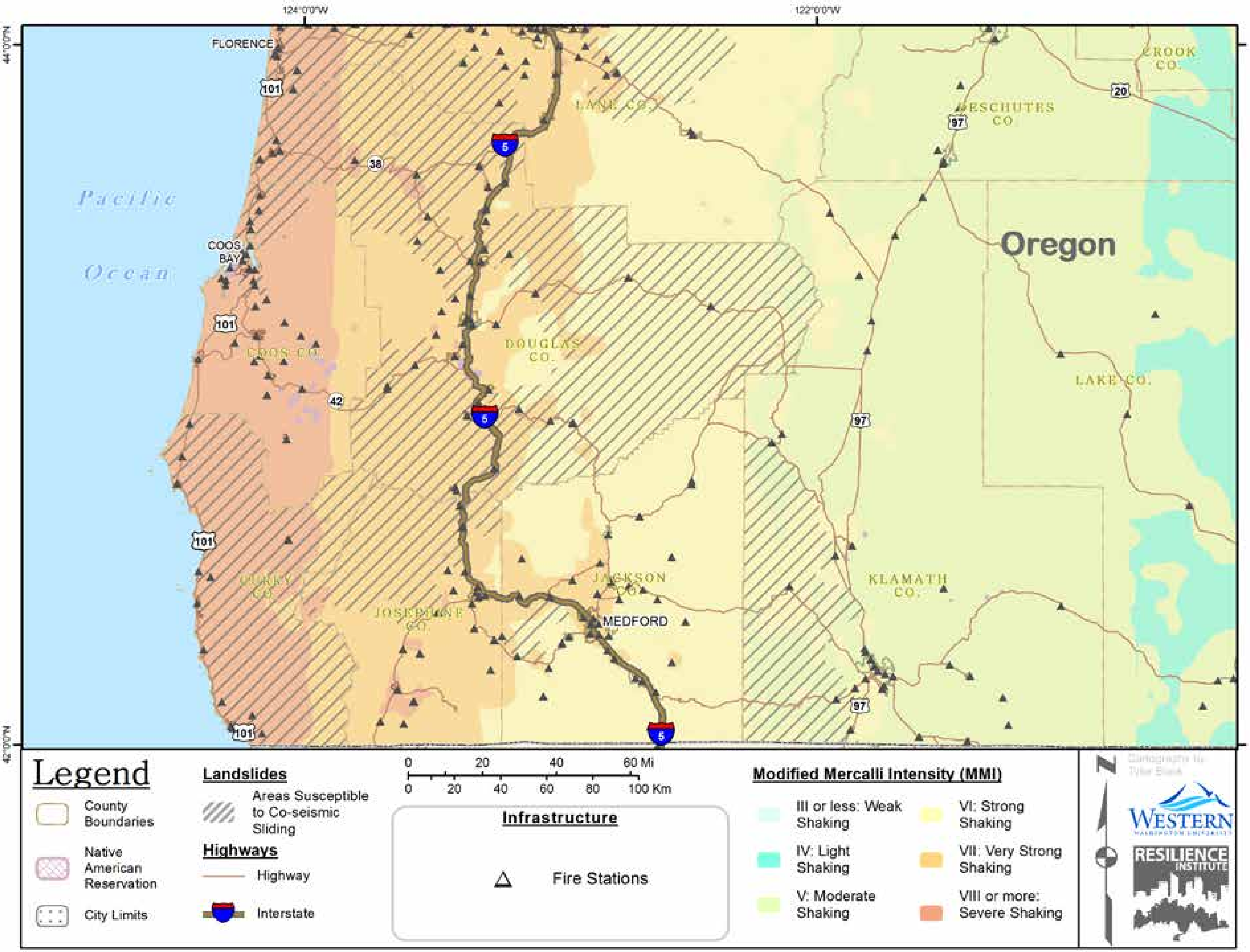

Figure 71. South Oregon fire stations in relation to shaking intensity and landslide potential

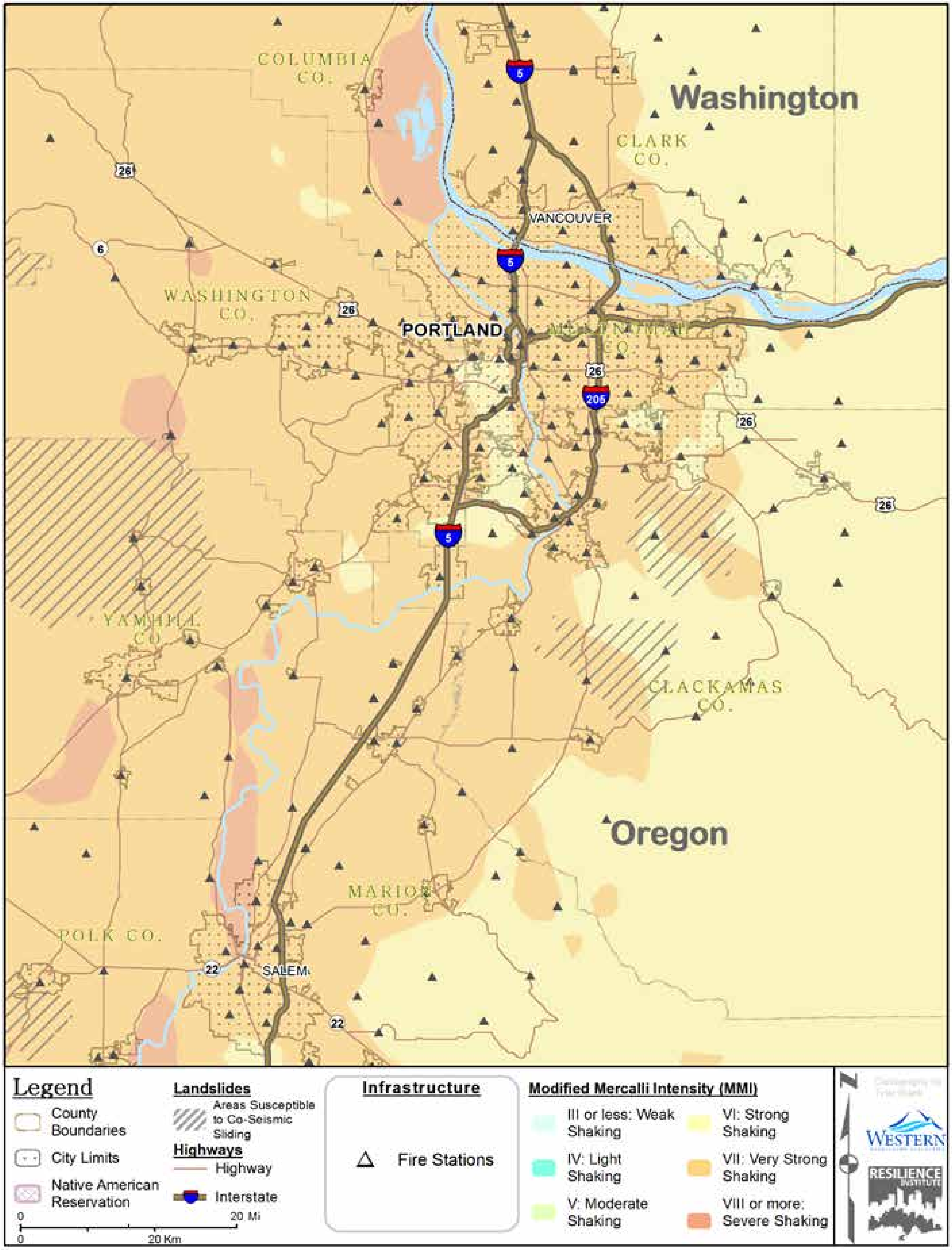

Figure 72. Portland metro region fire stations in relation to shaking intensity and landslide potential

POLICE STATIONS, SUPPORTING INFRASTRUCTURE, LAW ENFORCEMENT AND CORRECTIONS PERSONNEL

There are over 400 police facilities in the impacted area of Washington and Oregon. Roughly half may suffer medium to high damage from the initial earthquake. The added impacts of power outages, degraded transportation networks, loss of traditional dispatch, phone and email communication, restricted ability to fuel and maintain vehicles, etc. will diminish the police force's ability to provide traffic and crowd control, prevent crime, arrest violators, and protect survivors. Additionally, three quarters of all correctional facilities may sustain medium to high damage, thus limiting the ability for law enforcement to lodge arrestees.

Beyond the obvious concerns precipitated by the damage to infrastructure as noted above, it is critical to point out that many law enforcement and corrections personnel may themselves be unable to report for duty. Contemporaneously, there may be an exponential increase in the demand for police resources due to the catastrophic nature of a CSZ event; even more police or corrections resources may be required if it is necessary to relocate inmates from damaged jail or prison facilities.

WASHINGTON: LAW ENFORCEMENT

Most of the police stations serving communities in the Seattle-Tacoma metropolitan area may suffer minimal damage. As shown in Table 31, over half of the police stations in Washington's I-5 corridor may suffer no to low damage and may be immediately functional at a somewhat reduced level. Police stations located south of Olympia and throughout the coastal region may suffer higher levels of damage and may be inaccessible until repairs are made. Some of police stations in the tsunami inundation zone that survive the earthquake may potentially be destroyed by incoming waves.

The ability of state, local, and tribal law enforcement agencies to maintain public order for the affected areas, as well as the ability of corrections officers to maintain jail and prison facilities, may be limited during response operations. Power outages, loss of standard communications services, poor transportation access, and personnel shortages may further diminish response capabilities. The location of police stations in Washington, in relation to earthquake shaking intensity, is provided in Figures 73-75.

Table 31. Distribution of damage states for Washington state police stations, by areas of operation

	Damage State			
Area of Operation	**None**	**Low**	**Medium**	**High**
Coastal	0%	5%	38%	57%
I-5 corridor	8%	49%	6%	37%
East	100%	0%	0%	0%
Summary of damage description	Facility is fully functional.	Facility is structurally sound and able to be occupied, though damage to interior contents may make immediate use more difficult.	Facility is damaged and may need repair before full occupation.	Facility is not accessible.

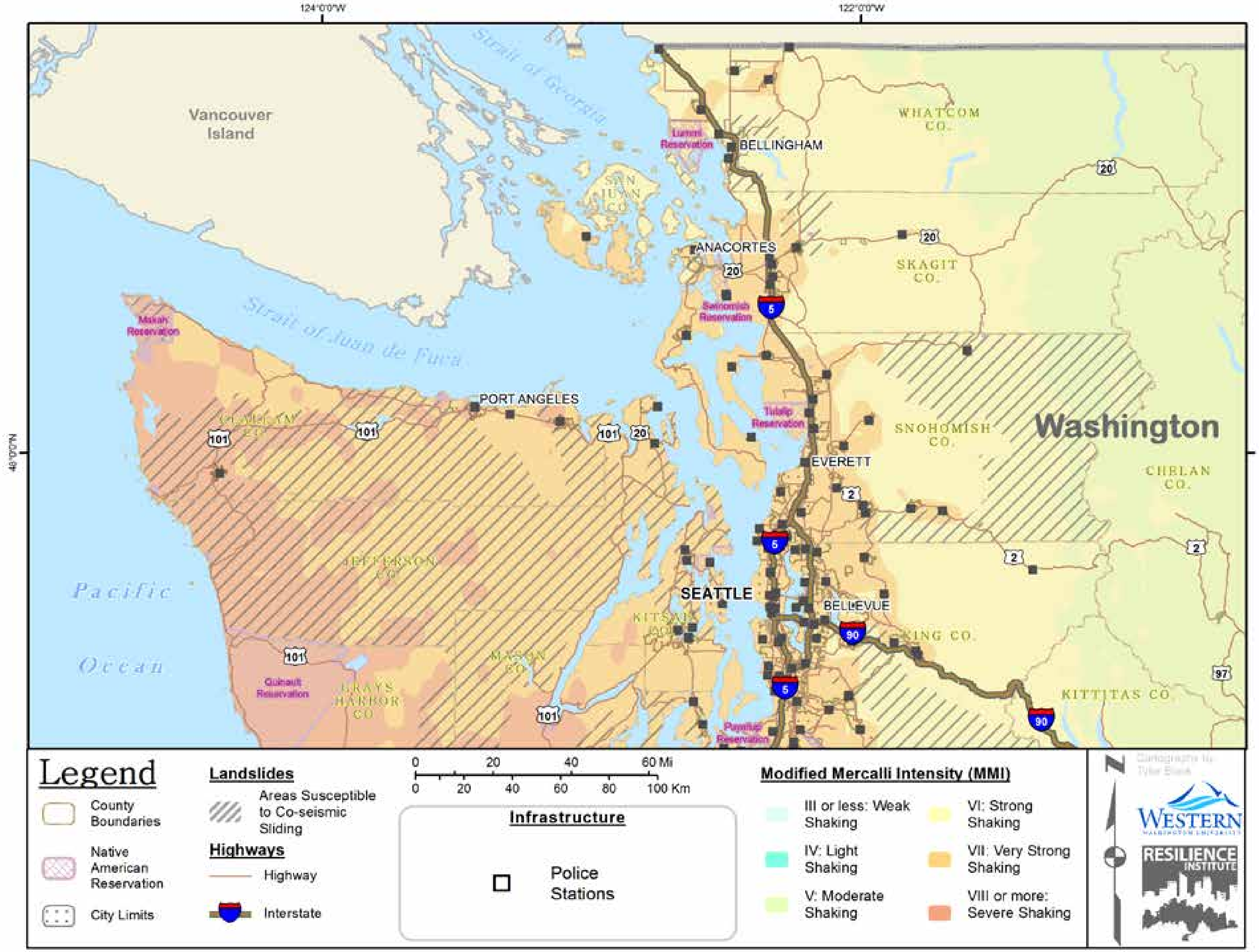

Figure 73. North Washington police stations in relation to shaking intensity and landslide potential

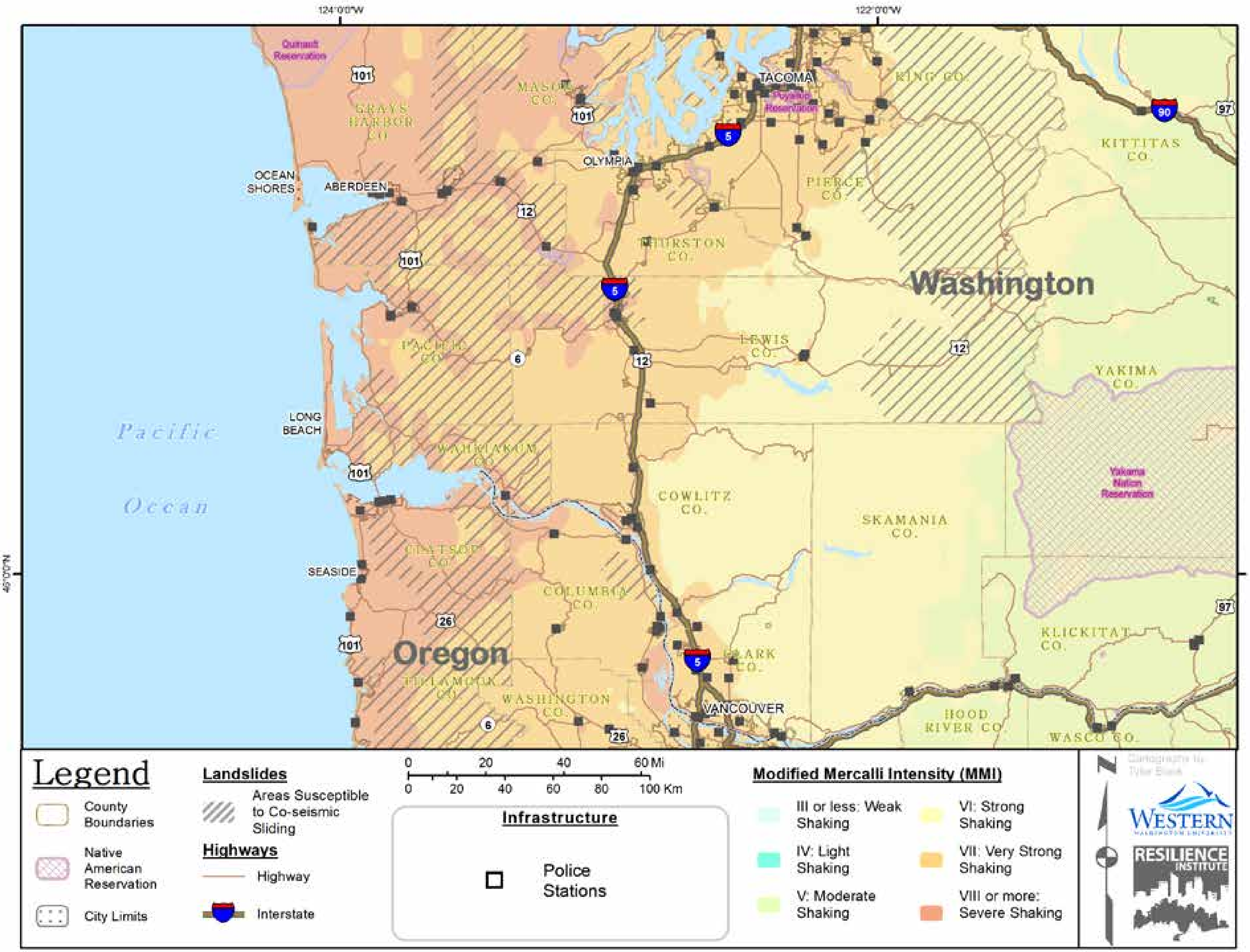

Figure 74. South Washington police stations in relation to shaking intensity and landslide potential

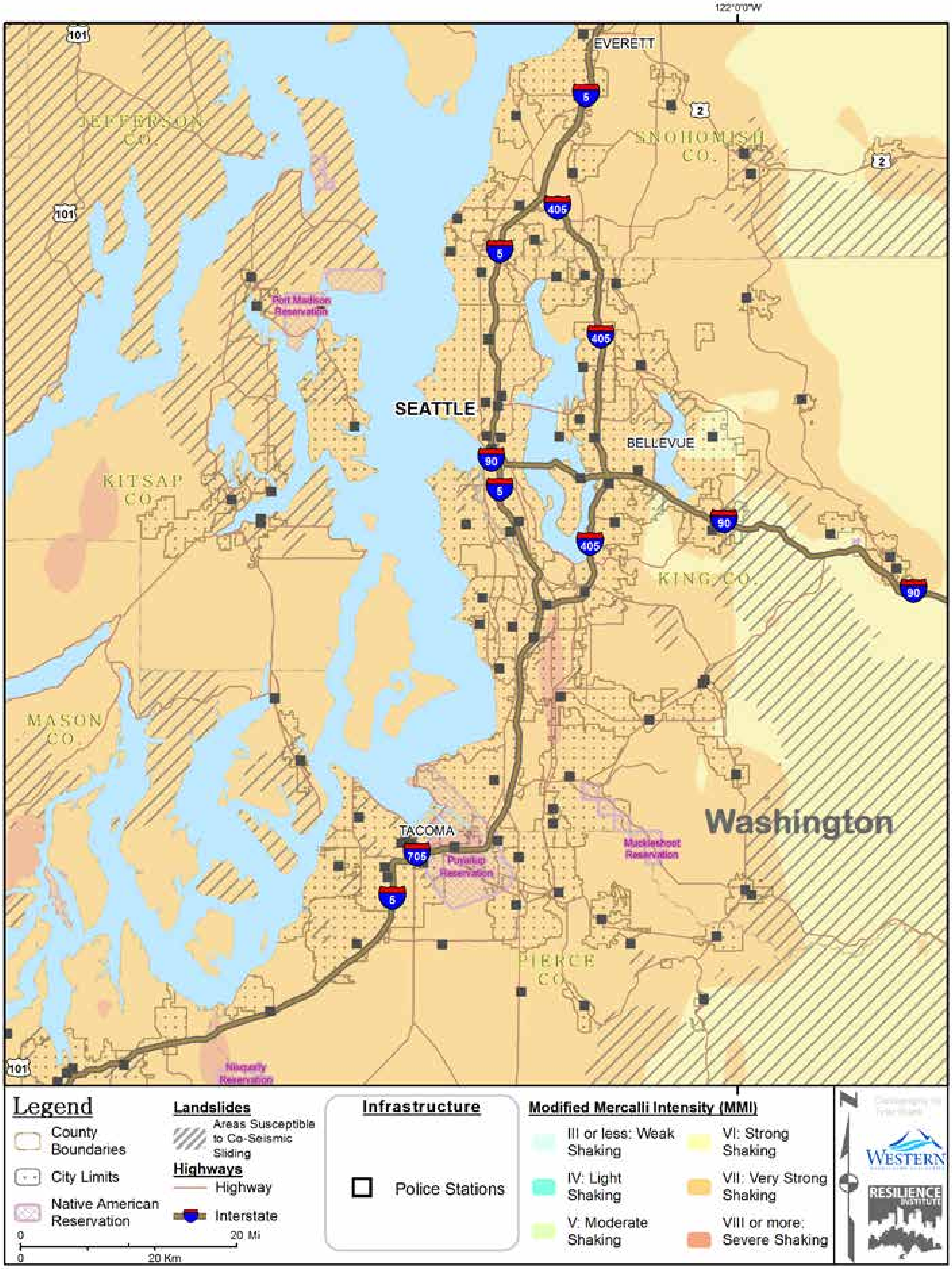

Figure 75. Seattle-Tacoma metro region police stations in relation to shaking intensity and landslide potential

OREGON: LAW ENFORCEMENT

In the aftermath of the earthquake, only a couple dozen police stations in Oregon's population centers may suffer minor structural damage and may be immediately functional at a somewhat reduced level. As shown in Table 32, 55 percent of police stations in the I-5 corridor and ninety-four percent in the coastal region may suffer high damage and may be inaccessible until repairs are made.

