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TSUNAMI EVACUATION ANALYSIS OF FLORENCE AND REEDSPORT, LANE AND DOUGLAS COUNTIES, OREGON

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BridgesIn_XXL1_WincesterBayOnly feature dataset:

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Bridges_In\EvacuationTime4fps_Roads_BridgesIn
Bridges_In\EvacuationTime4fps_Trails_BridgesIn
Bridges_In\WalkingSpeeds_Roads_BridgesIn
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BridgesOut_XXL1 feature dataset:

EvacuationFlowZones_BridgesOut
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Metadata in .xml file format:

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ABSTRACT

We evaluated pedestrian evacuation in the communities of coastal Lane and Douglas Counties in the event of a local tsunami generated by an earthquake on the Cascadia subduction zone (CSZ). Our analyses focused on a maximum-considered CSZ tsunami event covering 100% of potential variability, termed XXL1 and generated by a magnitude 9.1 earthquake. We determined ***minimum*** walking times to safety (defined as ~20 ft beyond the inundation limit) for a moderate walking speed of 4 fps (feet per second, 22 minutes/mile) using least-cost distance (LCD) routes determined by modification of the anisotropic path distance method of Wood and Schmidtlein (2012) and Wood and others (2016). Four feet per second is the standard speed for pedestrians to cross at signalized intersections (U.S. Department of Transportation, 2012). Evacuation paths were limited to roads, trails, and pedestrian pathways designated by local government reviewers as the most likely routes.

To estimate whether pedestrians can stay ahead of a tsunami along the evacuation routes, we produced maps of:

- Tsunami wave advance for an XXL1 event
- LCD walking time (at 4 fps)
- Detailed evacuation routes for the XXL1 scenario, and
- "Beat the Wave" (BTW) for the XXL1 scenario

The BTW maps depict the ***minimum evacuation speed*** required to stay ahead of the tsunami wave given a variety of scenarios that will increase evacuation difficulty. The primary scenario uses the existing road network and includes a 10-minute delay from start of earthquake before beginning evacuation. Additional challenges to evacuation are examined, including failure of non-retrofitted bridges and effects from liquefaction. In all cases, ***the identified minimum speeds must be maintained for the entire time it takes to evacuate from the inundation zone.*** Given the model limitations defined in the Methods section, results show that evacuation of the entire region is achievable at a moderate walking speed (4 fps) assuming the existing road and bridge network remains viable. Even for those with mobility limitations (i.e., those who cannot travel at speeds more than 4 fps), safety can be reached ahead of the wave from nearly every location within the city limits of Florence and Reedsport; this assumes the existing road and bridge network is not compromised. Evacuation challenges do exist in some of the outlying areas. Failure of the Salmon Harbor Bridge in Winchester Bay introduces evacuation challenges for evacuees starting from areas west of the bridge, and long distances to high ground and difficult walking conditions result in evacuation challenges for the open coast recreation areas on the Umpqua and Siuslaw Rivers.

Possible mitigation options include increasing the number of evacuation routes by constructing more earthquake-hardened bridges (built or remodeled to withstand shaking from a major earthquake); adding new evacuation routes; and/or installing a tsunami refuge, otherwise known as a vertical evacuation structure, on the Siuslaw Spit.

1.0 INTRODUCTION

A locally generated tsunami from a Cascadia subduction zone (CSZ) earthquake will inundate the Oregon coast within tens of minutes (Priest and others, 2009; Witter and others, 2011). For the majority of the population, spontaneous evacuation on foot will be the only effective means of limiting loss of life, because vehicle evacuation would be quickly compromised by traffic congestion and road blockages. CSZ earthquakes affecting the Oregon coast will likely be on the order of ~Mw 9.0 (Priest and others, 2009; Witter and others, 2011), severely damaging bridges and other infrastructure critical to evacuation. To evaluate CSZ tsunami impact, Witter and others (2011) used a logic tree approach to produce a suite of deterministic scenarios, five of which are mapped statewide, each covering the following percentages of potential variability of Cascadia tsunami inundation (Priest and others, 2013b):

- Extra-extra-large (XXL1) (100%)
- Extra-large (XL1) (98%)
- Large (L1) (95%)
- Medium (M1) (79%)
- Small (SM1) (26%)

In these scenarios a maximum-considered CSZ tsunami (XXL1, referred to as "XXL" for the remainder of this report) inundates virtually the entire coastal region of Lane and Douglas County but must travel several miles upriver to reach the population centers of Reedsport (**Figure 1-1**) and Florence (**Figure 1-2**). Due to their distance from the open coast, it will take up to 40 minutes for the tsunami to reach these communities and only the low-lying areas will experience flooding. Bridges can further complicate evacuation if they prove to be integral to a route and are not built to withstand the shaking from the earthquake. This does not turn out to be true for the Florence and Reedsport study areas where none of the major bridges prove to be essential for evacuation (i.e. safety can be reached without needing to cross a bridge). The objective of this study is to provide local government with a quantitative assessment of the time, speed, and challenges affecting tsunami evacuation in Reedsport and Florence for the XXL scenario. These results are important for evaluating mitigation options such as evacuation route improvements, better wayfinding, land use planning, and potential vertical evacuation options.

To understand further the evacuation landscape, we undertook a small socioeconomic analysis to assess the numbers of people, businesses, and critical facilities (schools, hospitals, police, and fire) in the XXL and Medium (M1) scenario tsunami zones. To date, socioeconomic exposure analyses have been completed for the Oregon coast using only the DOGAMI L1 scenario (Wood and others, 2015), which covers ~95% of potential CSZ inundation variability. By performing a similar analysis for XXL and M1, we now have a better understanding about the socioeconomic impact the next CSZ tsunami will have. Concurrent to this report, DOGAMI is preparing separate reports containing tsunami exposure analyses for much of the Oregon coast as a part of a larger multi-hazard risk assessment (MHRA) project that provides detailed exposure data for all five of DOGAMI's local tsunami scenarios (Small through XXL). Much of the socioeconomic analysis presented in this report comes from the Lane and Douglas County MHRA reports (in preparation, 2018).

Figure 1-1. DOGAMI (2013a) tsunami evacuation map for Reedsport, Gardiner, and Winchester Bay showing geographic information. Inundation for a maximum-considered Cascadia subduction zone (CSZ) tsunami scenario (XXL) is shown in yellow, while the maximum considered distant tsunami scenario (AKMax) is shown in orange. (Note: the Cascadia scenario encompasses BOTH the yellow and orange zones.) High ground outside the XXL hazard area is green. See Witter and others (2011) for detailed explanations of the tsunami scenarios shown on this map. The full-scale version of this map is available at http://www.oregongeology.org/tsuclearinghouse/.