The ability of state, local, and tribal law enforcement agencies to maintain public order for the affected areas, as well as the ability of corrections officers to maintain jail and prison facilities, may be limited during response operations. Power outages, loss of standard communications services, poor transportation access, and personnel shortages may further diminish response capabilities. The location of Oregon police stations, in relation to shaking intensity is provided in Figures 76-78.

Table 32. Distribution of damage states for Oregon police stations, by areas of operation

	Damage State			
Area of Operation	**None**	**Low**	**Medium**	**High**
Coastal	0%	0%	6%	94%
I-5 corridor	13%	27%	2%	58%
East	100%	0%	0%	0%
Summary of damage description	Facility is fully functional.	Facility is structurally sound and able to be occupied, though damage to interior contents may make immediate use more difficult.	Facility is damaged and may need repair before full occupation.	Facility is not accessible.

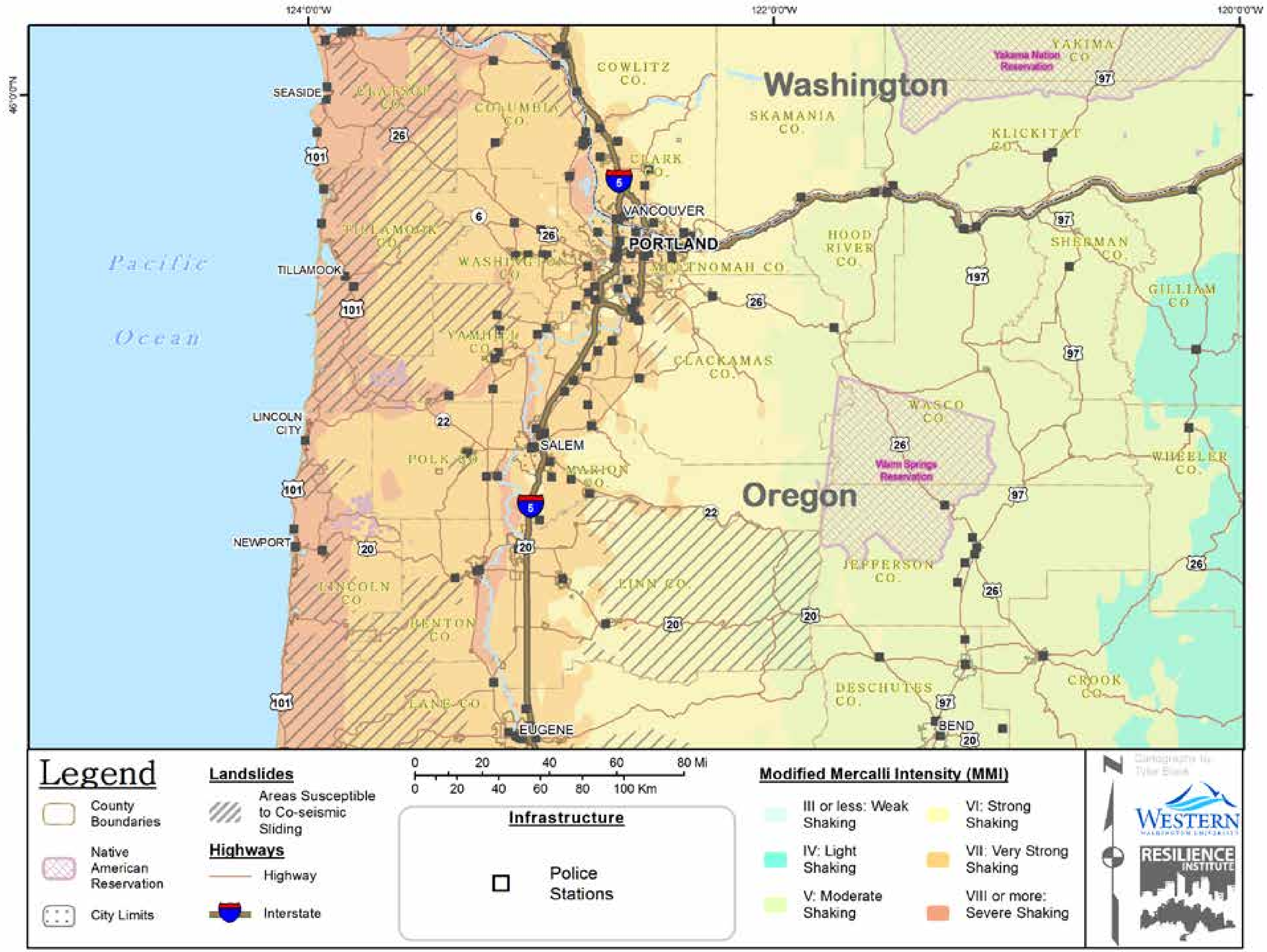

Figure 76. North Oregon police stations in relation to shaking intensity and landslide

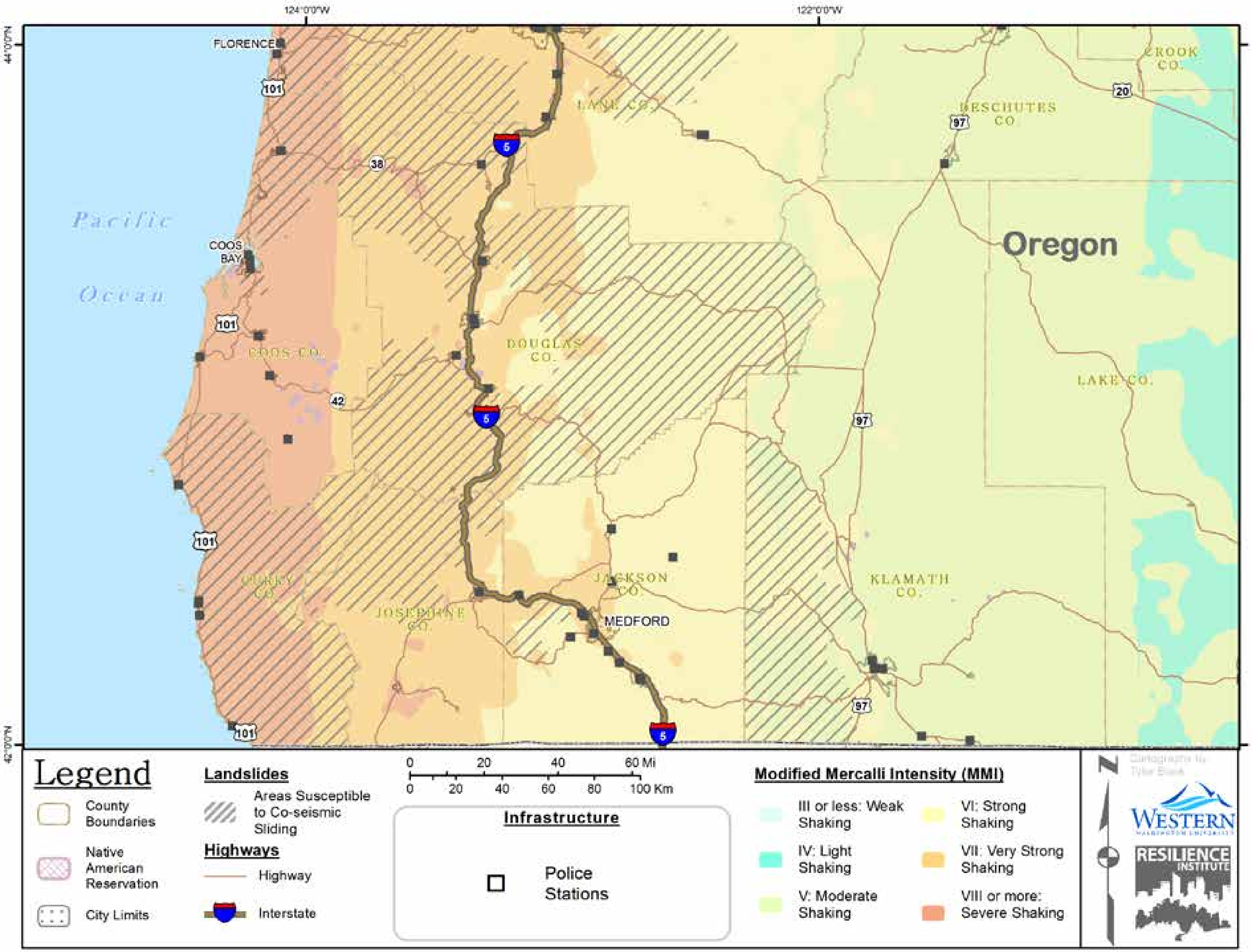

Figure 77. South Oregon police stations in relation to shaking intensity and landslide

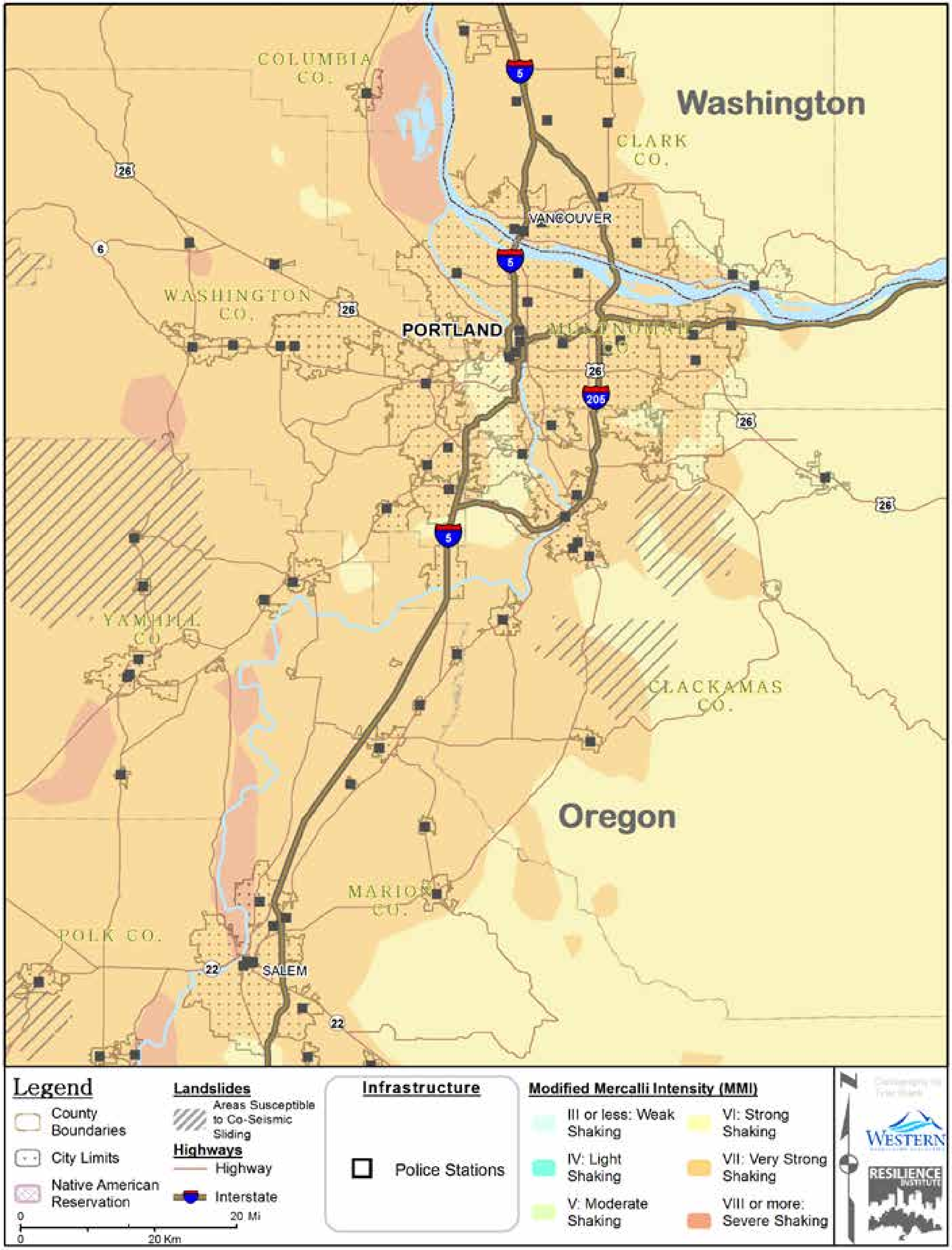

Figure 78. Portland metropolitan region police stations in relation to shaking intensity and landslide potential

HOSPITALS

In the hours and days after the initial event, tens of thousands of survivors will flood hospitals seeking treatment for minor cuts, broken bones, and other injuries, including life-threatening trauma injuries. At the same time, the majority of hospitals may suffer medium to high damage, resulting in the loss of hundreds of regular and critical beds needed to treat the influx of injured survivors.

Structural damage may vary depending on the building type, age of construction, and building location. The greatest amount of structural damage may be along the coast, where the shaking is most intense. However, widespread nonstructural damage may have an equal or greater impact on hospitals' ability to function. Broken pipes and ducts, dislodged equipment, fallen ceilings, elevator counterweight damage, and water damage from sprinkler systems can force structurally sound hospitals to shut down.

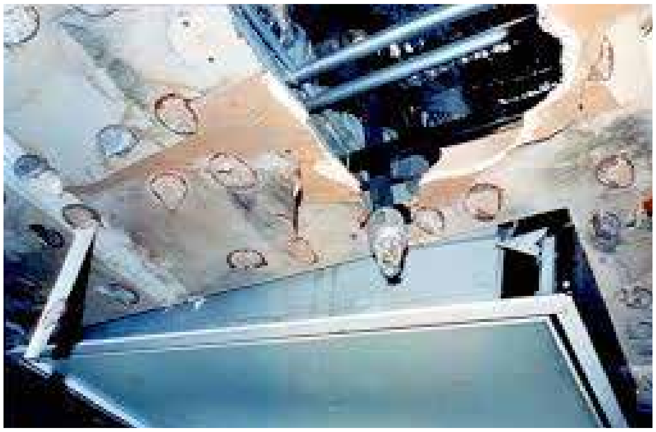

Figure 79. A hospital in Sylmar, California only suffered minor structural damage from the 1994 Northridge earthquake. However, a broken sprinkler pipe caused water damaged to the hospital. This type of damage can force hospitals to temporally shut down. At another facility, a damaged water tank on the roof leakd up to two feet of water at some locations. Photo: FEMA.

Figure 80. In the 1994 Northridge earthquake high damage to hospitals and medical facilities limited medical response to injured survivors and patients with on-going medical needs. Photo: M. Celebi, USGS.

In addition to structural and nonstructural damage, some hospitals may have to contend with the loss of essential utilities such as power, water, sewer, and medical supplies.

In coastal areas, ground transportation damage may prevent survivors from reaching clinics and hospitals. It may also make it challenging for essential medical personnel – doctors, specialists, and nurses – to report to work.

Because of these damages and associated challenges, as many as 24,000 hospital patients may require evacuation from the impacted areas of Washington and Oregon.

Hospitals in large urban areas and communities east of the coastal mountains may be heavily affected by a surge of injured and dying survivors. For hospitals within 250 miles of the highly impacted coastal zones, this surge may be so great as to overwhelm their capacity for regular inpatient care. As a result, as many as 20 hospitals on the coast and 100 in the I-5 corridor may require augmentation.

WASHINGTON: HOSPITALS

In Washington, over one-quarter of hospitals may suffer structural and nonstructural damage severe enough as to require the evacuation of patients (see Table 33). Several of these hospitals may collapse or may be in imminent danger of collapse. On the high range of estimates, as many as 15,000 hospital patients may require evacuation from these hospitals.

Most of the hospital evacuation needs will likely be in the I-5 corridor, where as many as 10,000 patients may need to be relocated to other hospitals outside of the impacted region. At the same time, roughly one-quarter of hospitals in the I-5 corridor may suffer damage significant enough to force the hospital to operate at limited capacity.

In coastal areas, close to half of the hospitals may suffer high damage, requiring the evacuation of as many as 500 hospital patients. Other coastal hospitals may be forced to operate at limited capacity. However, ground transportation damage may make it difficult or even impossible for survivors to reach functioning hospitals.

Roughly 40 percent of the hospitals in Washington may only suffer minor damage and remain operational. These hospitals may be capable of caring for their own patients. However, the increased demand for medical treatment coupled with the loss of capacity from other damaged hospitals may overwhelm their capacity for regular patient care. Dozens of hospitals may require augmentation. The location of Washington hospitals, in relation to shaking intensity, is provided in Figures 81-83.

Table 33. Distribution of damage states for Washington hospitals, by areas of operation

	Damage State			
Area of Operation	**None**	**Low**	**Medium**	**High**
Coastal	0%	7%	43%	50%
I-5 corridor	7%	42%	28%	24%
East	100%	0%	0%	0%
Summary of damage description	Hospital is fully functional.	Hospital is structurally sound and able to be occupied, though damage to interior contents may make immediate use more difficult.	Hospital is extensively damaged and operating at limited capacity. Partial evacuation may be required.	Hospital is severely damaged. Full evacuation may be required.