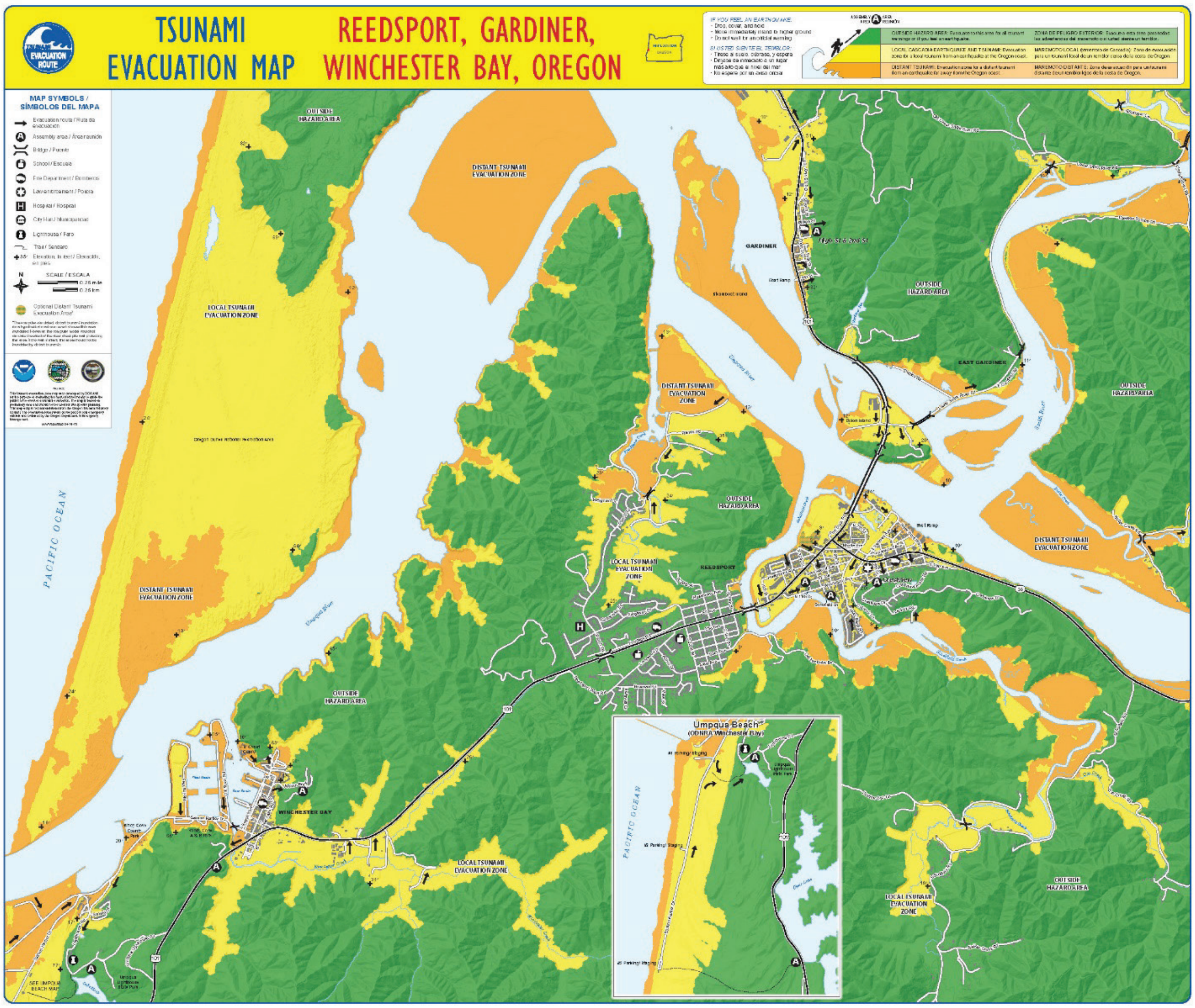
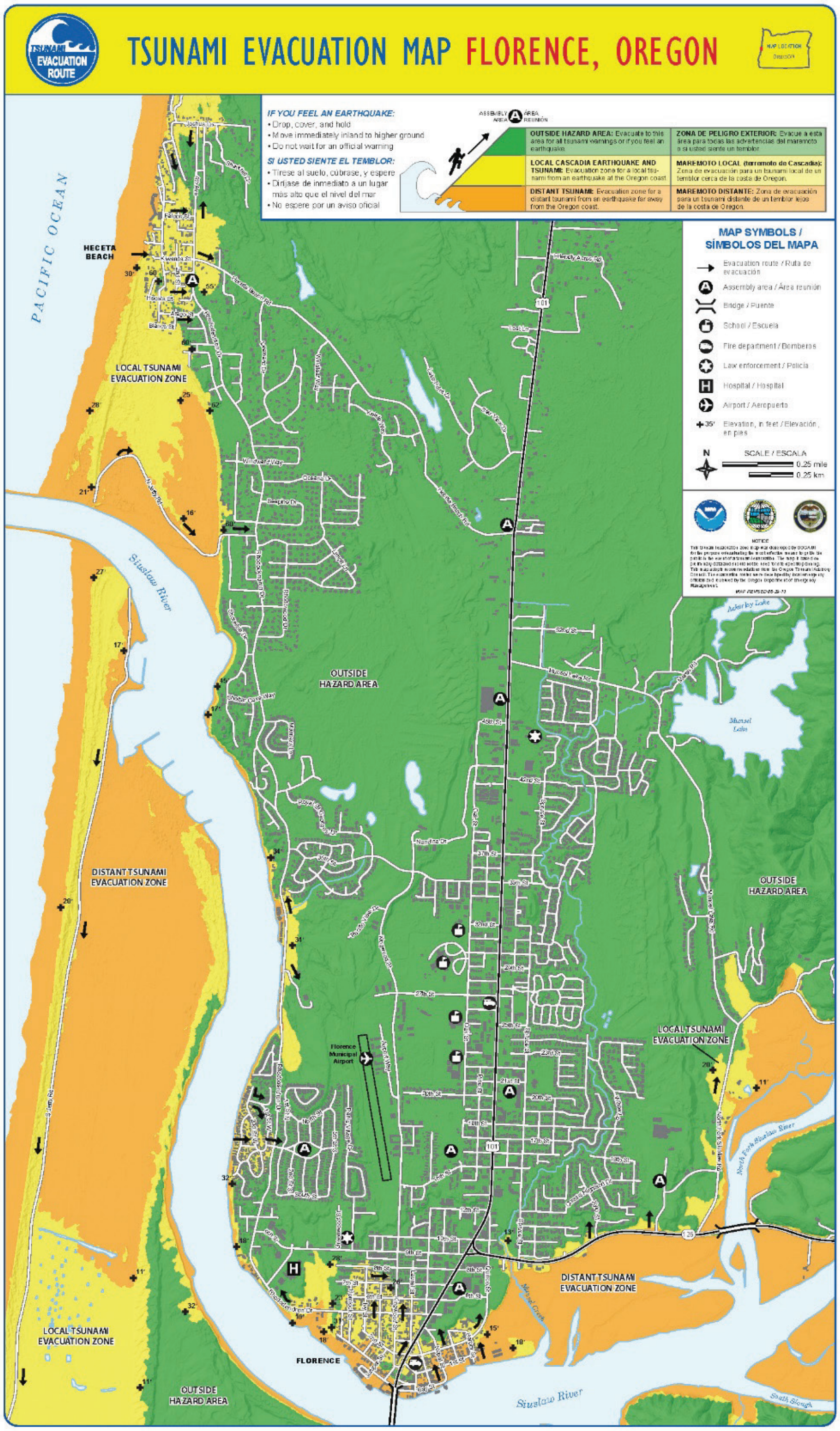