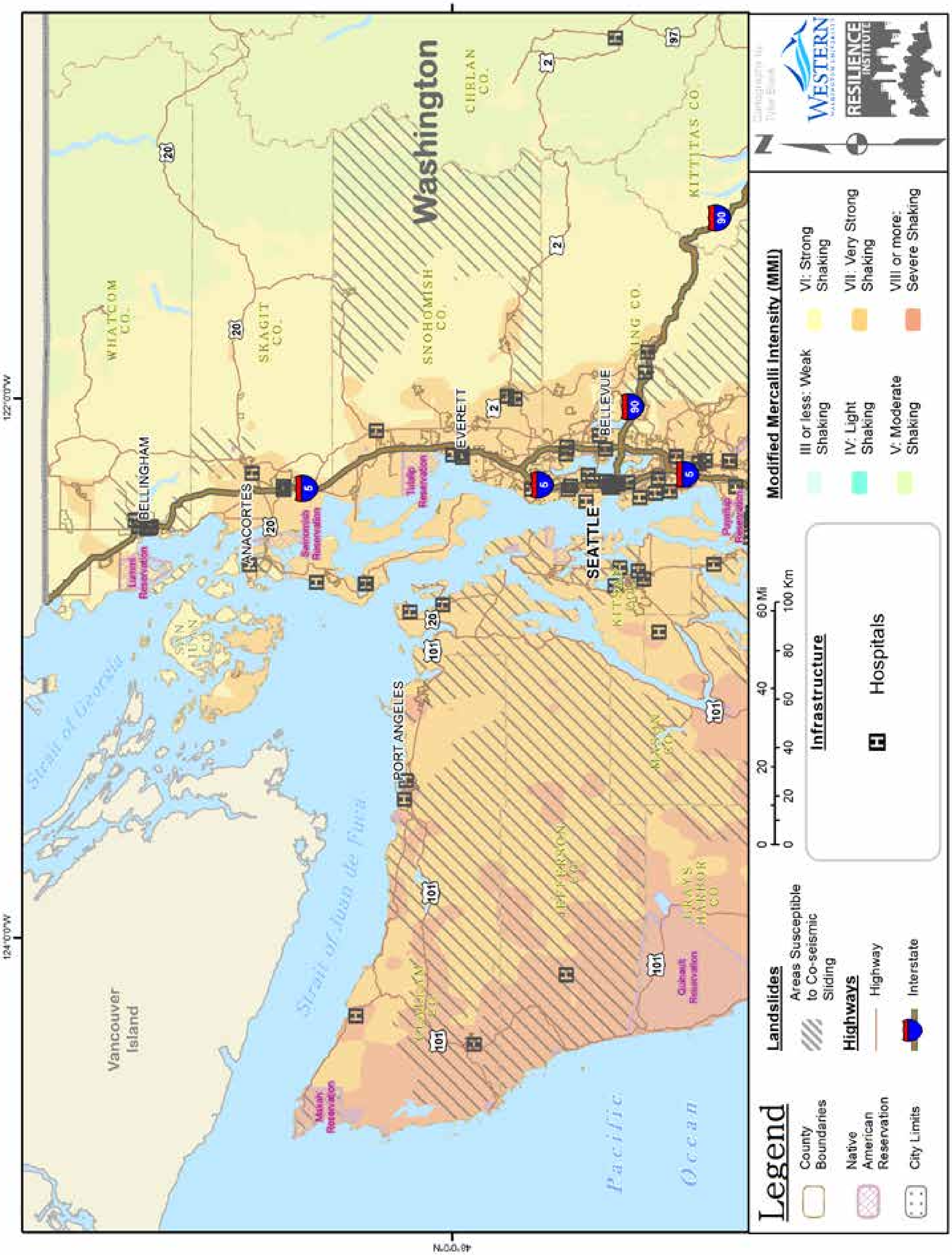

Figure 81. Location of hospitals in Northern Washington in relation to shaking intensity and landslide potential

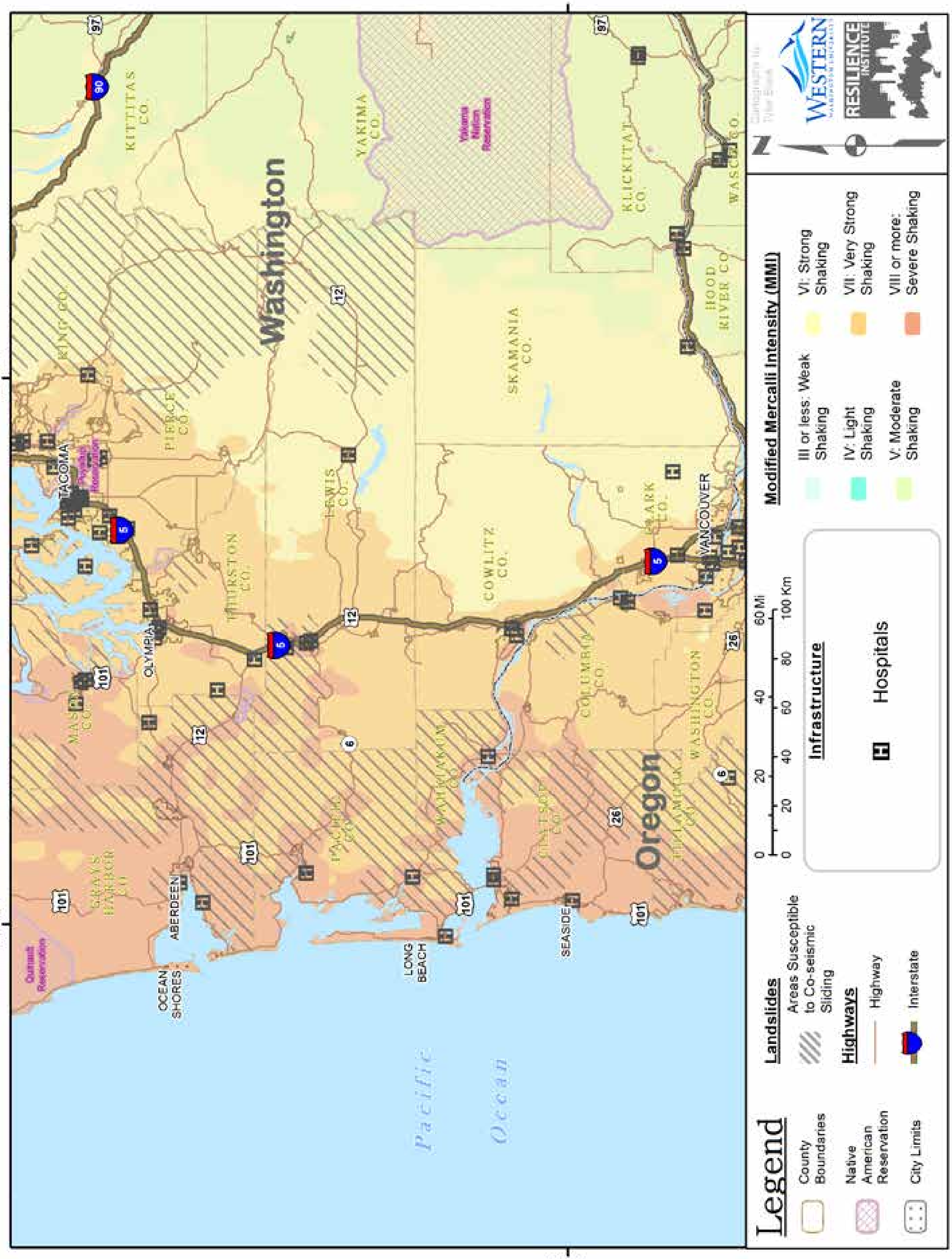

Figure 82. Location of hospitals in Southern Washington in relation to shaking intensity and landslide potential

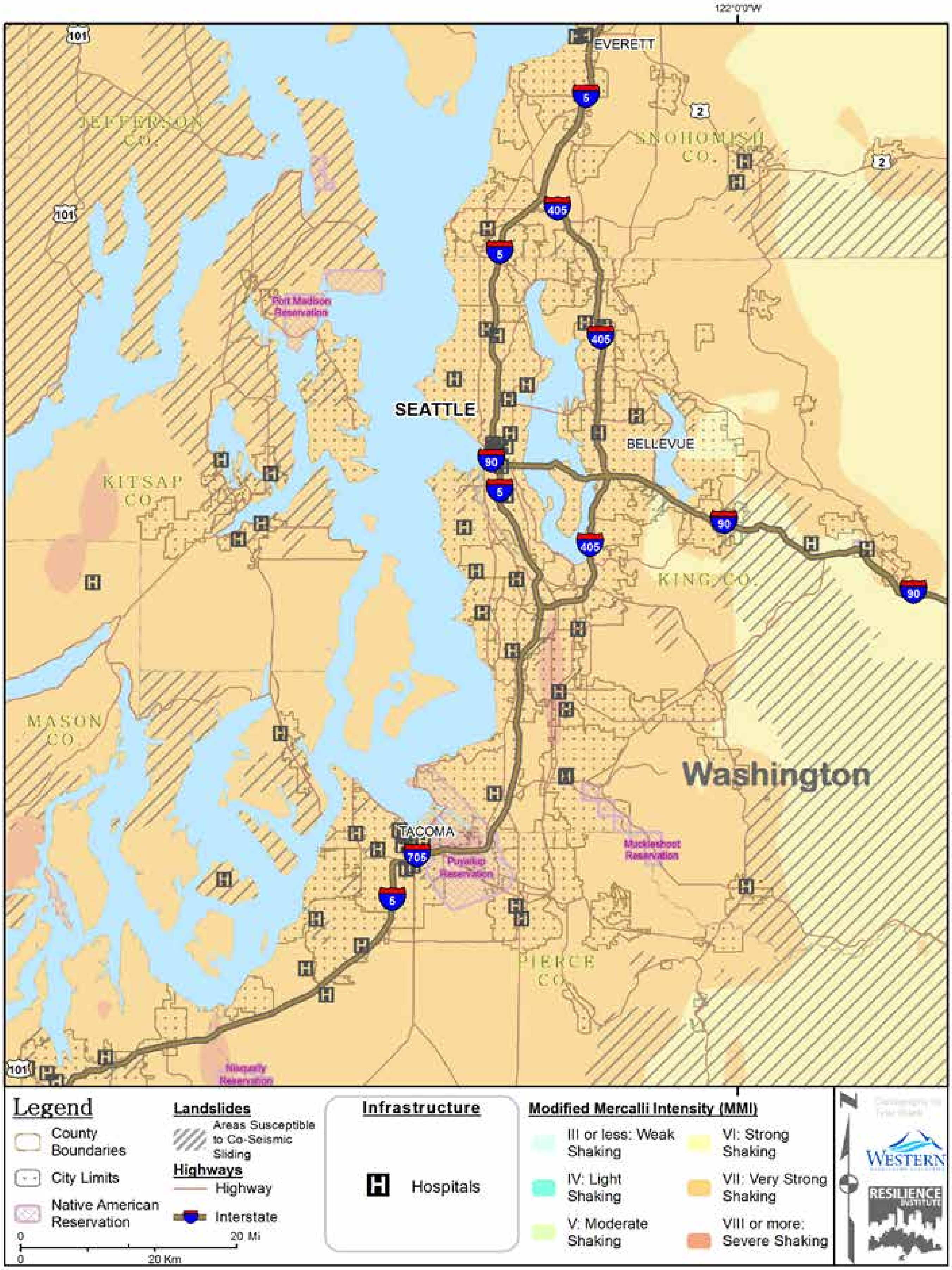

Figure 83. Seattle-Tacoma metro region hospitals in relation to shaking intensity and landslide potential

OREGON: HOSPITALS

In Oregon, over half of the hospitals in the impacted area may suffer structural damage severe enough to require immediate evacuation. Some of these hospitals may collapse or may be in imminent danger of collapse. On the high range of estimates, as many as 9,000 hospital patients may require evacuation from these hospitals.

Most of the hospital evacuation need is in the I-5 corridor where as many as 7,000 patients may need to be relocated to other hospitals. At the same time, roughly half of hospitals in the I-5 corridor may suffer damage significant enough to force the hospital to operate at limited capacity.

As shown in Table 34, 96 percent of hospitals in the coastal corridor may suffer high damage, requiring the evacuation of as many as 600 hospital patients. Due to ground transportation damage, these patients may need to be evacuated via water or air transport.

A few hospitals may suffer only minor damage and remain operational. These hospitals may be capable of caring for their own patients. However, the increased demand for medical treatment coupled with the loss of capacity from other damaged hospitals may overwhelm their capacity for regular patient care. Dozens of hospitals may require augmentation. Figures 84-86 plots the location of hospitals in Oregon.

Table 34. Distribution of damage states for Oregon hospitals, by areas of operation

	Damage State			
Area of Operation	**None**	**Low**	**Medium**	**High**
Coastal	0%	0%	4%	96%
I-5 corridor	13%	27%	2%	58%
East	100%	0%	0%	0%
Summary of damage description	Hospital is fully functional.	Hospital is structurally sound and able to be occupied, though damage to interior contents may make immediate use more difficult.	Hospital is extensively damaged and operating at limited capacity. Partial evacuation may be required.	Hospital is severely damaged. Full evacuation may be required.

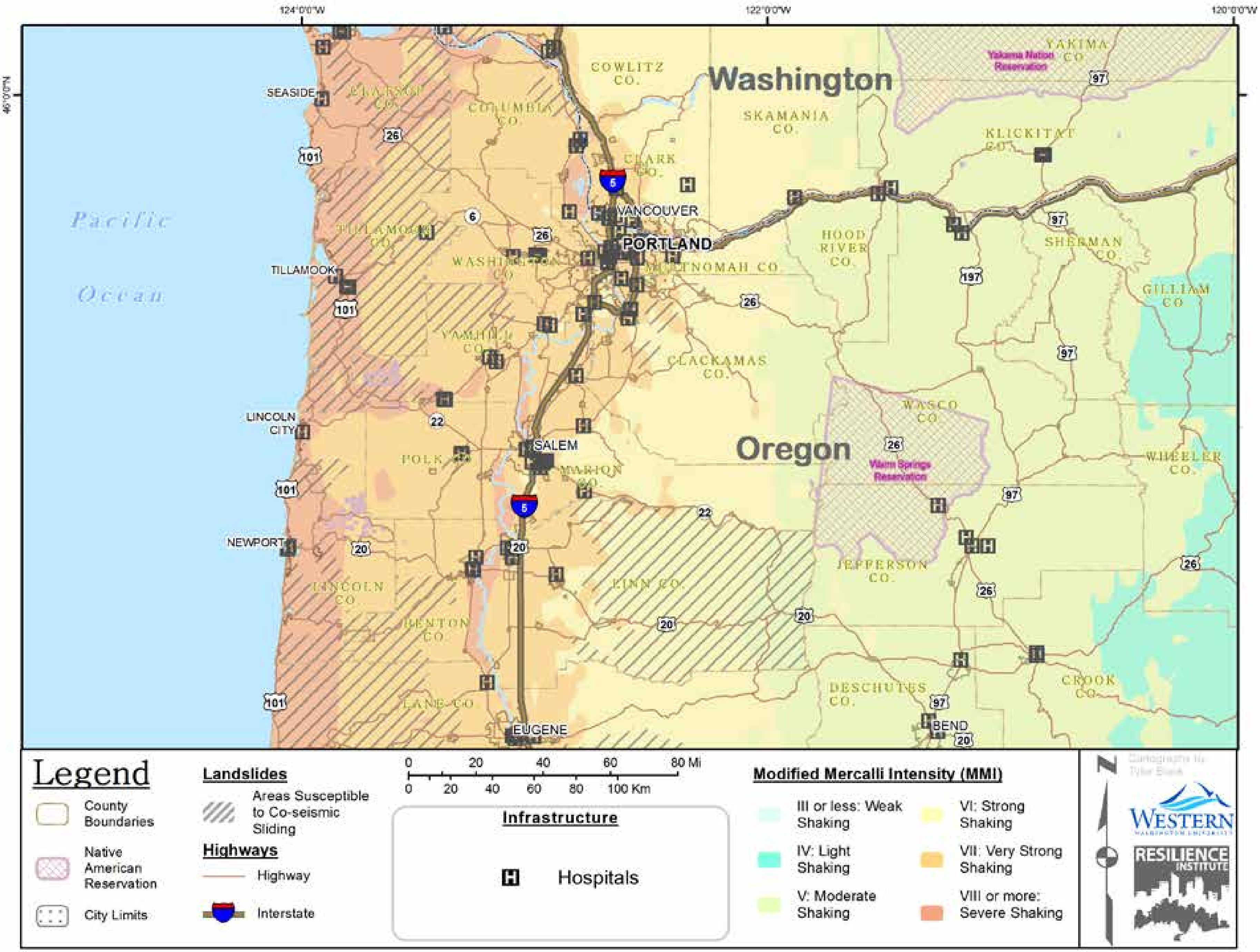

Figure 84. North Oregon hospitals in relation to shaking intensity and landslide potential

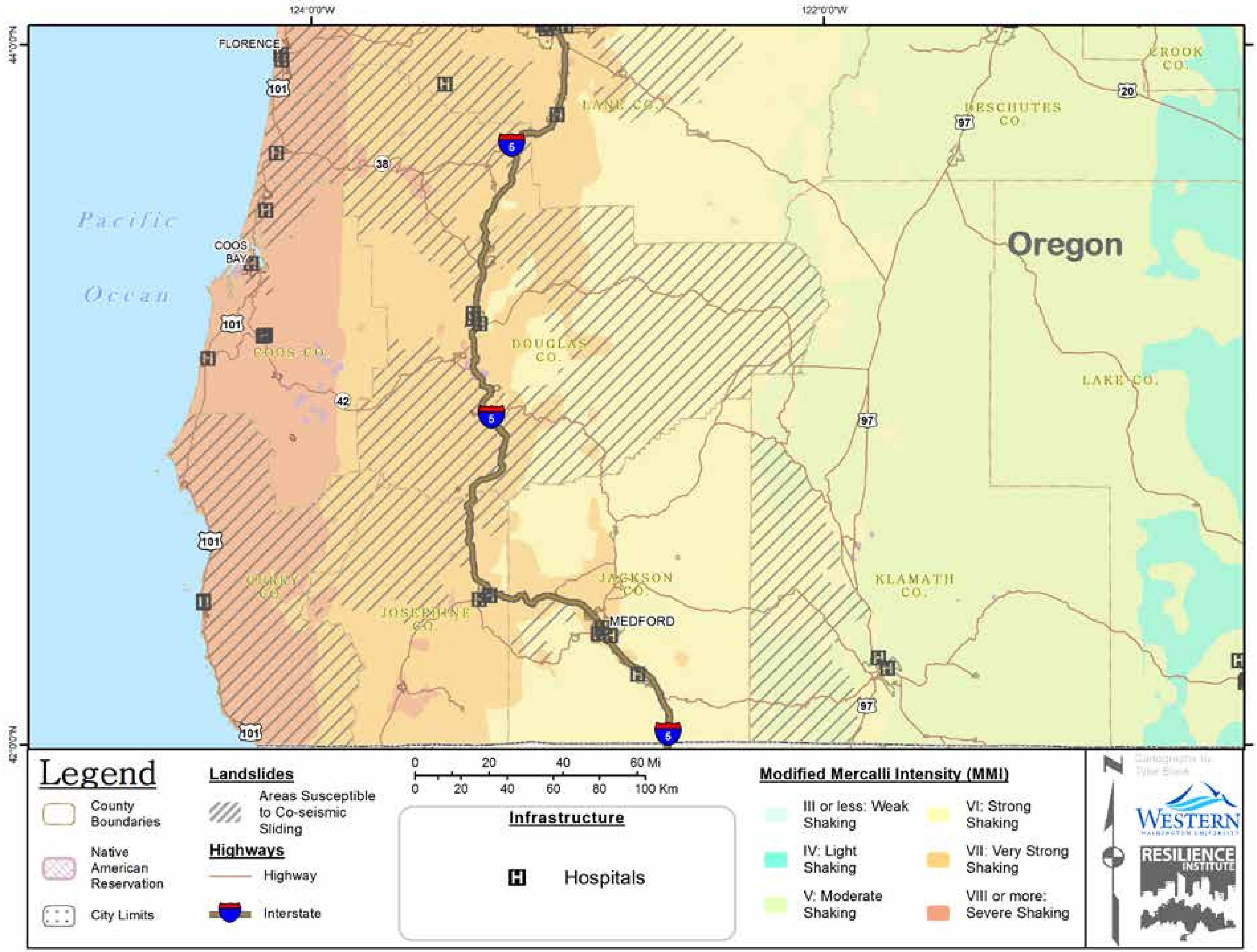

Figure 85. South Oregon hospitals in relation to shaking intensity and landslide potential

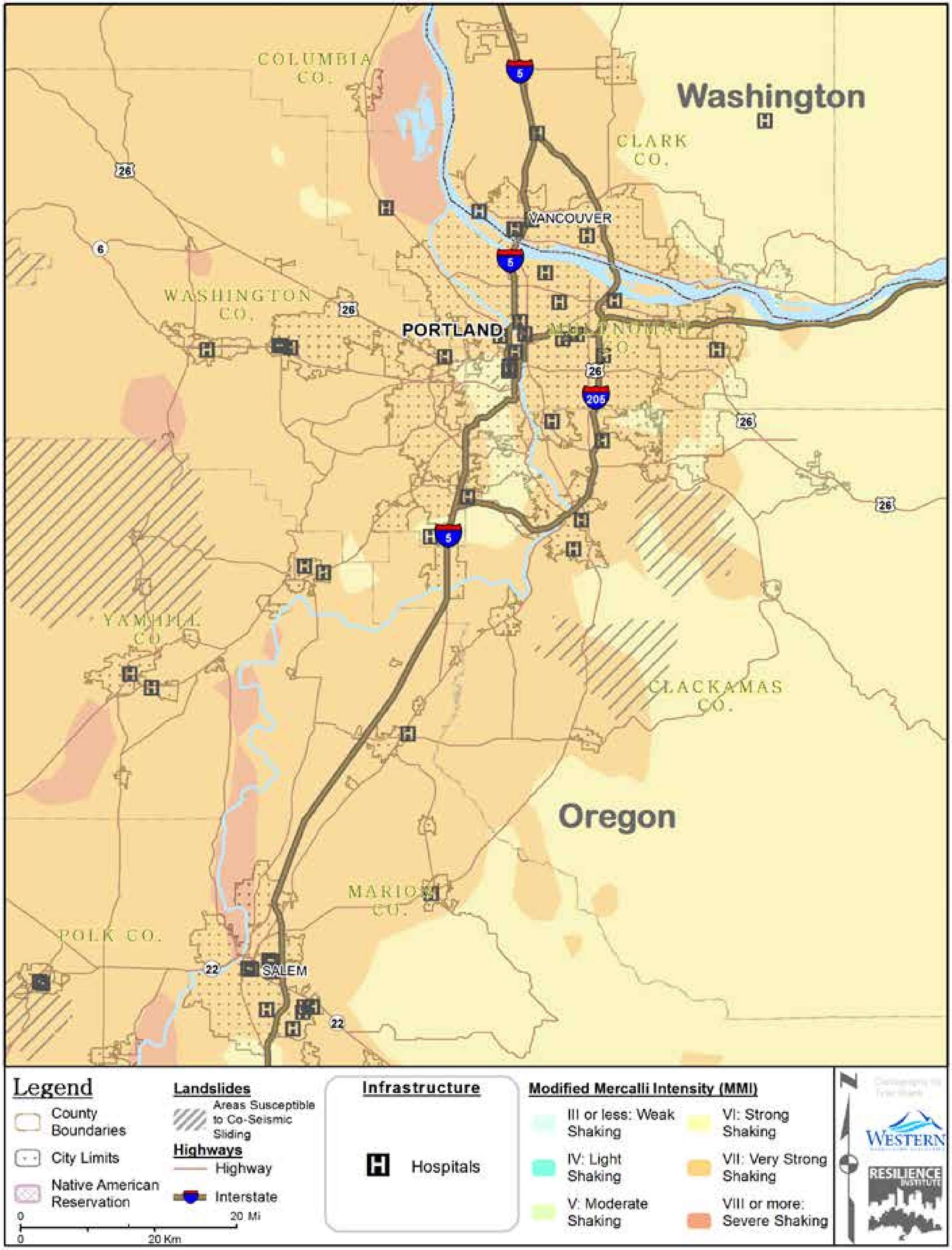

Figure 86. Portland metro region hospitals in relation to shaking intensity and landslide potential

SCHOOLS

The impacted area of Washington and Oregon contains over 5,000 schools and shelters listed in the National Shelter System (NSS) database. School types include: public and private K-12, college or university, and professional trade school. Following the earthquake and tsunami, many schools of these may be needed by local communities to serve as triage centers, distribution points for emergency supplies, and emergency shelters, especially those that have the capacity to hold a large number of people. However, many schools may not be immediately functional after the earthquake. Roughly two-thirds of the schools in the impacted area may suffer medium to high damage, rendering them immediately unavailable for sheltering. Table 35 provides descriptions of each damage state for school buidlings. Schools and campuses with the greatest level of damage may be older buildings or those located on poor soils that are susceptible to liquefaction.

In the aftermath of the earthquake, schools may struggle to meet their immediate obligations of sheltering and connecting children with their parents. Both the season and the time of day during which the earthquake and tsunami strike will have profound implications for the region's children. Events that strike during school hours occur while families are separated. School staff may be charged with keeping large numbers of scared students safe while parents struggle to reunite with their children. These attempts at reunification may extend well beyond school hours, especially for students whose parents or guardians have been injured or who need to travel on degraded transportation networks. Some parents may never arrive and social services will need to search for relatives and temporary homes for these students. Where school buildings are vulnerable to seismic shaking or tsunami inundation, or where staff have not ensured that heavy shelving, signage, and equipment are properly secured, students and staff may be injured in the event, and staff may need to respond to these injuries with the supplies and knowledge that they have at hand. Were the event to happen as students are being bussed to or from school, reunification may be complicated by parent confusion, damaged transportation infrastructure, and high child-to-adult ratios on most buses.

Figure 87. Following the 2011 M9.2 Tohoku earthquake classrooms like this one at Ando Elementary School were used as evacuation shelters. Functional school facilities can be utilized as temporary shelters for those displaced by the earthquake. Photo: Kiyoshi Ota, Getty Images.

Figure 88. The 2010 Baja California M7.2 earthquake caused extensive damage to Jefferson Elementary School in Calexico, California, such that the school was closed for the remainder of the semester. Interior damage and fallen items could injure or kill students and faculty. Photo: Kelly B. Hutson.

SCHOOLS (CONT.)

Table 35. Description of school building damage for each damage state

	Damage State			
Area of Operation	**None**	**Low**	**Medium**	**High**
Damage state description	School is fully functional.	School building suffers limited damage and can be immediately occupied. However, damage to interior contents, loss of power, damaged utilities, etc. impact usability.	School building suffers damages that make immediate occupancy unlikely. Shoring up of damaged structural elements and other more costly and time-consuming repairs likely needed before the school can be occupied again.	School building suffers extensive damages, which may include partial or full collapse. Immediate occupancy is impossible. Repairs will be extensive. Many buildings need to be demolished and rebuilt.

Universities, community colleges, and vocational/trade schools present many unique emergency response challenges after a major earthquake.

Schools with on-campus housing will need to consider the reunification and mass care needs of their resident population. All students, including those living off campus, may need assistance contacting their parents or guardians and making temporary living arrangements. It is unlikely that international students will be able to return to their home countries immediately and will require temporary living accommodations alongside students with domestic origins.

Many of the Region's universities and colleges have large residence halls and other on-campus facilities (e.g. sporting venues, cafeterias, auditoriums, etc.) that could prove useful to broader community mass care efforts. Schools will need to balance requests to utilize these assets with their duty to care for their student, faculty, and staff populations.

WASHINGTON: SCHOOLS

As shown in Table 36, half of the school buildings in the I-5 corridor may suffer no to low structural damage and may be immediately occupied. However, damage to interior contents, loss of power, and damaged utilities may impact usability. Most of these schools may need inspection and repair, but should be usable within a short time.

Schools south of Tacoma and on the coast may be particularly hard hit; nearly all may suffer medium to high damage. Many of these school may require extensive repair before they can be occupied and some may suffer unrepairable damage and may need to be demolished and rebuilt.

Within minutes of the earthquake, the resulting tsunami may send waves of water and debris that inundate several schools along the coast. In the heavily impacted coastal zones, it may take over a year for schools to be fully repaired or rebuilt and for students to return to traditional classroom settings. In less impacted areas, the recovery may take months, or less. The loss of these facilities will likely cause a high level of distress in the affected communities. Figures 89-91 show the location of schools in Washington.

Table 36. Distribution of damage states for Washington schools, by areas of operation

	Damage State			
Area of Operation	**None**	**Low**	**Medium**	**High**
Coastal	0%	3%	22%	75%
I-5 corridor	3%	47%	31%	19%
East	89%	11%	0%	0%
Summary of damage description	School is fully functional.	School building suffers limited damage and can be immediately occupied. However, damage to interior contents, loss of power, damaged utilities, etc. impact usability.	School building suffers damages that make immediate occupancy unlikely. Shoring up of damaged structural elements and other more costly and time-consuming repairs likely needed before the school can be occupied again.	School building suffers extensive damages, which may include partial or full collapse. Immediate occupancy is impossible. Repairs will be extensive. Many buildings need to be demolished and rebuilt.

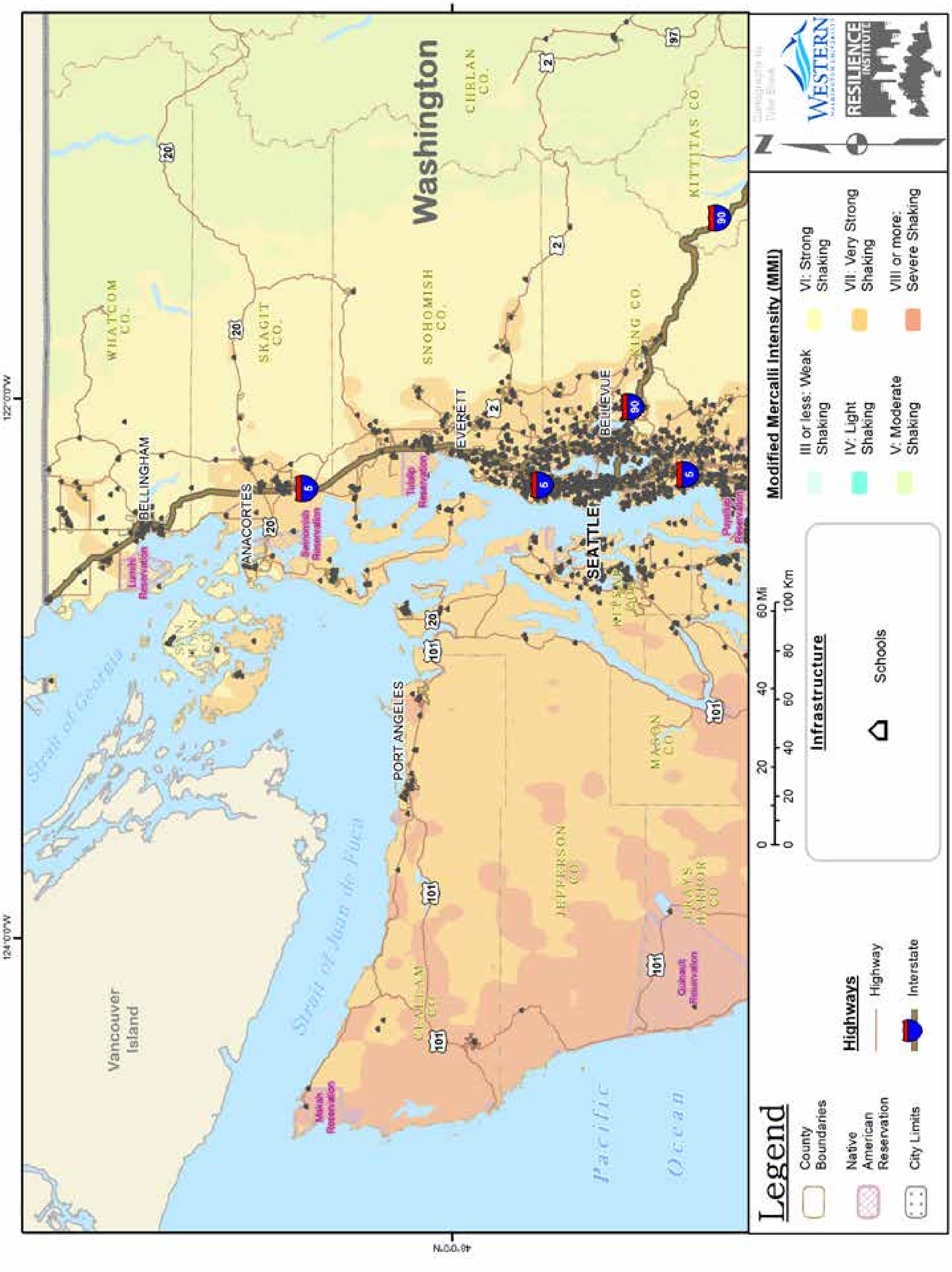

Figure 89. North Washington schools in relation to shaking intensity

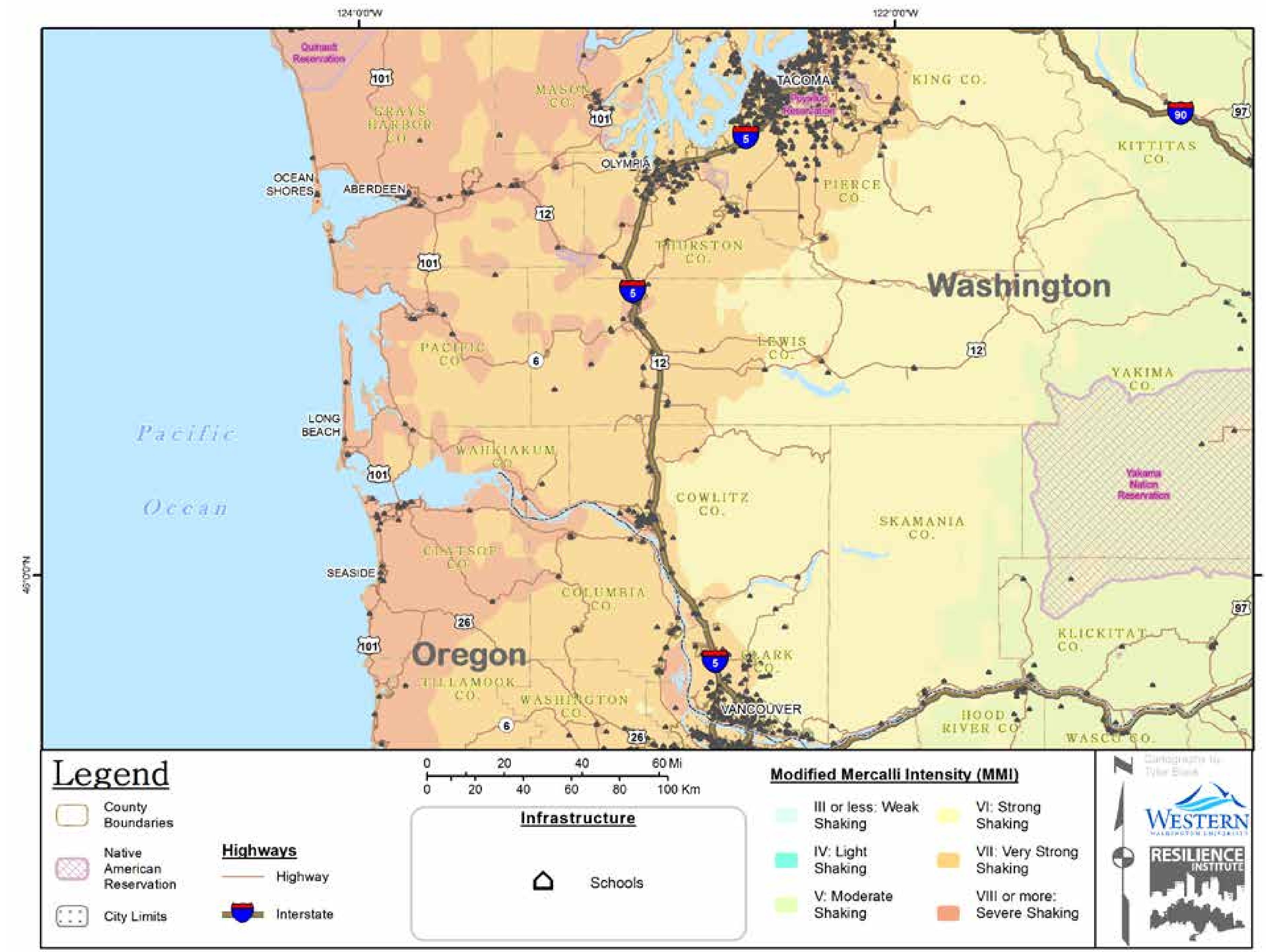

Figure 90. South Washington schools in relation to shaking intensity

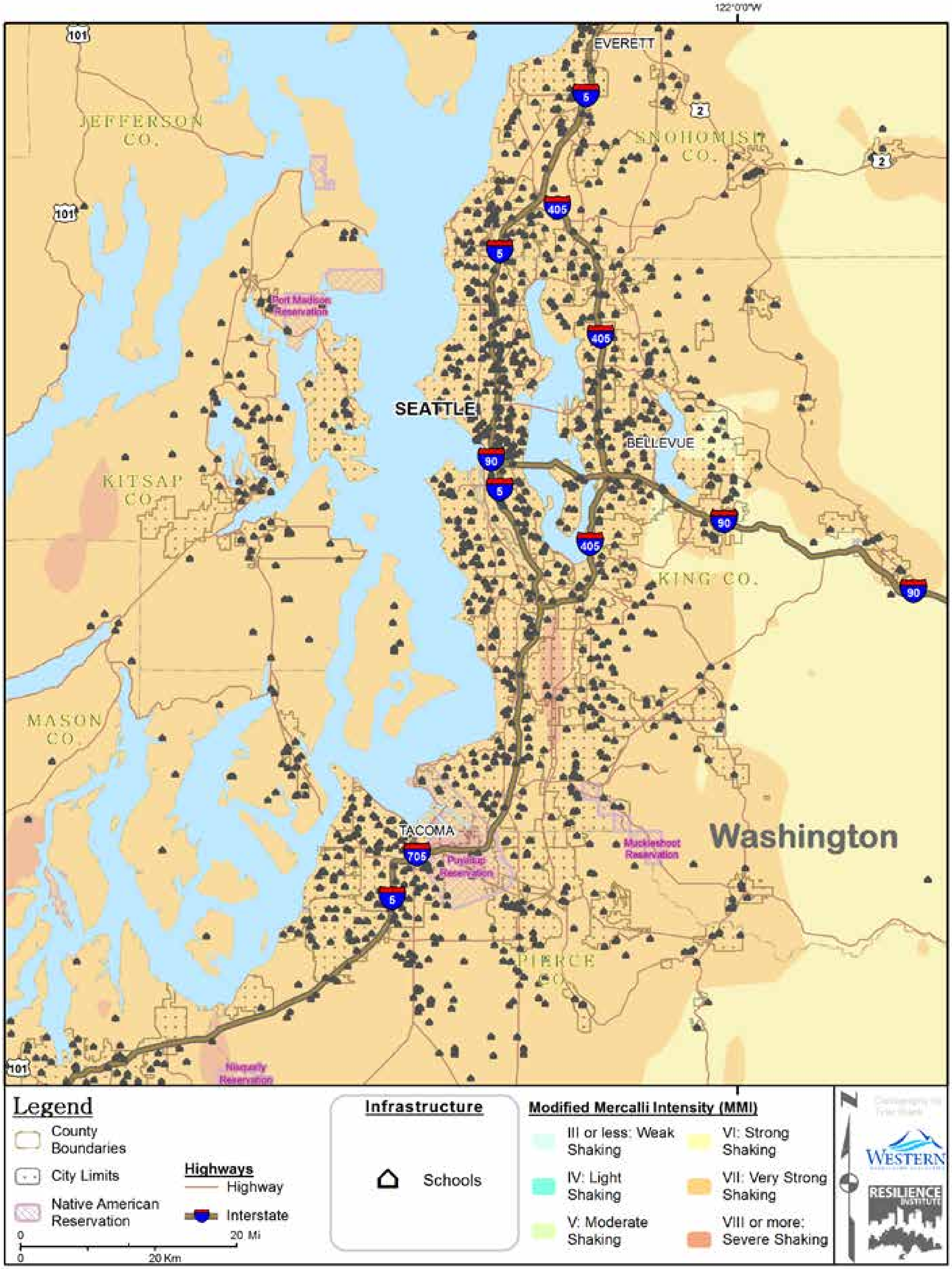

Figure 91. Seattle-Tacoma metro schools in relation to shaking intensity

OREGON: SCHOOLS

As shown in Table 37, nearly all schools in the I-5 corridor and coastal region may suffer medium to high damage and may require extensive repair before the schools may be occupied again. Schools on the coast may be particularly hard hit; nearly all may suffer high damage. Many of these school may require extensive repair before they can be occupied and some may suffer unrepairable damage and may need to be demolished and rebuilt.