Figure 1-2. DOGAMI (2013b) tsunami evacuation map for Florence showing geographic information. Inundation for a maximum-considered Cascadia subduction zone (CSZ) tsunami scenario (XXL) is shown in yellow, while the maximum considered distant tsunami scenario (AKMax) is shown in orange. (Note: the Cascadia scenario encompasses BOTH the yellow and orange zones.) High ground outside the XXL hazard area is green. See Witter and others (2011) for detailed explanations of the tsunami scenarios shown on this map. The full-scale version of this map is available at http://www.oregongeology.org/tsuclearinghouse/.



We evaluate tsunami evacuation difficulty by:

1. Using the least-cost distance (LCD) approach of Wood and Schmidtlein (2012) to provide estimates of walking times to safety for every place of origin in the community,
2. Illustrating how quickly the wave front of an XXL tsunami advances across the area after the earthquake,
3. Determining whether an evacuee can stay ahead of the tsunami all the way to safety on the routes defined by the LCD analysis, termed "beat the wave" (BTW),
4. Running multiple BTW scenarios to investigate potential vulnerabilities and mitigation options, and
5. Analyzing socioeconomic exposure data and comparing results with BTW walking speeds to identify potentially vulnerable populations.

2.0 METHODS

Agent-based and LCD modeling are the two most common approaches for simulating pedestrian evacuation difficulty. Agent-based modeling focuses on the individual and how travel would most likely occur across various cost conditions, such as congestion points (Yeh and others, 2009). LCD modeling focuses on characteristics across the evacuation landscape, such as slope and land cover type. LCD modeling calculates a least-cost path to the tsunami inundation limit for every point in the inundation zone, artificially increasing distances for non-optimal walking conditions (e.g., steep slopes, difficult land cover) and choosing the best routes accordingly. Time to traverse a route can then be estimated by dividing the least-cost path by a single pedestrian walking speed. We used the LCD model of Wood and Schmidtlein (2012) because we wanted to understand the spatial distributions of evacuation times in the Reedsport and Florence areas without having to create a large number of scenarios for specific starting points required by agent-based models. BTW models integrate tsunami wave arrival data directly into the LCD analysis to produce map of ***minimum*** speeds that must be maintained to reach safety. Additional information on the methodology is given by Gabel and Allan (2017) and Priest and others (2015a, b).

2.1 Road and trail network

We used a model that considered only roads, paths, and the dry sand backshore of beaches as evacuation pathways; all other land cover classes were essentially excluded. This removes the complication of crossing private property and allows us to generate informative maps. Geospatial data representing roads, pedestrian paths and beaches were generated through manual classification of imagery, field verified, and then reviewed by local officials. The backshore is defined as areas landward of the beach-dune junction approximated by the 18-ft NAVD88 (North American Vertical Datum of 1988) contour. The beach (below 18 ft) was excluded owing to uncertainty of travel difficulty (cost) on wet versus dry sand and potentially liquefied sand during a local subduction zone earthquake. Due to the wide variety in beach surfaces, modeled BTW speeds on beach "trails" is intended to provide only a rough approximation of the time and speeds required to evacuate the area. We chose to ignore travel time from buildings or other parts of urban areas to the roads, because there is large uncertainty in conditions both before (e.g., fenced yards) and after the earthquake (e.g., fallen debris). Because of these assumptions and factors, the modeling approach produces ***minimum*** evacuation speeds to safely evacuate from the inundation zone.

2.2 Hypothetical scenarios

For each community, the evacuation landscape was first evaluated using the existing road, trail, and bridge network. An inventory of infrastructure at risk of failure during the earthquake was collected and a suite of scenarios was developed to investigate the resulting evacuation route challenges. These include the potential failure of bridges and road blockages (slowdowns) caused by landslides or liquefaction. Additional scenarios were then designed with various hypothetical mitigation options to address these challenges, including constructing new trails, hardening existing roads or trails, seismically retrofitting a bridge, constructing new pedestrian and/or car bridges, and building vertical evacuation structures. Multiple review sessions with community officials ensured local needs and concerns were addressed by the scenarios.

Evacuation time maps showing the time to reach safety at a constant walking speed of 4 ft/sec (fps) are provided for every community in **Appendix A**. Because BTW studies have only been done for a small number of communities along the Oregon coast, the evacuation time maps allow for direct comparison to other existing or future least-cost distance modeling studies for the region (e.g., Wood and others, 2016). Evacuation time maps are excluded from the main body of the report to avoid confusion with BTW results. This is because evacuation time maps assume a constant "slow" rate of evacuation, while ignoring the needed travel speed to safety in order to "beat" the tsunami. Detailed evacuation route maps can be found in **Appendix A**. Final BTW maps are presented in **Appendix C**. These provide the same BTW data presented in this chapter, presented in a manner fit for public use with instructions on how to read and interpret BTW data.

As noted above, the most important vulnerabilities affecting safe evacuation are bridge failure and liquefaction effects. A vertical evacuation structure is considered for one location. We also evaluate two issues related to wayfinding:

- whether people should be directed along unmarked trails in the Umpqua Dunes Recreation Area; and
- whether people should be directed to small "islands" of high ground within the inundation zone rather than farther to the "main" safety area outside the inundation zone.

Bridge failure was simulated by removing that section of the road network, forcing the model to recalculate routes that originally relied on bridge connectivity. As of the date of this publication, none of the bridges have been designed to withstand significant seismic forces (Douglas County Public Works and City of Florence Public Works, oral communication, 2018). Bridge failure typically results in longer distances to safety, either by requiring a longer route to the original safety destination or by rerouting to a completely different destination. There are also several cases where the removal of a bridge does not affect anyone's evacuation potential because there is high ground on both sides of the bridge. This information can be important when prioritizing which bridges to retrofit or construct as part of a long-term resilience plan.

In coastal towns, landslide-prone slopes and saturated sandy soils are common; therefore slides, liquefaction (**Figure 2-1A**), and lateral spreading (**Figure 2-1B**) are likely to occur during an earthquake (Madin and Wang, 1999). These hazards will damage roads and reduce walking speeds by significant but indeterminate amounts. Because knowing where to remove routes remains highly uncertain and site specific, we did not model the effect of lateral spreading on evacuation difficulty. However, we did evaluate evacuation difficulty due to liquefaction in areas with high susceptibility (Madin and Burns, 2013). This was achieved by adjusting the land cover values to reflect loose sand instead of pavement for those roads potentially susceptible to liquefaction, thereby increasing the time it would take to evacuate along these roads; additional information describing land cover values is discussed in section **2.3.3**. By identifying at-risk areas, a community can focus additional efforts on possible mitigation options like retaining walls, soil replacement, vibro compaction, and construction of liquefaction-proof paths.

Figure 2-1. Water-saturated sand can turn to quicksand during strong shaking, forming sand boils, ponding, and sunken roads. In these examples, (A) extensive liquefaction occurred along River Road in Christchurch, New Zealand following the February 2011 earthquake, while (B) effects from lateral spreading along numerous Christchurch roads constructed next to waterways resulted in major failures to road infrastructure as roads slumped toward river channels. During a Cascadia subduction zone event, such processes could compromise tsunami evacuation routes as well as the time and speed to safety in areas prone to liquefaction. (Photo credits: Martin Luff, licensed under CC BY-SA 2.0)

For landslide potential, we used the Statewide Landslide Information Database for Oregon (version 3.4, http://www.oregongeology.org/slido/index.htm) to evaluate previously identified landslides in the Reedsport and Florence areas. We also considered possible landslide activity based on susceptibility mapping by Burns and others (2016). From these data we determined that there were no obvious situations where a landslide could completely remove an evacuation route, so we did not consider hypothetical scenarios involving landslides. This decision is reinforced by the fact that the local geology, composed primarily of resistant sandstones, appears to be not particularly slide prone. However, it is likely that the area will be littered with smaller surficial slides (and possibly new deep-seated slides) after the earthquake, which will likely affect many roads; evaluating such landslides is beyond the scope of this study.

In some localities, safe and effective evacuation to high ground may not be feasible due to terrain challenges (high ground is too far away) or to potential failure of critical evacuation infrastructure such as bridges. Given these circumstances, communities may want to explore the construction of a vertical evacuation structure, designed to withstand the forces directed at it by the tsunami. Such structures include soil berms, multi-story parking garages, community facilities, commercial facilities (e.g., hotels), and schools (Applied Technology Council, 2012). In the United States, the first vertical evacuation (VE) structure was opened in June 2016 at the Ocosta Elementary School on the Westport Peninsula in Washington State. The structure is the school's new gymnasium and has unrestricted (open) access to its rooftop, where schoolchildren and residents may congregate during a tsunami evacuation. We incorporate VE structures into BTW modeling by editing the tsunami hazard zone to exclude a small polygon of safety at the location of a hypothetical structure.

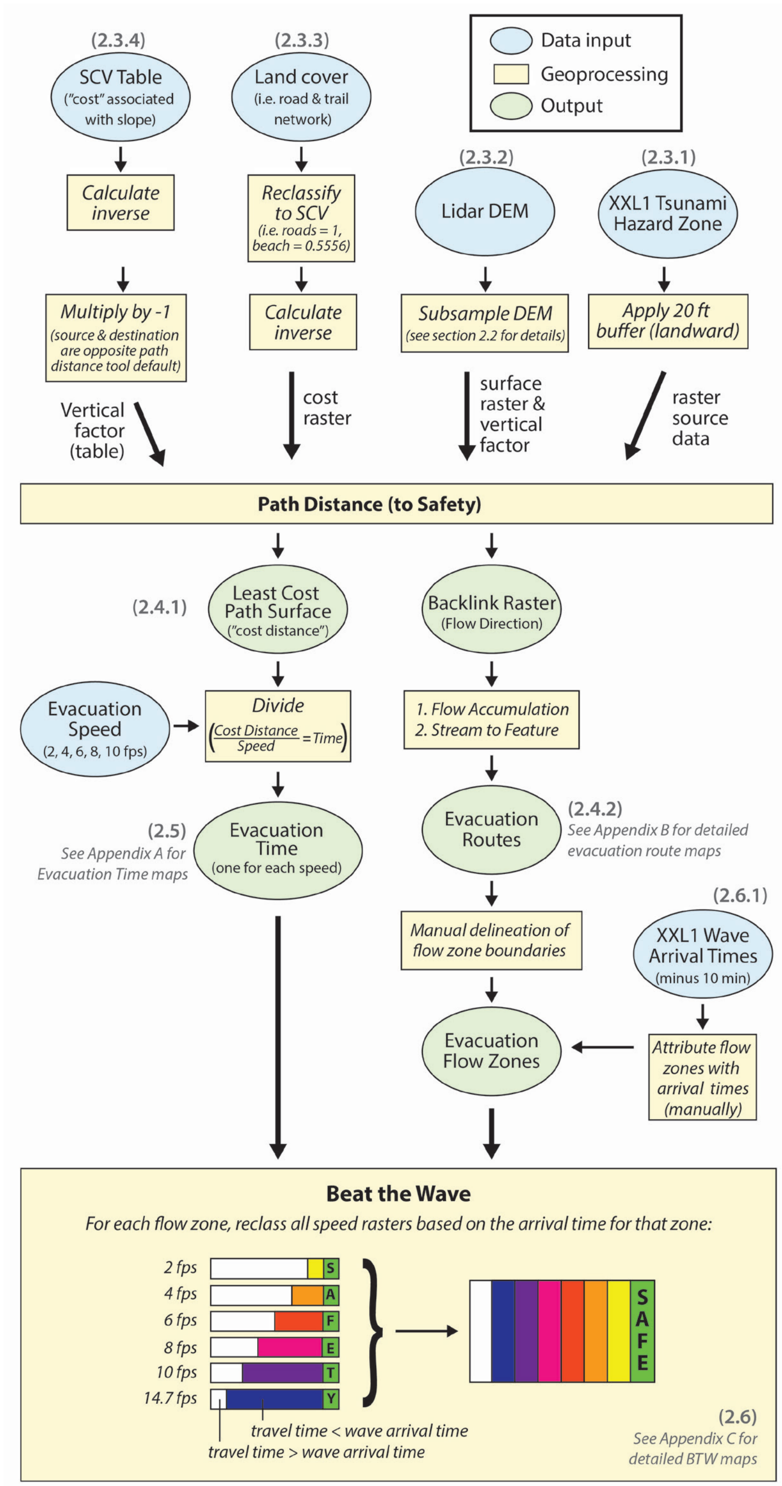
Mitigation scenarios considered for the Reedsport and Florence project areas include the construction of new evacuation trails and vertical evacuation structures. Overall, the evacuation landscape in both areas is quite good, and wayfinding and outreach appear to be more important to survival than significant infrastructure improvements. As a reminder, we are only referring to mitigation in terms of life safety, meaning getting people out of the tsunami zone in the short amount of time between the earthquake and tsunami.