Within minutes of the earthquake, the resulting tsunami may send waves of water and debris that inundate several schools along the coast. In the heavily impacted coastal zones, it may take over a year for schools to be fully repaired or rebuilt and for students to return to traditional classroom settings. In less impacted areas, the recovery may take months, or less. The loss of these facilities will likely cause a high level of distress in the affected communities. Figures 92-94 show the location of schools in Oregon.

Table 37. Distribution of damage states for Oregon schools, by areas of operation

	Damage State			
Area of Operation	**None**	**Low**	**Medium**	**High**
Coastal	0%	0%	1%	99%
I-5 corridor	0%	2%	47%	51%
East	92%	8%	0%	0%
Summary of damage description	School is fully functional.	School building suffers limited damage and can be immediately occupied. However, damage to interior contents, loss of power, broken utilities, etc. may impact usability.	School building suffers damages that make immediate occupancy unlikely. Shoring up of damaged structural elements and other more costly and time-consuming repairs likely needed before the school can be occupied again.	School building suffers extensive damages, which may include partial or full collapse. Immediate occupancy is impossible. Repairs will be extensive. Many buildings need to be demolished and rebuilt.

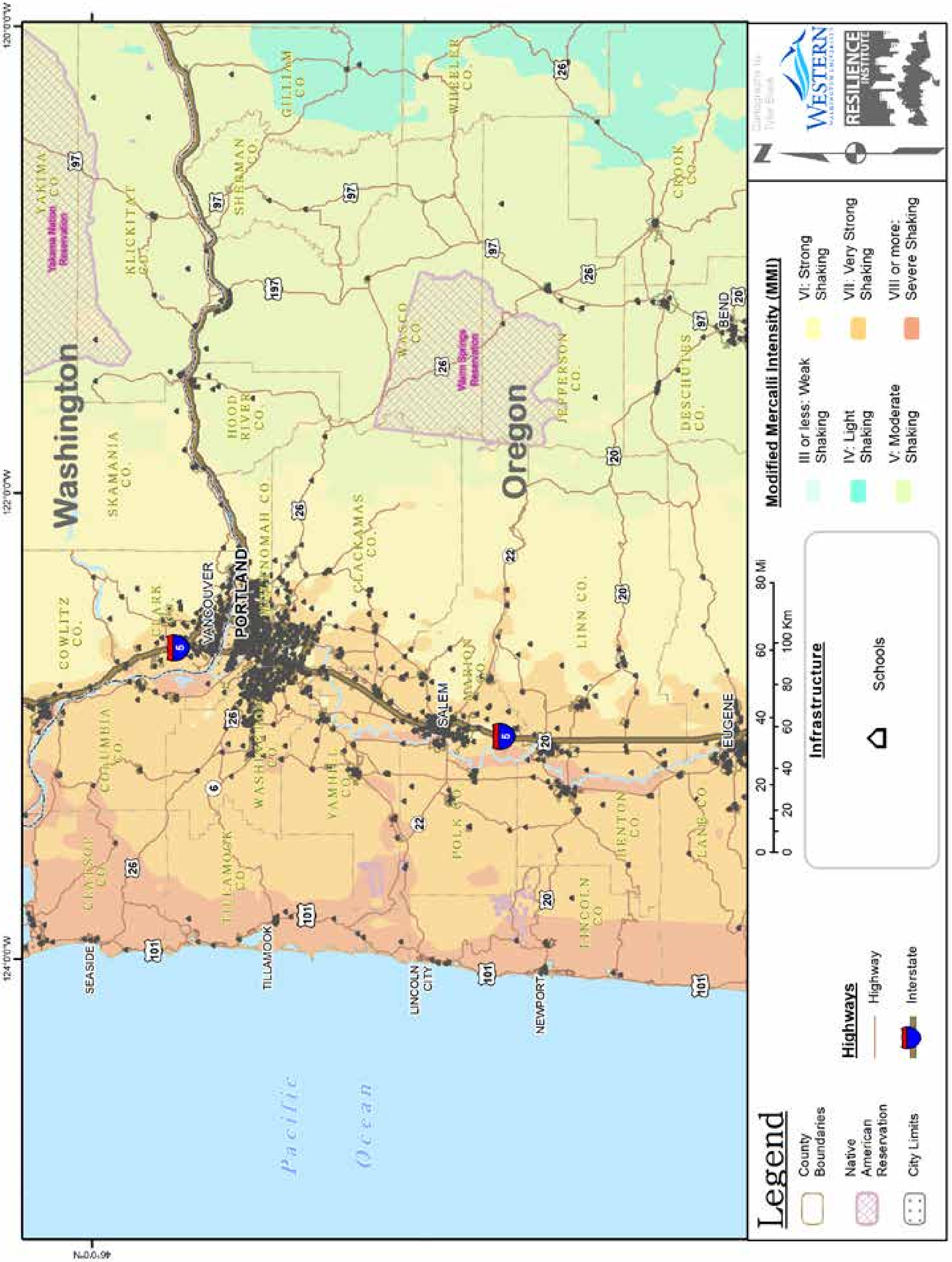

Figure 92. North and south Oregon schools in relation to shaking intensity

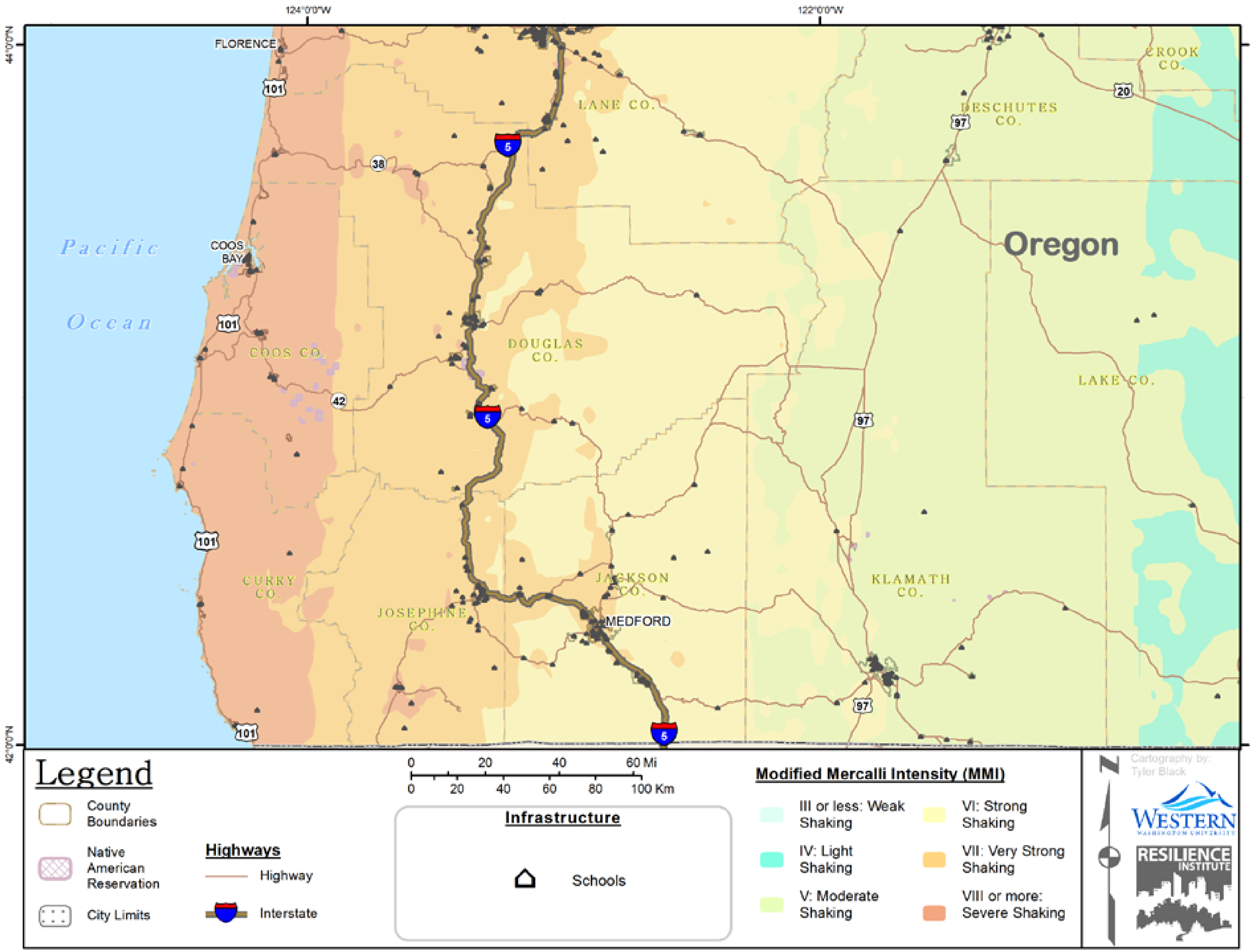

Figure 93. North and south Oregon schools in relation to shaking intensity

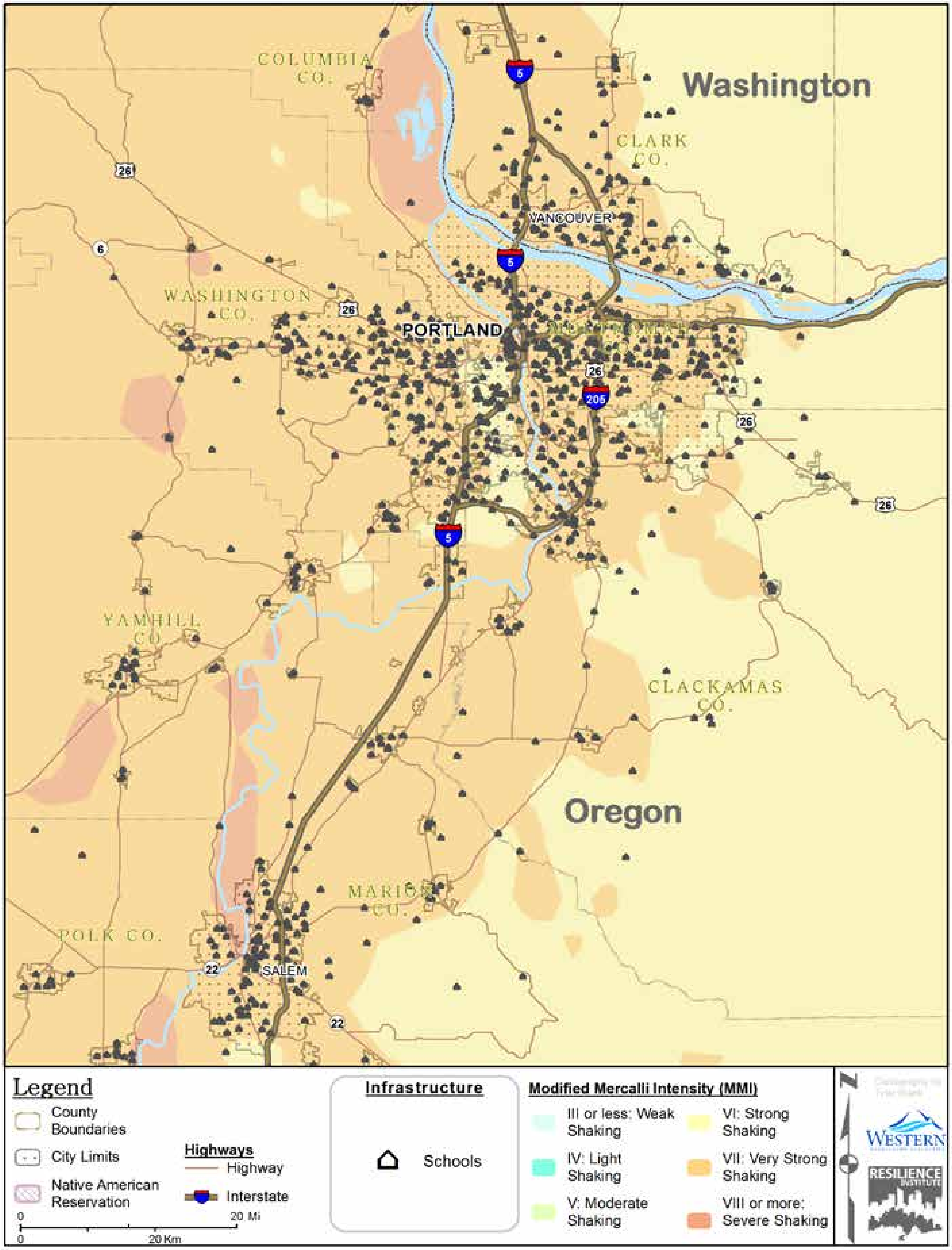

Figure 94. Portland metro region schools in relation to shaking intensity

WATER AND WASTE WATERTREATMENT FACILITIES

Definition: The water and wastewater infrastructure includes the potable water storage and delivery system and the collection and conveyance of wastewater effluent to sewage treatment plants within a community

The region's water and wastewater systems – its system of pipelines, treatment plants, and pumping stations – stretch across large areas. Many pipelines stretch across soils that may liquefy during an earthquake; treatment plants are often also necessarily situated on river banks and coastlines where soils are weak and liquefiable.

Following a Cascadia Subduction Zone earthquake and tsunami, the region's access to potable water may be drastically reduced. During the earthquake, old concrete and cast iron pipes buried in liquefied soil may crack or break and modern PVC pipelines may pull apart at joints. In either situation, the damage may result in a total loss of water pressure at homes, businesses, hospitals, and other facilities.

Of the potable water facilities in Washington and Oregon, 88 percent may sustain medium to high damage. These damage states are described in Table 38. Water distribution pipes for fighting fires may be equally damaged. Broken fuel lines and fallen power lines may ignite hundreds of fires across the region, yet fire hydrants may not have the water or water pressure needed to fight fires.

Potable water may be unavailable for weeks to months in coastal areas, and with damage to transportation networks, delivering water to isolated coastal communities may be challenging. With breakages across the region, water may not be completely restored for several months, and possibly years.

Damage to wastewater systems may have even greater impacts on communities. Concrete and PVC pipes carrying waste water to treatment plants may crack or pull apart, flooding streets with raw sewage and backing it up into home toilets. Damage to equipment and pipe connections or a loss of power pumping stations may have similar impacts.

Of the wastewater facilities in Washington and Oregon, 77 percent may suffer medium to high damage. This damage may be severe enough to shutdown wastewater treatment plants and lift-stations for a week or longer. Facilities suffering high damage may be irreparable.

WATER AND WASTEWATER TREATMENT FACILITIES (CONT.)

Table 38. Description of water and wastewater facility damage for each damage state

	Damage state		
Infrastructure Component	Low	Medium	High
Water and wastewater treatment plant **Damage state description**	Loss of electric power and backup power, resulting in temporary malfunction for less than three days. Sedimentation basins, chlorination tanks, or chemical tanks may suffer slight damage. Loss of water quality may occur.	Loss of electric power and backup power, resulting in malfunction for about a week. Extensive damage to various equipment, considerable damage to sedimentation basins, considerable damage to chlorination tanks with no loss of contents, or considerable damage to chemical tanks. Loss of water quality is imminent. Damaged pipes connecting to basins and chemical units, which may result in a shutdown of the plant.	Complete failure of pipings, or extensive damage to the filter gallery.
Lift-stations and pumping plants	Slight building damage or loss of electric power and back-up power for a short time (less than three days).	Considerable damage to mechanical and electrical equipment, moderate to extensive building damage, or the loss of electric power for about a week. Damage to pumps may be beyond repair.	Pumping plant building collapse.
Water storage tanks	Minor damage to the tank roof due to water sloshing, minor cracks in concrete tanks, or localized wrinkles in steel tanks.	Considerable to severe damage to tanks, resulting in loss of content. In some cases, tanks may go out of service.beyond repair.	Storage tank collapse and loss of contents.

WATER AND WASTEWATER TREATMENT FACILITIES (CONT.)

At waterfront treatment facilities, earthquake shaking may cause facilities to shift towards water banks and sever connecting pipes. Breaks in main trunk lines will affect larger regions than failures in pipes or pumping stations in upper sections of the sewer system.

When wastewater treatment plants fail, raw sewage may discharge into nearby lakes and rivers. Rivers may quickly become polluted with untreated sewage, contaminating drinking sources and spreading waterborne disease. These failures may further impact community health and safety if healthcare facilities have to operate with limited water.

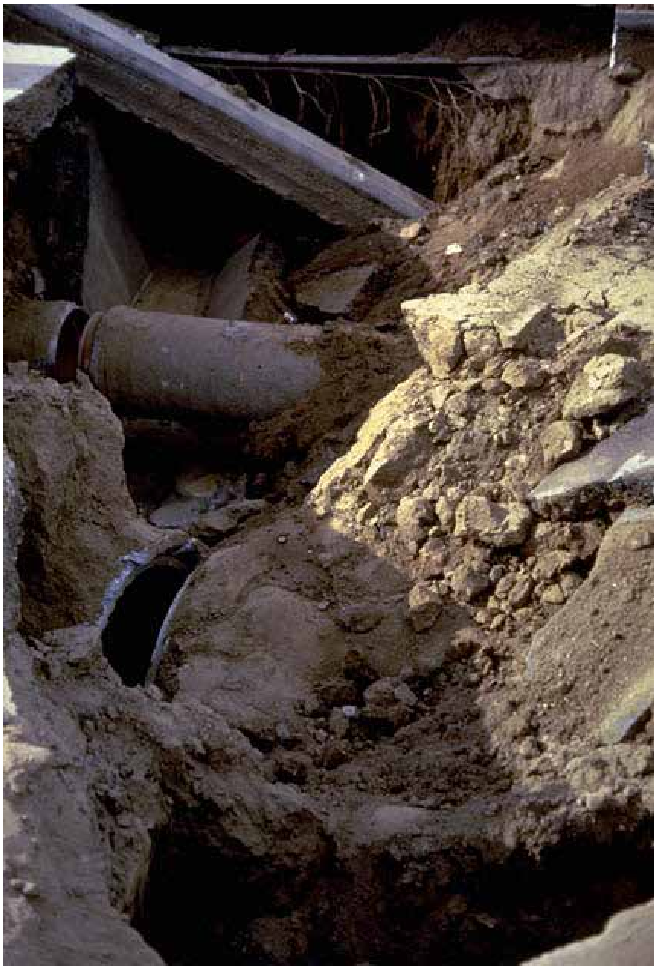

Figure 95. Pipes carrying potable water may be damaged or contaminated, leaving many survivors without a critical resource. Breaks in wastewater pipes can confound this issue, causing sewage backup into streets, plumbing, and other damaged pipe infrastructure. Photo: Vitelmo V. Bertero.

WASHINGTON: WATER AND WASTEWATER TREATMENT

Washington's water and wastewater systems may be severely disrupted in the aftermath of the earthquake. Much of the potable water systems in the Seattle-Tacoma metropolitan region may suffer medium damage, including widespread breaks and leaks. Where service is available, however, cracked pipelines may result in contaminated water supply.

The most substantial damage to potable water systems may be on the coast and in the coastal mountain chain, where the shaking is most intense. As shown in Table 39, all of the potable water facilities in the coastal region may suffer medium to high damage and may be unavailable until major repairs are made. Delivering repair materials and drinking water to coastal communities, isolated due to road damage, may be a challenge. It may be several weeks to half a year before coastal communities have access to potable water systems.

Most of the wastewater infrastructure in the impacted area of Washington may suffer some level of damage. Widespread sewage release and sewer-line backups may result in a shutdown of the system until repairs are completed. Restoration timelines could be three weeks to seven months, with the greatest damage and longest restoration times near the coastline. Complete restoration of some damaged wastewater systems could take several years. Figures 96 and 97 show the location of water and wastewater facilities in Washington.