2.3 LCD model inputs

LCD modeling is based on four inputs: the XXL tsunami inundation limit, a digital elevation model (DEM), a land surface cost raster, and a table relating slope to cost. The road and trail network is provided via the land surface cost raster. The tsunami inundation limit (plus 20 feet for conservatism) serves as the destination for all evacuation routes. The DEM is used to determine actual distances and slopes. The slope data, in conjunction with the slope table, are used to apply a cost reflecting evacuation difficulty due to hilliness. The land cost raster contains a second set of cost values reflecting evacuation difficulty due to terrain. A detailed discussion of all four inputs is presented in the following sections.

We implemented LCD modeling by using Esri® ArcGIS® 10.6 software. The path distance tool uses geospatial algorithms to calculate the most efficient route from each point in the evacuation zone to "safety," defined for the purposes of this study as ~20 feet (6 m) beyond the maximum inundation limit; this is where the tsunami flow depth and velocity are effectively zero. The product of this tool is referred to as the least-cost path distance surface and it reflects an artificial distance to safety for every point in the evacuation zone that contains the difficulty of walking that route. **Figure 2-2** summarizes the steps and inputs into the path distance tool as well as the subsequent BTW approach.

Figure 2-2. Model diagram of path distance approach from Wood and Schmidtlein (2012) and Wood and others (2016). SCV is speed conservation value; DEM is digital elevation model. The methodology was first detailed by Priest and others (2015a,b). XXL is the maximum-considered Cascadia subduction zone (CSZ) tsunami scenario, covering 100 percent of potential CSZ tsunami inundation (Witter and others, 2011, Priest and others, 2013b). Unit fps is feet per second. Grey numbers indicate sections in this report where a step is discussed in detail.



2.3.1 Tsunami hazard zone

Safety is reached when an evacuee has reached ~20 feet beyond the limit of tsunami inundation for the purposes of this study. The inundation zone used in this study is XXL1, derived from digital data of Priest and others (2013a,b). This zone covers 100 percent of potential CSZ inundation (Witter and others, 2011), meaning it is the largest CSZ event likely to occur based on the 10,000 year record, and reflects the zone used for evacuation as shown in community brochures (http://www.oregongeology.org/tsuclearinghouse/pubs-evacbro.htm) and online (http://nvs.nanoos.org/TsunamiEvac) for the entire Oregon coast.

Safety destinations represent locations on the road and trail network that are ~20 feet beyond the limit of XXL inundation. These locations were created by applying a buffer of 20 feet (6 m) on the landward side of the inundation boundary polyline and converting this into a raster data file.

2.3.2 DEM

Initially, we created a high-resolution digital elevation model (DEM) by interpolating lidar ground points into a 6-ft-resolution raster; in areas characterized by bridges, we used lidar highest-hit data to define the bridge walking surface. We smoothed the DEM grid, because generated slope profiles are too noisy, introducing slope artifacts of significant amplitude (e.g., a 3-inch elevation difference between cells 1 foot apart yields a 14° slope) that add significantly more time to the total calculated time (Priest and others, 2015a,b). To smooth the data, we created points at 50-foot intervals along all evacuation paths including major roads and at intersections, and we attributed those points with elevation values from the native 3-foot-cell lidar DEM. Priest and others (2015a,b) performed trials at 25, 50, and 100 feet and found that the 50-foot interval achieved the best compromise between accuracy and smoothness. Final sampling interval was ~50 feet on straight paths and somewhat less for curved paths in order to depict accurately the curvatures. We then interpolated those points using an Esri Natural Neighbor function to produce a smoothed DEM that closely emulated the actual elevation values of the lidar while dramatically reducing slope noise.

2.3.3 Land cover raster

The land cover raster serves two purposes: 1) it defines the spatial extent of the road and trail network, and 2) it describes the land cover for all surfaces in the region, by assigning a specific level of difficulty of movement across the surface for each pixel. In the Wood and Schmidtlein (2012) approach these difficulty or cost values are categorized as speed conservation values (SCV), where each value is representative of a land cover type across the landscape. Land cover SCVs adjust the base travel speed using terrain-energy coefficients discussed by Soule and Goldman (1972), including "No Data'' to note where travel is not allowed (e.g., over water, through fences or buildings, and across most natural/undeveloped areas for this case study). The base travel speed assumes constant energy expenditure. Conversely, the constant energy expenditure assumption yields slower walking speeds under non-ideal walking conditions. Ultimately, the SCVs artificially increase the path distance across a pixel (6 ft) to reflect the difficulty in walking that section of road or trail. The SCV values used are shown in **Table 2-1**, and a sample land cover raster is shown in **Figure 2-3**.

Table 2-1. Speed conservation values used in modeling pedestrian evacuation difficulty in this study.

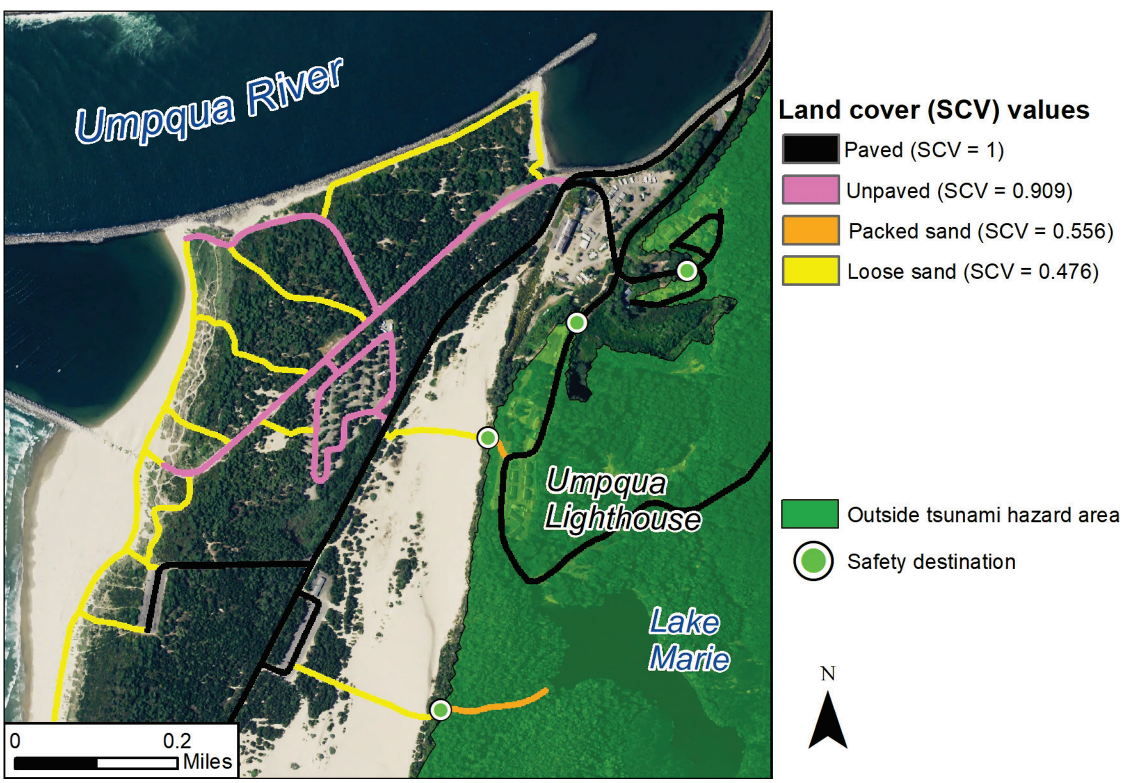
Feature Type	Speed Conservation Value*
Roads (paved surface)	1
Unpaved trails	0.9091
Dune trails (packed sand)	0.5556**
Muddy bog	0.5556
Beaches (loose sand)	0.476
Everywhere else	0

*Speed conservation values (SCV) are derived from Soule and Goldman (1972).

**Trails in the dune areas given the same SCV as sand given by Wood and Schmidtlein (2012).

GIS polylines representing all roads and trails in the project area were converted to polygons and attributed with land cover values (i.e., 1 for paved surfaces, 0.556 for packed sand, etc.). The polygons were then converted into a raster (6 ft cell size) for input into the LCD model.

Figure 2-3. Example of land cover raster, which serves the dual purpose of defining the road and trail network as well as classifying it with land cover values. Base map is 2014 National Agriculture Imagery Program (NAIP) imagery; the XXL inundation boundary (the non-green area) on this and following figures is from Priest and others (2013b).



2.3.4 Speed conservation value (SCV) slope table

We created a table that associates slopes with a specific SCV value. This table uses the same values as those of Wood and Schmidtlein (2012), and, as in their approach, we estimated the effect of slope on speed from Tobler's (1993) hiking function:

$$\text{walking speed (km/hr)} = 6e^{-3.5 \times \text{abs}(\text{slope}+0.05)}$$

where slope is equal to the tangent of the slope angle. This formula is based on empirical data of Imhof (1950) and predicts that speed is fastest on gentle (−3°) downslopes. **Table 2-2** presents an example set of slope and SCV values. The actual table used includes slope values from −90° to +90° in 0.5° increments. A positive slope (upward) results in a slower walking speed and is assigned a larger cost. The same applies for a large negative slope (steeply downward), while a slight decline (~3°) in the slope reflects the optimal condition

Table 2-2. Speed conservation values used to calculate evacuation difficulty due to traversing hills, with slope determined for each pixel from the digital elevation model.

Slope (degrees)	Tobler Walking Speed (fps)	Speed Conservation Value*
−10	3.6	1.5
−5	4.8	1.1
−2.75 (ideal)	5.5	1
5	3.4	1.6
10	2.5	2.2

*Table displays an example set of values. Actual table used in modeling includes slope values from −90° to +90° in 0.5° increments. fps is feet per second.