WASHINGTON: WATER AND WASTEWATER TREATMENT (CONT.)

Table 39. Distribution of damage states for Washington state potable water and wastewater facilities, by areas of operation

	Damage State			
Area of Operation	**None**	**Low**	**Medium**	**High**
		Wastewater Facilities		
Coastal	0%	0%	44%	56%
I-5 corridor	0%	12%	576%	12%
East	21%	79%	0%	0%
		Potable Water Facilities		
Coastal	0%	0%	67%	33%
I-5 corridor	0%	11%	86%	3%
East	0%	100%	0%	0%
Summary of damage description	No structural damage to water and wastewater treatment plant, lift-stations, pumping plants and water storage tanks.	Loss of electric power and backup power, resulting in temporary malfunction for less than three days. Loss of water quality may occur. Minor water storage tank damage without loss of functionality.	Loss of electric power and backup power, resulting in malfunction for about a week. Loss of water quality is likely. Damaged pipes connecting to basins and chemical units, which may result in a shutdown of treatment plant. Damage to pumps and lift-stations may be beyond repair. Considerable to severe damage to water storage tanks, resulting in loss of content.	Complete failure of pipings, or extensive damage to the filter gallery at treatment plant. Pumping plant or lift-station building collapse. Water storage tank collapse and loss all of content.

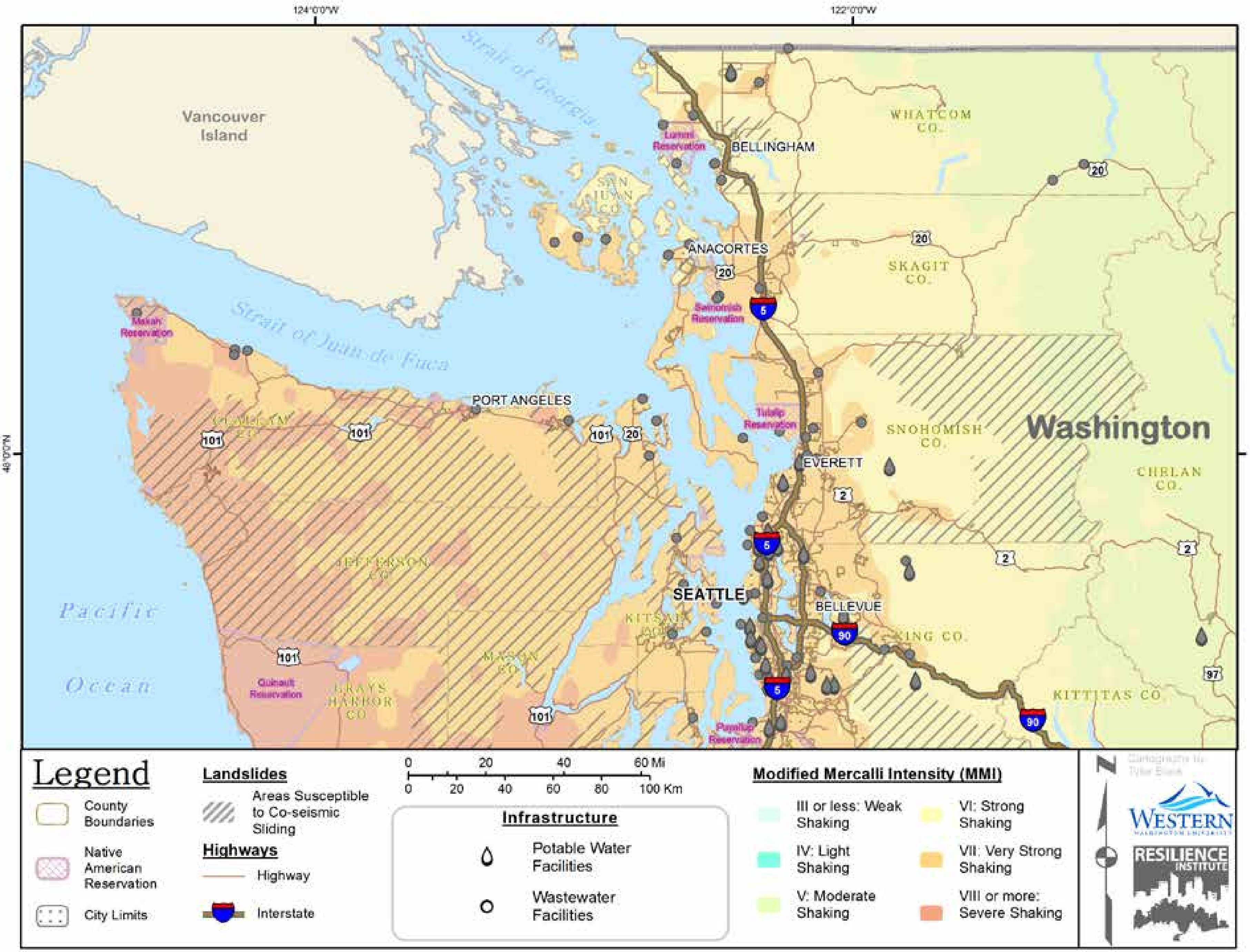

Figure 96. North Washington potable water facilities and wastewater facilities in relation to shaking intensity and landslide potential

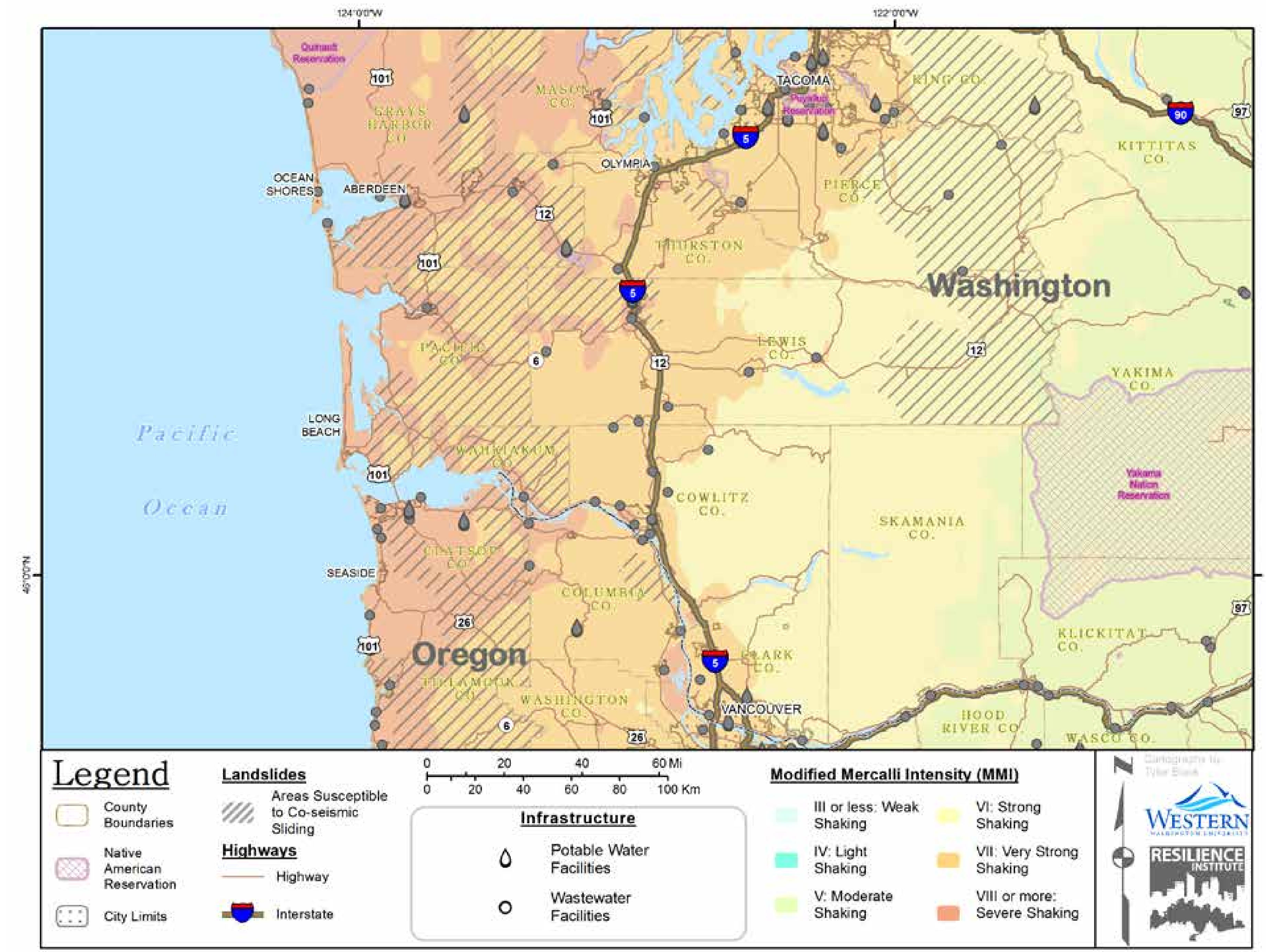

Figure 97. South Washington potable water facilities and wastewater facilities in relation to shaking intensity and landslide potential

OREGON: WATER AND WASTEWATER TREATMENT

Oregon's water and wastewater systems may be severely disrupted in the aftermath of the earthquake. Much of the potable water systems in the Portland metropolitan region may suffer medium damage, including widespread breaks and leaks. Where service is available, cracked pipelines may result in contaminated water supply.

The most substantial damage to potable water systems may be on the coast and in the coastal mountain chain, where the shaking is most intense. As shown in Table 40, all of the potable water facilities in the coastal region may suffer medium to high damage and may be unavailable until major repairs are made. Delivering repair materials and drinking water to coastal communities, isolated due to road damage, may be a challenge. It may be several weeks to half a year before coastal communities have access to potable water systems.

Most of the wastewater infrastructure in the impacted area of Oregon may suffer some level of damage. Widespread sewage release and sewer-line backups may result in a shutdown of the system until repairs are completed. Restoration timelines could be three weeks to seven months, with the greatest damage and longest restoration times near the coastline. Complete restoration of some damaged wastewater systems could take several years. Figure 98 and 99 show the location of water and wastewater facilites in Oregon.

OREGON: WATER AND WASTEWATER TREATMENT (CONT.)

Table 40. Distribution of damage states for Oregon potable water and wastewater facilities, by areas of operation

	Damage State			
Area of Operation	**None**	**Low**	**Medium**	**High**
		Wastewater Facilities		
Coastal	0%	0%	19%	81%
I-5 corridor	0%	13%	59%	28%
East	28%	72%	0%	0%
		Potable Water Facilities		
Coastal	0%	0%	23%	77%
I-5 corridor	0%	10%	65%	25%
East	0%	100%	0%	0%
Summary of damage description	No structural damage to water and wastewater treatment plant, lift-stations, pumping plants and water storage tanks.	Loss of electric power and backup power, resulting in temporary malfunction for less than three days. Loss of water quality may occur. Minor water storage tank damage without loss of functionality.	Loss of electric power and backup power, resulting in malfunction for about a week. Loss of water quality is imminent. Damaged pipes connecting to basins and chemical units, which may result in a shutdown of treatment plant. Damage to pumps and lift-stations may be beyond repair. Considerable to severe damage to water storage tanks, resulting in loss of content.	Complete failure of pipings, or extensive damage to the filter gallery at treatment plant. Pumping plant or lift-station building collapse. Water storage tank collapse and loss of contents.

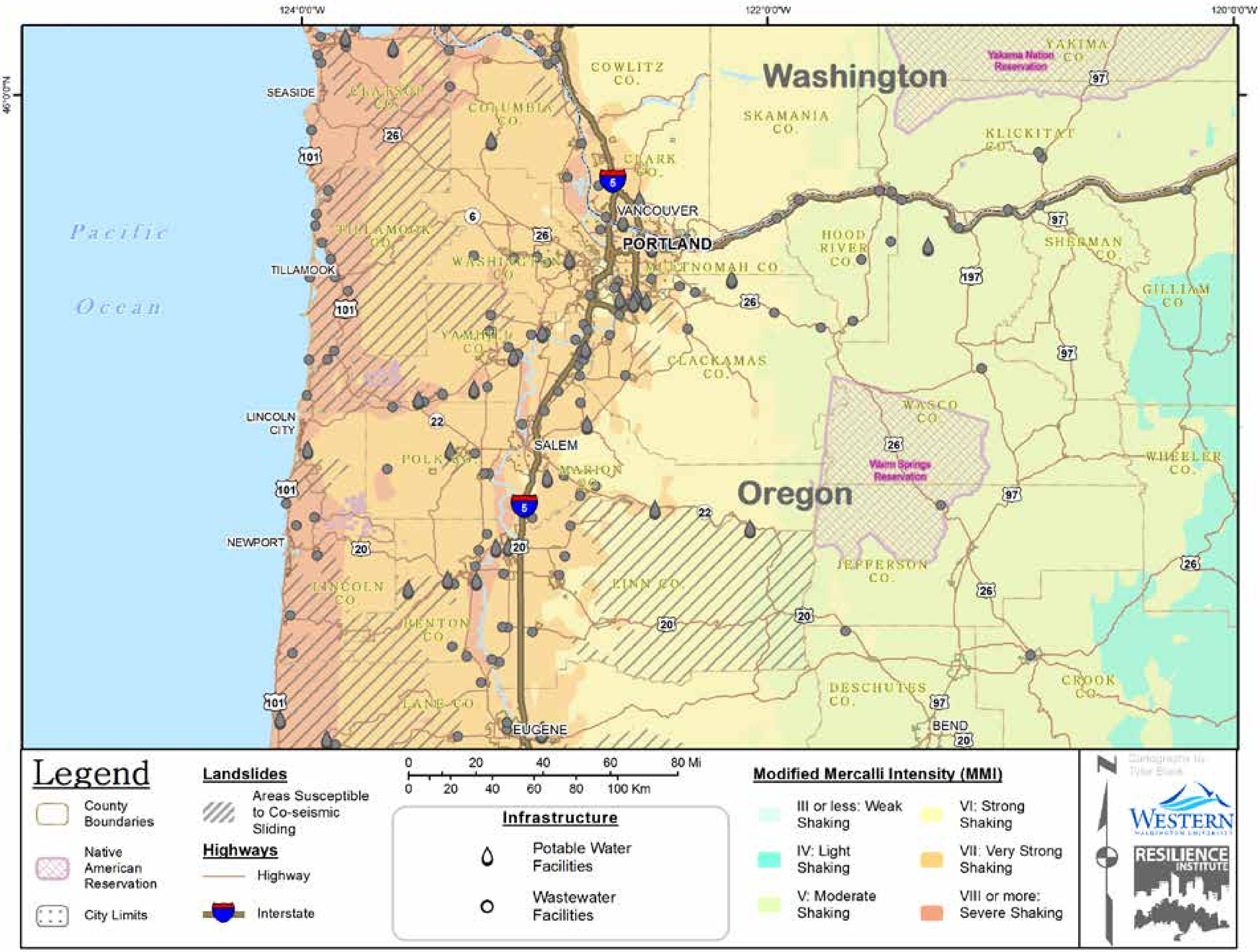

Figure 98. North Oregon potable water facilities and wastewater facilities in relation to shaking intensity and landslide potential

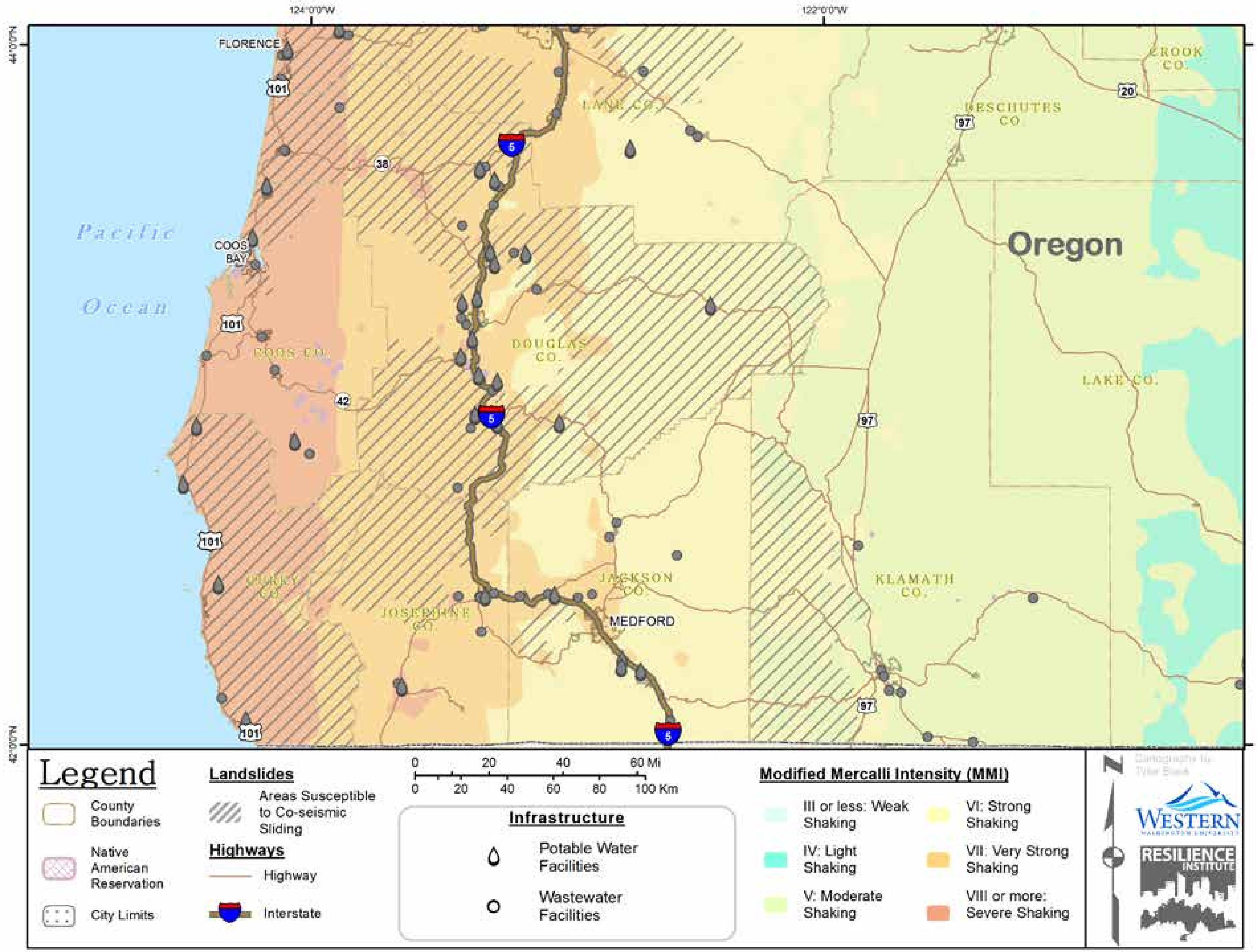

Figure 99. South Oregon potable water facilities and wastewater facilities in relation to shaking intensity and landslide potential

HAZARDOUS MATERIALS FACILITIES

As many as 80 chemical facilities in Washington and Oregon may suffer medium or greater damage from the initial earthquake. Industrial sites with tanks and pipes holding nitric acid or nitrate compounds may overturn or rupture in the violent shaking. These damaged facilities, tanks and pipes may release noxious gases or leak life-threatening chemicals onto the ground and into bodies of water. Even in undamaged, but open-topped tanks, chemicals may slosh around and spill. Where these releases are flammable (e.g. ruptured gas lines) fires may ignite. Some damaged facilities may release life-threatening ingestible and inhalable chemicals, such as ammonia and chlorine, which may pose the greatest immediate health threat for those in the immediate vicinity of the release. These immediate threats may add to widespread lower-risk releases from damaged storage tanks, breaks in oil and gas pipelines, and toxic dust and debris from collapsed buildings. Yet, in the immediate aftermath, the number of hazardous spills may be underreported due to disruptions in standard reporting mechanisms.