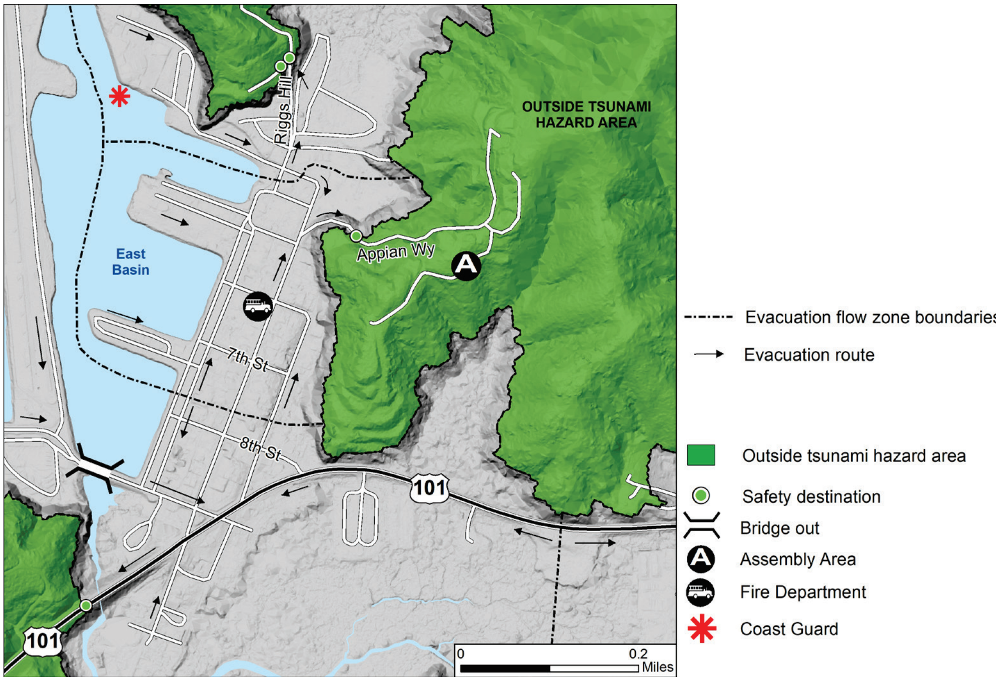
2.4 LCD model outputs

The LCD model outputs a path distance surface showing the effective distance to safety from each pixel and a flow direction raster containing detailed route information. From these data we create route, evacuation time, and BTW maps.

2.4.1 Path distance surface

The pixel values on the path distance surface represent the effective distance, along the least-cost path, from the pixel to the point where the path intersects safety. For example, from the Winchester Bay rural fire station (fire truck symbol in **Figure 2-4**), the actual distance to safety on Appian Way is 900 feet while the least-cost path distance is 913 feet (path distances not shown on map). This difference is due to the model having accounted for variations in slope and landcover along the entire route. The fact that the difference is small in this example highlights how some locations do not encounter much evacuation difficulty. In this case, the route from the fire station to Appian Way is relatively flat until the very end, and the path is paved the entire way.

Figure 2-4. Example of a network of generalized evacuation flow zones and select evacuation route arrows from a least-cost-distance analysis limited to trails and streets. Base map on this and subsequent figures is shaded relief from 2009 lidar data (Oregon Lidar Consortium South Coast Project).



2.4.2 Evacuation routes and flow zones

The LCD backlink raster shows, for each cell, the direction of the next cell on the least-cost path. This raster makes it possible to trace the path to safety from any pixel and is equivalent to a flow direction raster, which is the first step in hydrologic modeling of topographic surfaces. We use the hydrologic tools in ArcGIS 10.6 and the backlink raster to extract a “stream” network to visualize the paths depicting the most efficient pedestrian flow for evacuation. Evacuation flow zones with arrows depicting the most efficient routes are shown in **Figure 2-4**. These paths represent the shortest effective distances to the nearest safety destination and are referred to as evacuation routes. Detailed evacuation routes are presented in **Appendix A**.

The routes can be simplified by identifying the boundaries of evacuation flow toward the nearest safety location. At these boundaries, one could travel in alternate directions to reach safety on separate paths that require equal amounts of effort (distance with slope and land cover effects included). These evacuation flow zones are directly analogous to watershed boundaries or drainage divides in hydrologic modeling. As an example, **Figure 2-4** shows that the nearest safety destination for people on 7th St in Winchester Bay is Appian Way while the nearest safety destination for people on 8th St is Highway 101 to the south. The dashed black line delineates the evacuation flow zone boundary.

Flow zone polygons are drawn manually using the evacuation routes as a guide. Flow zone rasters may also be generated using the Esri Watershed tool in the Hydrology toolset. However, we found this latter method to be useful as a guide only, not as a source of functional data.

The importance of these boundaries varies depending on the area. In some areas, everyone needs to head in the same general direction (e.g., the northern margin of Old Town Florence; **Figure B-5**), and the decision to take one road versus another is minor. In other locations such as the previous example in

Winchester Bay, flow zone boundaries inform the decision to travel in potentially opposite directions (e.g., north to Appian Way or south to Highway 101; **Figure 2-4**).

2.5 Evacuation time maps

The path distance surfaces were converted to walking times to compare tsunami arrival times to pedestrian arrival at various critical junctures. This was done by dividing the path distance surface raster by a constant speed (distance ÷ speed = time). We assumed a pedestrian walking speed of 4 feet per second (fps) (22 minute/mile; 1.22 meters/second), listed as a moderate walk by Wood and Schmidtlein (2012). This is the speed generally required to cross from curb to curb at signalized intersections (Langlois and others, 1997; U.S. Department of Transportation, 2012).

As we constructed the 4 fps evacuation time maps, it became apparent that in order to fully explore an array of evacuation speeds appropriate for specific populations (e.g., elderly or small children versus able-bodied adults) we would have to make many more time maps using different speeds. This is explored further in the next section where we discuss the development of tsunami wave front advance maps and integrating tsunami wave arrival data directly into the LCD analysis to produce beat the wave (BTW) maps that estimate the ***minimum speed*** needed to reach safety ahead of the wave.

2.6 Beat the Wave (BTW) modeling

BTW modeling integrates the results of the tsunami wave arrival times and the least-cost path distance analyses to enable the public to better understand the ***minimum speeds*** required to evacuate the inundation zone to avoid being caught by the approaching tsunami. BTW modeling is done by producing a suite of evacuation time maps at different walking speeds and combining them into one map based on unique wave arrivals for each evacuation flow zone. The goal of BTW maps is to highlight areas that have elevated evacuation difficulty in order to direct future mitigation efforts as well as to educate the public on where to go and how fast they must travel.

2.6.1 Wave arrival times

To understand the complexities of tsunami wave advance across the landscape, we extracted the time after the CSZ earthquake at which the XXL tsunami flow depth reached more than 0.5 ft at each computational grid point and interpolated those arrival data to create a continuous map showing wave arrival time. We examined profiles of the data on various LCD paths to identify possible locations along routes where waves arrive so fast that minimum BTW speeds necessary to reach safety are too slow to get an evacuee past the compromised location (Priest and others, 2015a); however, no locations were found in the Reedsport and Florence study areas.