Areas affected by hazardous material releases may face a range of emergency management problems that slow response. Disruptions in public message distribution systems may prevent the dissemination of life-saving warning messages to affected communities. Fires and HAZMAT releases may constrain movement into affected areas, which may hamper search and rescue operations. Hazardous materials may contaminate drinking water, which may pose a threat for those in the immediate vicinity, but may also pose a threat to surrounding communities.

Figure 100. Shaking from the 1983 M6.5 Coalinga earthquake caused the pipe connections to break at a Chevron facility. Oil spilled out of the damaged connection, but was retained by dikes. Photo: Karl V. Steinbrugge.

Adding to the complexity of the problem, tsunami and flood waters may inundate chemical facilities along the shoreline, picking up and carrying harmful chemicals with the incoming waters. As the tsunami slams into homes, businesses, and farms it may be contaminated with common chemicals and fuels found in cleaning and construction supplies, appliances, fertilizers stocks, and farm animal excrement. As the water recedes, the contaminants picked up by the tsunami may cause widespread, low-level contamination in inundated areas along the coast, posing health risks to both survivors and responders.

WASHINGTON: HAZARDOUS MATERIALS FACILITIES

In the impacted areas in Washington, there are over one thousand facilities with reportable quantities of extremely hazardous substances (EHS). According to the state's reporting threshold, an even higher number, around 3,000 facilities, have reportable quantities of less dangerous materials. The severity of hazardous releases may be unknown due to disruptions in HAZMAT reporting mechanisms.

HAZMAT facilities in the impacted area of Washington and the corresponding shaking intensity are shown on Figures 101 and 102. In addition to possible damage caused by the intense shaking, tsunami waves will likely inundate a few chemical facilities along the coastline.

Figure 101. Washington facilities with hazardous material in relation to shaking intensity and landslide potential

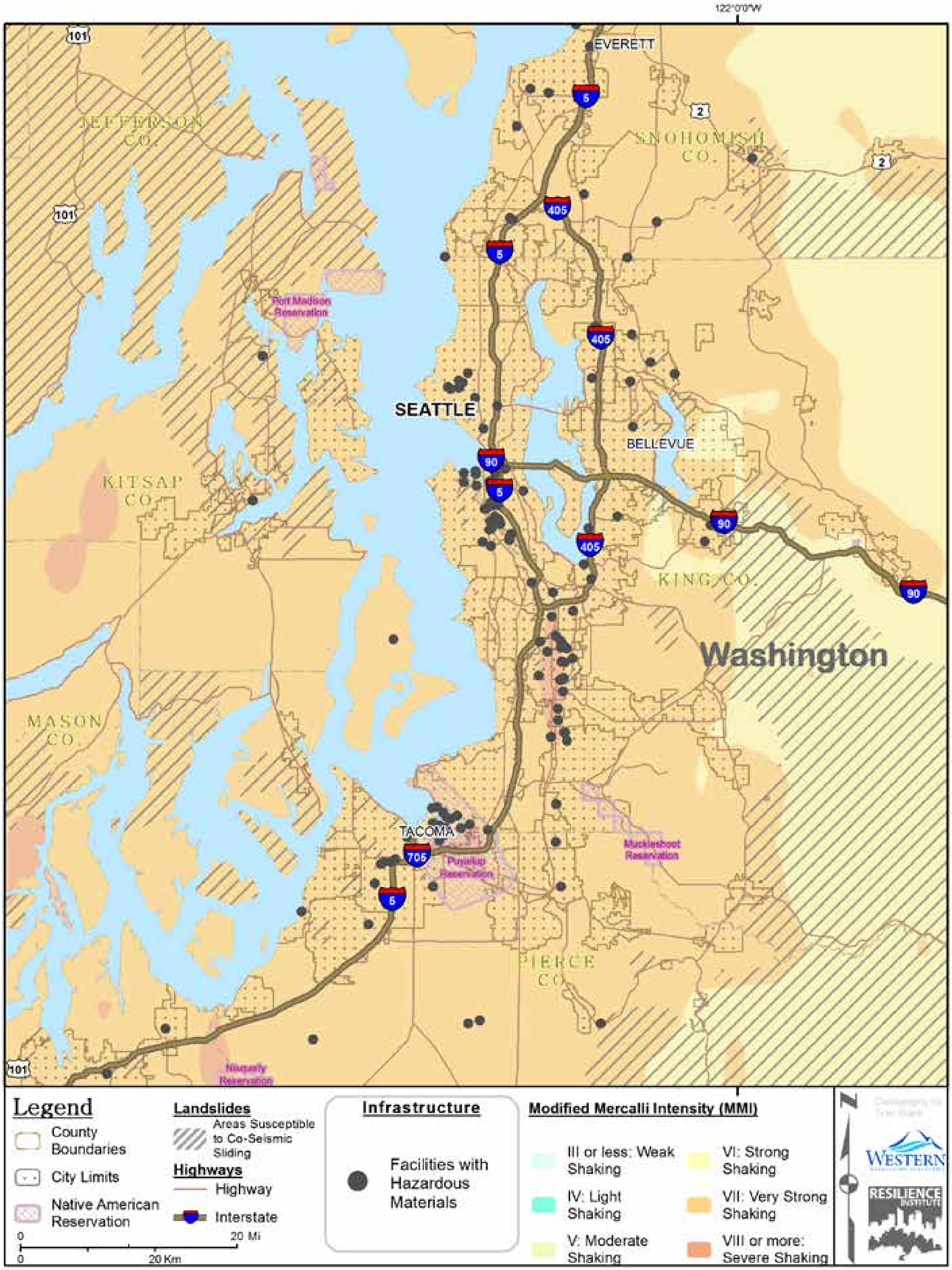

Figure 102. Seattle-Tacoma metro region facilities with hazardous material in relation to shaking intensity and landslide potential

OREGON: HAZARDOUS MATERIALS FACILITIES

In the impacted areas of Oregon, there are nearly a thousand facilities that have reportable quantities of Extremely Hazardous Substances (EHS). According to the state's reporting threshold, approximately 18,000 facilities have reportable quantities of less dangerous materials. The severity of hazardous releases may be unknown due to disruptions in HAZMAT reporting mechanisms.

The HAZMAT facilities in the impacted area of Oregon and the corresponding shaking intensity are shown on Figures 103 and 104. In addition to possible damage caused by the intense shaking, tsunami waves will likely inundate a couple chemical facilities along the coastline.

Figure 103. Oregon facilities with hazardous material in relation to shaking intensity and landslide potential

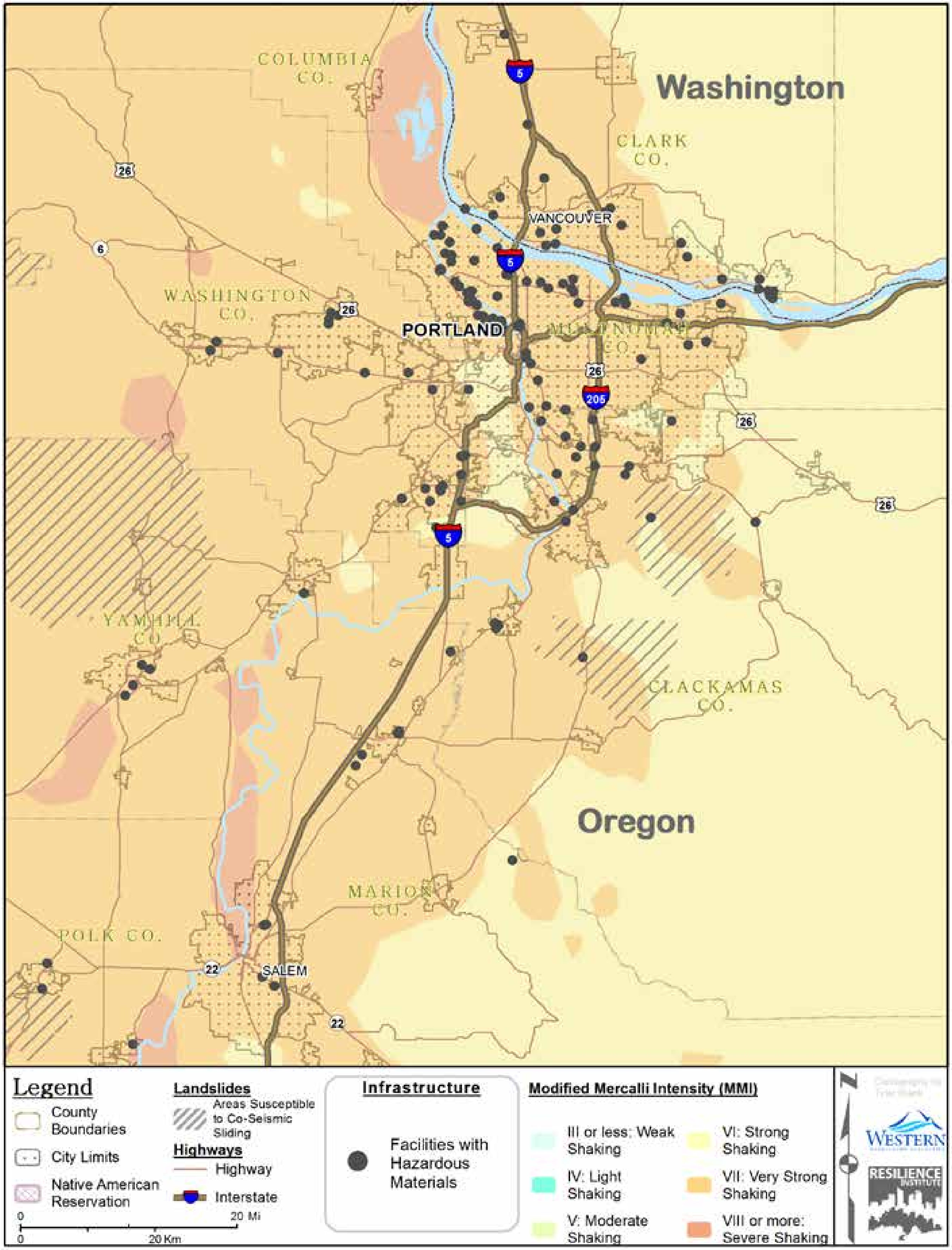

Figure 104. Portland metro region facilities with hazardous materials in relation to shaking intensity and landslide potential

COMMUNICATION SYSTEMS

Definition: Communication systems consist of central offices and broadcasting stations, transmission lines connecting central offices, and cabling. A communication facility consists of a building, unanchored or anchored central switching equipment, and backup fuel or battery generators.

In the immediate aftermath of the earthquake, all forms of communication may be disrupted – at a time when they are needed most. Survivors and responders may have limited access to internet, cell phone, landline phone, and television services due to the combination of communication and power disruptions.

Intergovernmental communication capabilities may be significantly degraded, which may limit their ability to coordinate. Responders may be unable to collect information and provide situational awareness, which may delay the delivery of lifesaving and life-sustaining assistance. Survivors may have limited access to news, social media, and other informational outlets that could help them determine what to do and where to go. Rumors may fill the void created by the absence of traditional information channels.

There are over a thousand telecommunications facilities in the impacted area of Washington and Oregon. Roughly two-thirds of these facilities may suffer medium to high damage from the initial earthquake. As shown in Table 41, the majority of communications facilities in Washington's I-5 corridor may suffer medium to high damage. The shaking may rattle equipment off of cell towers, dislodge central control boards and damage central communications offices. Communication facilities that suffer no or low damage may also be un-operational due to antennae being thrown out of alignment or the breaking of cables connecting these facilities.

Figure 105. Shaking form the 1989 M6.9 Loma Prieta earthquake damaged radio transmission towers in California. Even radio and cell towers that do not experience severe damage may still be un-operational after the quake if antennae, cables, or other hardware become unaligned or damaged. Photo: USGS.

Table 41. Communications facility damage level description

	Damage State		
Infrastructure	**Low**	**Medium**	**High**
Communications Facilities	Slight damage to the communication facility building, or loss of the center's ability to provide services for up to a few days due to loss of electric power and backup power. The facility may be functional with minor repairs.	Moderate to severe damage to communication facility buildings, many digital switching boards dislodged, resulting in malfunction. The central office may be without service for a few days due to loss of electric power or loss of backup power, typically due to overload.	Severe to complete damage to the communication facility building, with most switching boards dislodged, resulting in malfunction. The damage to digital switching boards may beyond repair.

COMMUNICATION SYSTEMS (CONT.)

In areas experiencing power outages, communications facilities may be forced to operate on backup generators. However, these backup power systems typically last for only eight to twelve hours. Refueling these systems may be a challenge; damaged roadways may make it difficult for crews to reach communications towers. Personnel shortages may also limit the number of teams sent out to repair facilities. As facilities running on backup power begin to go offline, communications may further deteriorate. The accumulation of numerous points of failure may result in widespread failure far beyond the impacted area.

People who still have cell or landline service calling loved ones or emergency services may overwhelm the remaining lines, causing them to jam up or crash completely. In total, up to ten million people across the region may lose access to standard communication services.

Figure 106. The 2004 Indian Ocean tsunami compounded communication infrastructure damage already caused by the earthquake, including completely knocking over cell towers. Widespread damage to communication systems can delay the response time of emergency services and leave survivors without crucial information. Source: USGS.

Coastal communications may be especially degraded due to damage to communication facilities and damage to electric and transportation infrastructure in the areas of highest shaking. Most coastal cell towers and central control buildings may suffer high damage from the violent shaking and may be completely inaccessible for repair. Even if communications buildings themselves withstand the earthquake, unsecured equipment may be tossed to the ground and central control boards may dislodge, resulting in malfunction. Some communication facilities may be completely destroyed by the tsunami waves. Communications in these areas may be limited to radio and satellite phones. Figure 106 illustrates the type of damage the force of a tsunami wave can do to the steel support columns of a cell tower. Many coastal broadcast facilities that provide AM/FM radio and television services may also suffer high damage and may be unable to provide service. Even facilities sustaining low damage may experience service disruptions due to misdirected or downed antennae. As a result, broadcast services may be disrupted for inland populations as well.

The potential loss of broadcast services may severely limit the ability of state and local authorities to disseminate emergency information to affected areas through the EAS national public warning system. While television and FM broadcast may be available in some areas of the I-5 corridor, their signals will be unable to reach past the coastal mountain range to provide service to survivors in the heavily damaged coastal regions. With AM radio's longer broadcast range, survivors with power, or those who attempt to listen in their vehicles, may be able to receive AM radio signals.

For local, state, and tribal governments with backup reporting and communications systems, limited communication may be possible up until the point when fuel for backup generators runs out.

WASHINGTON AND OREGON: LONG-HAUL FIBER OPTIC CABLES

Undersea transpacific cables are the primary communications links connecting both Alaska and East Asia to the contiguous United States. Damaged transpacific cables may cause disruption in communication to and from East Asian countries, as well as to and from Alaska.

Underground landslides and the shifting of the ocean floor may sever undersea cables that traverse the offshore regions of the Cascadia Subduction Zone. The remaining cable systems on the northern transpacific routes landing in Puget Sound and the Oregon coast may see some disruptions, but the southern routes through California may remain functional.

With the loss of undersea cable capacity, communications systems may face abnormally high congestion. While alternative routes using satellite microwave communications may exist, the bandwidth is limited. The restoration of these cables may take several months.

On land, regional long-haul fiber optic cables may be severed by landslides or the collapse of the bridges they span, which may cause regional and nationwide delays in internet and long-distance services as the network attempts to reroute around the impacted area.

Figure 107. Internet and phone providers believe that a small earthquake severed this underwater cable and caused a phone and data outage in the San Juan Islands. Following an earthquake survivors may not be able to use undamaged landlines as the volume of emergency calls will likely overwhelm surviving infrastructure capabilities. Photo: KING.

WASHINGTON: COMMUNICATIONS SYSTEMS

The majority of communications infrastructure on the coast may be severely damaged and inaccessible for repair. Facilities along the immediate coastline will likely be destroyed by the force of the tsunami wave. Communications in these areas may be limited to radio frequency and satellite phones.

As shown in Table 42, most of the communication facilities in eastern Washington may suffer less physical damage from the earthquake. However, the lower availability of power may limit the capability of these facilities to provide service. Figures 108 and 109 plot the location of cell towers and broadcast television stations in Washington.

Table 42. Distribution of damage states for Washington state communications facilities, by areas of operation

	Damage State			
Area of Operation	**None**	**Low**	**Medium**	**High**
Coastal	0%	0%	33%	67%
I-5 corridor	5%	19%	55%	21%
East	95%	5%	0%	0%
Summary of damage description	No damage to facility building or equipment. Antennae misalignment may temporarily disrupt service.	Slight damage to the communication facility building, or loss of the center's ability to provide services for up to a few days due to loss of electric power and backup power. The facility may be functional with minor repairs.	Moderate to severe damage to communication facility buildings, many digital switching boards dislodged, resulting in malfunction. The central office may be without service for a few days due to loss of electric power or loss of backup power, typically due to overload.	Severe to complete damage to the communication facility building, with most switching boards dislodged, resulting in malfunction. The damage to digital switching boards may beyond repair.

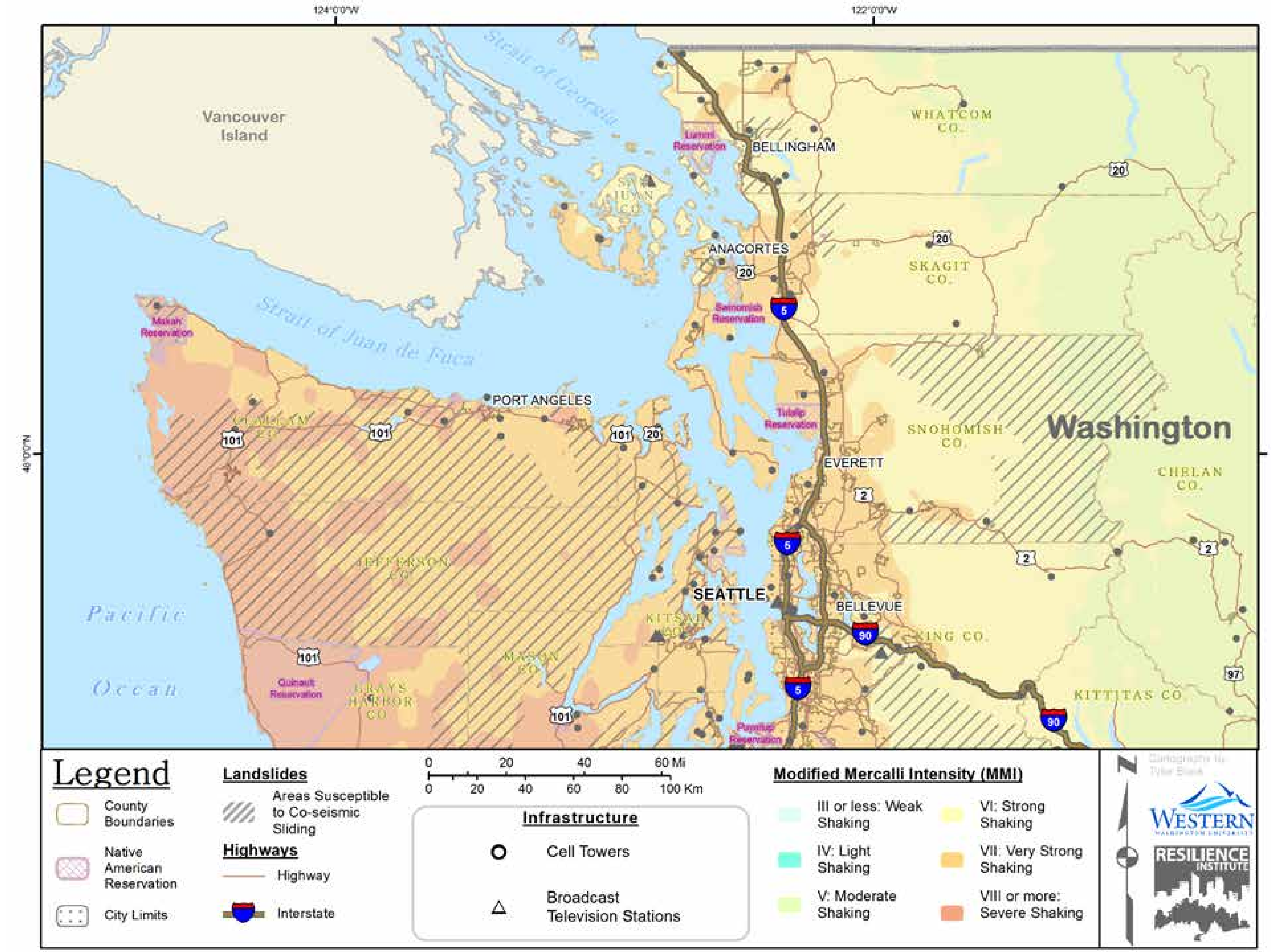

Figure 108. North Washington cell towers and broadcast television stations in relation to shaking intensity and landslide potential

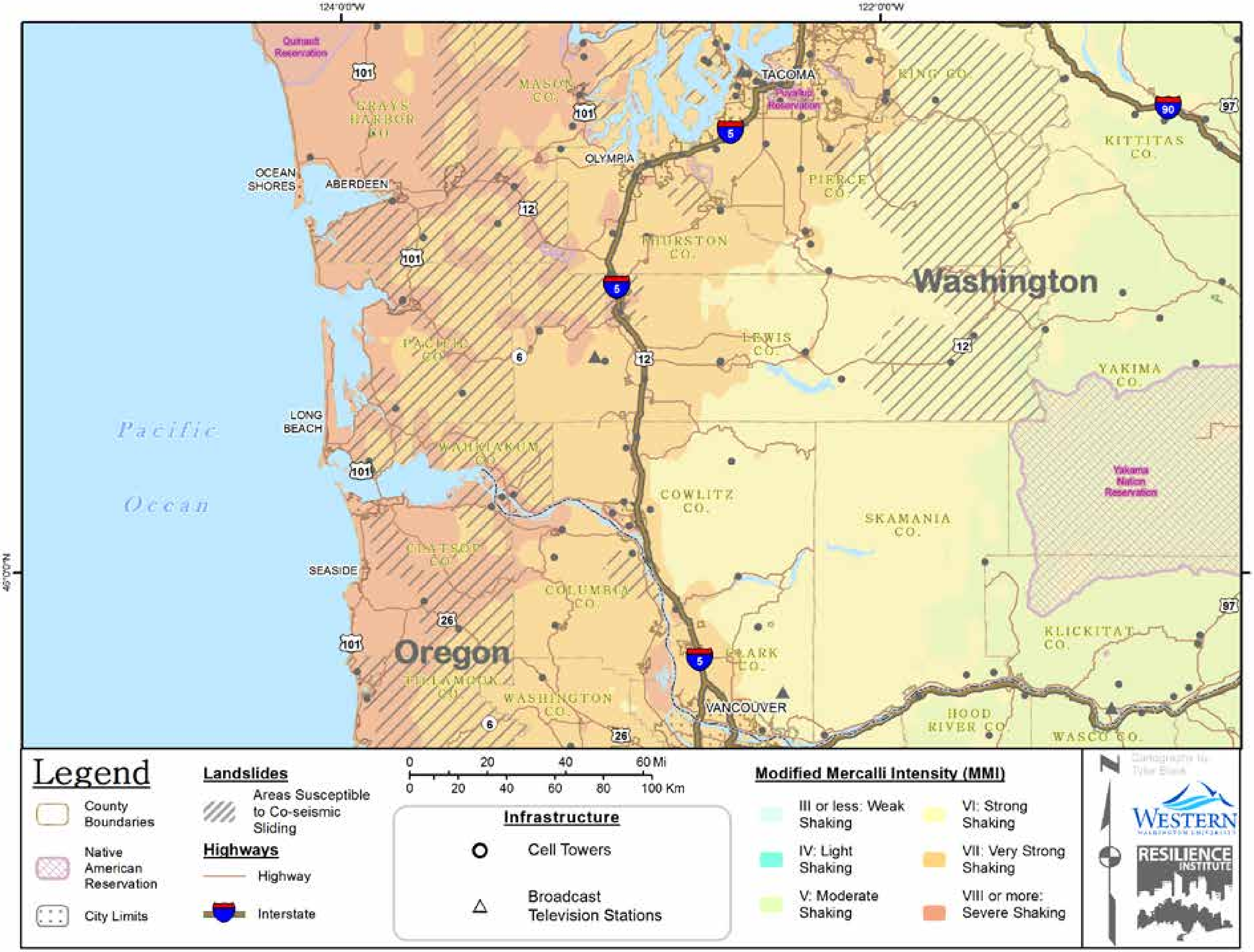

Figure 109. South Washington cell towers and broadcast television stations in relation to shaking intensity and landslide potential

OREGON: COMMUNICATIONS SYSTEMS

The majority of communications infrastructure on the coast may be severely damaged and inaccessible for repair (see Table 43). Facilities along the immediate coastline will likely be destroyed by the force of the tsunami wave. Communications in these areas may be limited to radio frequency and satellite phones.

Most of the communication facilities in eastern Oregon may suffer less physical damage from the earthquake. However, the lower availability of power may limit the capability of these facilities to provide service. Figures 110 and 111 plot the location of cell towers and broadcast television stations in Oregon.

Table 43. Distribution of damage states for Oregon communications facilities, by areas of operation

	Damage State			
Area of Operation	**None**	**Low**	**Medium**	**High**
Coastal	0%	0%	18%	82%
I-5 corridor	8%	15%	58%	19%
East	98%	0%	0%	2%
Summary of damage description	No damage to facility building or equipment. Antennae misalignment may temporarily disrupt service.	Slight damage to the communication facility building, or loss of the center's ability to provide services for up to a few days due to loss of electric power and backup power. The facility may be functional with minor repairs.	Moderate to severe damage to communication facility buildings, many digital switching boards dislodged, resulting in malfunction. The central office may be without service for a few days due to loss of electric power or loss of backup power, typically due to overload.	Severe to complete damage to the communication facility building, with most switching boards dislodged, resulting in malfunction. The damage to digital switching boards may beyond repair.

Figure 110. North Oregon cell towers and broadcast television stations in relation to shaking intensity and landslide potential

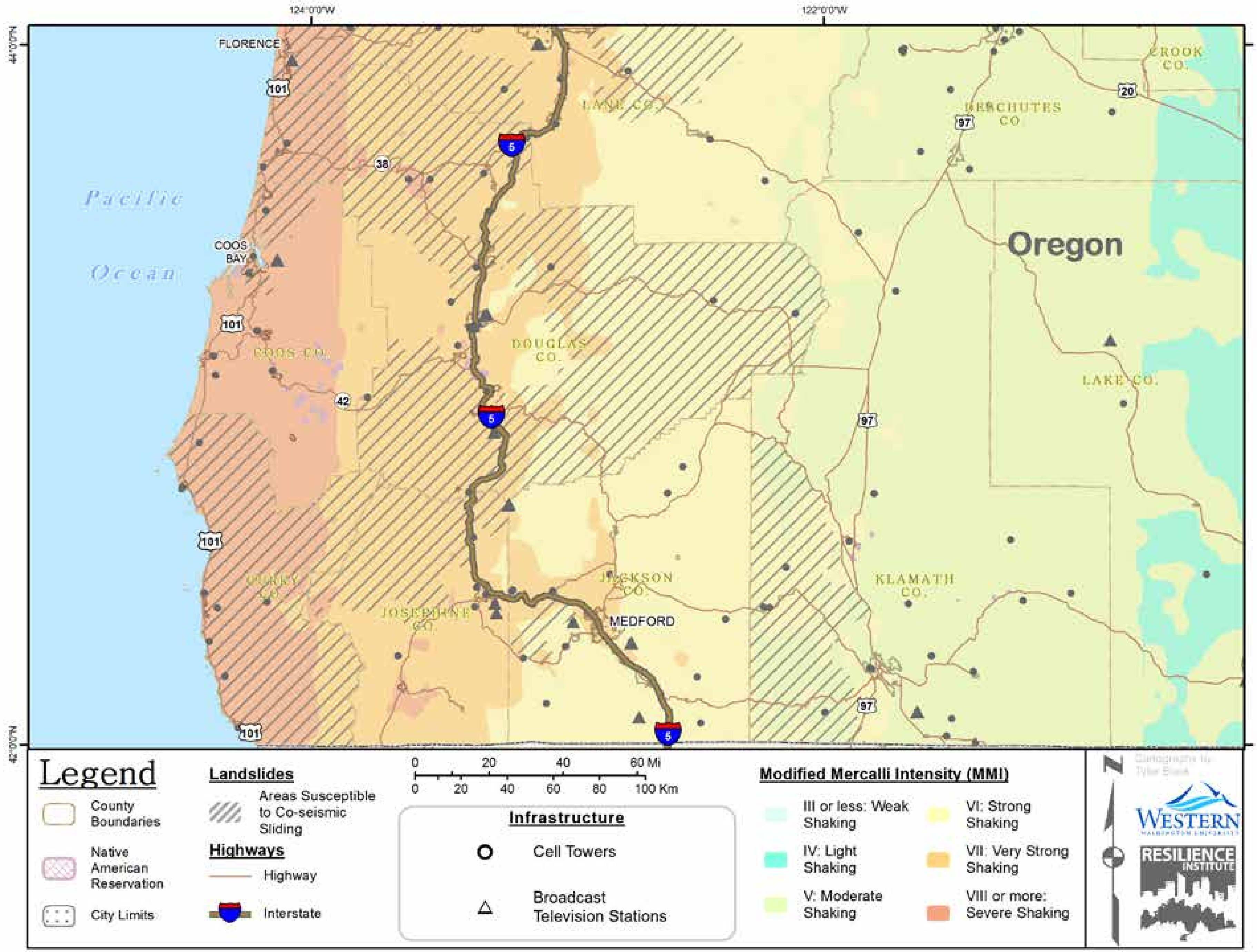

Figure 111. Ssouth Oregon cell towers and broadcast television stations in relation to shaking intensity and landslide potential

BUILDINGS

As with other types of structures, the performance of a building during the earthquake will depend on when it was built, where it is located, the strength and flexibility of its materials, and how long the ground shakes. For tall buildings, large-magnitude earthquakes pose a particular challenge. High-rises and other tall structures vibrate at a lower frequency than shorter buildings. Because the frequency of a large earthquake's seismic waves is also low, some tall structures may resonate with the waves. This will amplify the intensity of the shaking and may increase the damage.

Some buildings should hold up fairly well. Structures that were designed and built to meet current seismic codes may sustain damage, but should not collapse. These may be usable after the earthquake, although they may lack utilities. Many houses in the Pacific Northwest are wood-frame structures. This type of building is lightweight, flexible, and unlikely to collapse during the quake, although it may shift off of its foundation if not bolted to it (this is a major concern for houses built prior to 1976). Connections to utilities may also break, and fallen chimneys are quite common, as were seen during the Nisqually earthquake in 2001.

Other buildings will perform very badly. Unreinforced masonry buildings (URMs), for example, predate seismic codes. Built of brick or concrete without steel reinforcement, they are prone to collapse during strong earthquakes, particularly when the shaking lasts for several minutes. URMs are often the cause of earthquake-related fatalities. Because of the danger such buildings pose, some governments are taking steps to eliminate or strengthen URMs. California state law requires local governments in seismic hazard zones to inventory URMs and adopt mitigation programs aimed at reducing the risk of collapse. Complete inventories have been done only in California, but URMs are common throughout the Northwest: Oregon has an estimated 5,000 to 10,000 statewide, with about 1,800 in the city of Portland alone. Seattle, which has about 1,000 URMs, and has experienced three damaging earthquakes in the last 64 years, is considering adoption of a mandatory retrofit program similar to California's.

A Cascadia earthquake may cause nonstructural damage even in buildings that were built or retrofitted to meet higher structural seismic standards. Strong shaking can knock fittings and equipment loose and move anything that is not securely bolted down. Suspended ceilings, fire sprinkler systems, elevators, partition walls, air handling units, and hot water tanks are just a few of the vulnerable components.

RESIDENTIAL BUILDINGS

In the immediate aftermath of the earthquake, as many as one million residential buildings may be damaged by the initial earthquake. This damage may range from small cracks at the corners of doors, windows, and in masonry chimneys, to the complete failure of walls, load bearing systems, and foundations, leading to partial or complete collapse of the building. In addition to structural damage, millions of homes may sustain a range of nonstructural damage, such as fallen bookshelves, televisions, computers, lights, dishes, and ventilation ducts. The photos below illustrate the range of structural and nonstructural damage.

Figure 112. The interior of residential dwellings can be damaged during seismic events, such as this living room following the 1994 M 6.7 Northridge earthquake. Large pieces of furniture, fire sprinkler systems, suspended ceilings, air conditioning units and hot water tanks are among the vulnerable household elements. Photo: Jonney Wiss.

Figure 113. The 1983 M 6.2 Coalinga earthquake caused the cripple walls of wood-frame houses to fail, resulting in the house sliding off its foundation. Wood frame houses are flexible enough that collapse is unlikely for most of them, but many built prior to 1976 are at risk of shifting off of their foundations. Photo: Karl V. Steinbrugge.

Figure 114. The 1989 Loma Prieta earthquake shifted this house over two feet off its foundation causing the structure to detach from the concrete stairway and collapsing all four shear walls. Photo: J.K Nakata, USGS.

Figure 115. The tsunami following the 2011 East Japan earthquake obliterated many houses it inundated, stripping the walls off some and sweeping others completely off of their foundations. Similar tsunami damage in the region could affect over 45,000 buildings, most of them residential. Photo: EPA/Alex Hofford.

WASHINGTON: RESIDENTIAL BUILDINGS

In Washington, as many as half a million residential buildings may be damaged by the initial earthquake.

The population centers along the I-5 corridor may have the highest number of damaged residential buildings; over 400,000 residential buildings may suffer some level of structural damage. The majority of damaged residential buildings may only sustain minor structural damage, and may be immediately inhabitable after the earthquake. Roughly 5 percent of the damaged buildings may sustain moderate structural damage requiring repair before it is safe to occupy.[viii]

The highest level of building damage may be along the coast and west of the coastal mountain chain. As many as 70,000 residential buildings may be damaged by the earthquake. Roughly a quarter of the damages to buildings may be severe enough as to render the structure uninhabitable without major repairs.

The tsunami will likely damage as many as 20,000 residential buildings along the coast, including roughly half of the residential buildings in Grays Harbor and Pacific Counties.
The length of time it takes to repair these structures may depend on the location of the building, damage to surrounding infrastructure, and the damage state of the structure.

OREGON: RESIDENTIAL BUILDINGS

In Oregon, as many as 440,000 residential buildings may be damaged by the earthquake.

The population centers along the I-5 corridor may have the highest number of damaged residential buildings; over 300,000 residential buildings may suffer some level of structural damage. The majority of damaged residential buildings may only sustain minor structural damage, and may be immediately inhabitable after the earthquake. Roughly 5 percent of the damaged buildings may sustain moderate structural damage requiring repair before it is safe to occupy.[viii]

The highest level of building damage may be along the coast, where as many as 100,000 residential buildings may be damaged by the earthquake. Roughly a quarter of the damages to buildings may be severe enough as to render the structure uninhabitable without major repairs. The tsunami will likely damage as many as 20,000 residential buildings along the coast.

The length of time it takes to repair these structures may depend on the location of the building, damage to surrounding infrastructure, and the damage state of the structure.

SHELTERS

In the immediate aftermath of the Cascadia Subduction Zone event, as many as one million people may need short-term sheltering. Most displaced survivors may seek shelter because their homes are no longer safe to occupy, or they may be unable to reach their homes due to impassable roads. Many of these survivors will shelter-in-place, that is, seek shelter with family and neighbors, while many others will seek out government and Red Cross managed formal emergency shelters. Visitors to the region will also need short-term sheltering. At the same time, roughly two-thirds of emergency shelter buildings may suffer medium to high damage. While some of these shelters may suffer moderate building damage, others may suffer damage severe enough as to render the building uninhabitable. Others may need to operate without power and water.

The large volume of displaced survivors seeking shelter will likely overcrowd the remaining working shelters, raising the possibility of public health threats emerging from unsanitary conditions likely to develop in these crowded shelters.

Table 44 shows the approximate number of people in need of shelter in Washington and Oregon.

Table 44. Initial short-term sheltering requirements- both shelter-in-place and emergency sheltering (90th percentile)[ix]

	Short-term sheltering requirement			Initial short-term feeding and hydration requirment
	Earthquake	Tsunami	Total	
Washington	370,000	45,000	415,000	1,100,000
Oregon	500,000	20,000	520,000	1,300,000
Total	870,000	65,000	915,000	2,400,000

APPENDIX A: REPORT CONTRIBUTORS

We would like to thank the Western Washington University, Resilience Institute for the authorship of this report:

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We would also like to formally thank representatives from the following organizations for their contributions to this report:

U.S. Department of Homeland Security – FEMA Region 10
U.S. Department of Homeland Security – Office of Infrastructure Protection
U.S. Department of Homeland Security – National Coordinating Center for Communications
U.S. Department of Homeland Security – United States Coast Guard, District 13
U.S. Department of Defense – United States Army Corps of Engineers
U.S. Department of Interior – Bureau of Reclamation
U.S. Department of Interior – United States Geological Survey
U.S. Department of Justice – Bureau of Alcohol, Tobacco, Firearms, and Explosives
U.S. Department of Energy – Bonneville Power Administration
U.S. Department of Commerce – National Oceanic and Atmospheric Administration
Washington Emergency Management Division
Washington State Department of Transportation
Washington Department of Natural Resources
Snohomish County, WA, Office of Emergency Management
Grant County, WA, Office of Emergency Management
King County, WA, Office of Emergency Management
Oregon Office of Emergency Management
Oregon Department of Geology and Mineral Industries
Clackamas County, OR, Office of Emergency Management
California Department of Conservation
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Cascadia Region Earthquake Workgroup (CREW)
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APPENDIX B: REFERENCE MATERIALS

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[i] Precise figure is 6,703,210 based on 2012 U.S. Census Bureau Projections (Washington, Oregon, and California) and Statistics Canada figures from the 2011 Canadian Census.

[ii] FEMA Region 10 CSZ Response Plan

[iii] Precise GDP figure is $448,659,000 (Portland and Seattle metro areas combined) according to the U.S. Bureau of Economic Analysis.

[iv] Precise GDP figure is $101.2 billion according to The Brookings Institution's 2012 Global MetroMonitor.

[v] Data based on the U.S. Census Bureau's 2009 American Community Survey 1-Year Estimates for Educational Attainment.

[vi] Statistics compiled by U.S. Census Bureau – Top States and Cities Visited by Overseas Travelers.

[vii] Statistics compiled by U.S. Census Bureau – Selected U.S.-Canadian and U.S.-Mexican Border Land-Passenger Gateways: 2010.

[viii] As of date, there is no comprehensive HAZUS output for residential building damage states for both Washington and Oregon. The percentage of medium and high damage levels presented here was estimated using the Washington State Seismic Hazards Catalog – a web-based tool using HAZUS loss estimates and GIS. Using the Seismic Catalog tool, residential building damage levels were queried for counties on the coast and the I-5 corridor. Based on the sampled data, less than one percent of the damaged residential buildings in the I-5 corridor may sustain medium and approximately five percent may sustain high damage. Approximately fifteen percent of the damaged residential buildings in coastal counties may sustain medium damage and ten percent may sustain high damage.

[ix] One limitation of this analysis is that sheltering requirements for tsunami inundation areas were calculated for both earthquake and tsunami impacts. This may have resulted in an overestimate. Also, residential buildings were used to represent residences for the earthquake sheltering calculations. Residential structures can include multiple residences; thus, earthquake sheltering requirements may have been underestimated.