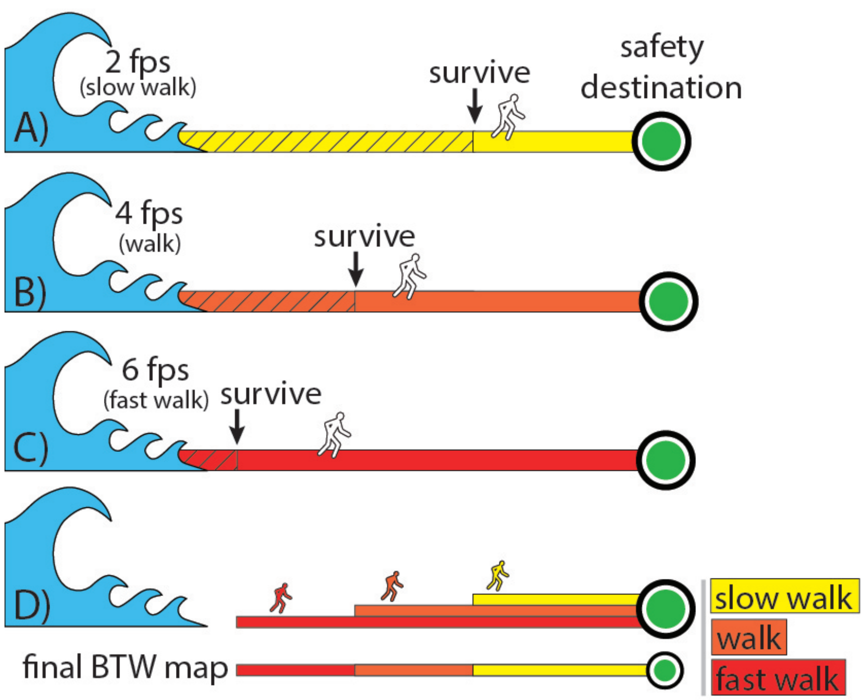
Wave arrival times were then assigned to each evacuation flow zone based on the time when the first wave reaches the *point of safety* for each zone. Depending on the safety destination, this time can be less than 15 to more than 30 minutes after the tsunami first reaches land. We then subtracted 10 minutes from the simulated tsunami arrival times to account for the time in which earthquake shaking takes place, as well as disorientation, and the time required to evacuate buildings. Using the March 11, 2011 Tohoku earthquake (USGS, 2012) as an analogue to an XXL or L1 scenario, the minimum delay is probably ~3–5 minutes of strong shaking for the ~Mw 9.0 event. There are little empirical data on how long it takes people to begin evacuation after shaking, but Mas and others (2013) determined a mean of 7 minutes in 2010 and 2011 surveys at La Punta, Peru, which had experienced several local earthquakes and tsunamis over the last ~400 years, the last being in 1974. We therefore simulate a delay of 10 minutes mainly for earthquake shaking (the minimum of 3 minutes for shaking plus 7 minutes based on the La Punta survey). This is a rough estimate meant to account for the myriad of unique actions taken by evacuees such as looking for family members, digging out of rubble, or packing a bag.

For the open coast recreation areas (South Jetty in Florence and Umpqua Dunes in Reedsport), we reduced the delay from 10 minutes to 5 minutes to reflect the likelihood of people being outside (or inside an RV or tent) when the earthquake begins. Less time will be required to exit a building and yard before beginning an evacuation.

2.6.2 Reclassifying evacuation time maps into BTW

We generated multiple evacuation time maps using pre-determined evacuation speeds (2, 4, 6, 8, 10, and 15 fps). These time maps were then clipped twice: once to separate flow zones and again based on the unique wave arrival time for each zone. For each evacuation speed within a flow zone, the surface was clipped at the point where the time to reach safety was greater than the wave arrival time. These clipped grids were then mosaicked together, with the minimum speed for each cell maintained. These steps are described graphically in the final step of **Figure 2-2** and in **Figure 2-5**.

Figure 2-5. Graphic explanation of evacuation time reclassification. (A) At a speed of 2 fps, only evacuees quite close to the safety destination can get there in time. At (B) 4 fps and (C) 6 fps, evacuees farther from safety can reach safety ahead of the tsunami. (D) Evacuation time maps clipped at wave arrival thresholds are combined to generate BTW maps showing minimum speeds necessary to reach safety ahead of the tsunami.



Binning of evacuation speeds was initially limited to five categories, which allow enough contrast in color choice that areas can be easily perceived on the map. A literature review of typical pedestrian speeds by Fraser and others (2014) found five travel speed groups: adult impaired, adult unimpaired, child, elderly, and running (**Table 2-3**). The ranges of speeds for these groups at one standard deviation (the last two rows of **Table 2-3**) provide some guidance for establishing bins that would be useful on the BTW map. Speed categories in the map explanation were then given qualitative names such as "slow walking" and "running," so the public could relate speed bins to their experience. Of particular interest are groups that will be most vulnerable, such as impaired adults and the elderly with mean speeds of 3 fps and a range of ~2–4 fps (**Table 2-3**). After examining the range of BTW speeds for Seaside (Priest and others, 2015b) and reviewing a number of references describing speed categories (Paul, 2013; Margaria, 1968), we settled on the following five speed bins:

- Very slow walking at 0–2 fps
- Slow walking at 2–4 fps for elderly and impaired adults
- Walking at 4–6 fps for unimpaired adults
- Fast walking to slow jogging at 6–8 fps for fit adults
- Running at >8 fps

However, for extremely long path distances and fast wave-arrival times, we further divided the highest bin (>8 fps) into three bins to understand better the likelihood of survivability:

- Running at 8–10 fps
- Sprinting at 10–14.7 fps (14.7 fps = 10 mph)
- Unlikely to survive at > 14.7 fps

A small experiment was conducted at Seaside to evaluate the validity of the ***walk***, ***fast walk***, and ***slow jog*** BTW evacuation speed bins and to assess the difficulty in maintaining a constant minimum speed over the course of an entire evacuation route (Gabel and Allan, 2016). Five key routes were traversed by Gabel and Allan, who recorded their average speed along the route and the times when they reached critical locations (bridges, low areas, and safety). Overall, the tests indicated that when traveling at the speed specified by the BTW data, an evacuee will reach safety ahead of the tsunami. However, as speeds fall below the prescribed BTW speeds, the results of Gabel and Allan confirmed that the tsunami could overrun the individual. This limited test of BTW data suggests that the data are reasonable guides to <u>minimum</u> evacuation speeds necessary to reach safety ahead of the tsunami.

Table 2-3. Travel speed statistics for each travel speed group, compiled from travel speeds in the literature by Fraser and others (2014). σ denotes standard deviation.

	Adult Impaired	Adult Unimpaired	Child	Elderly	Running
Minimum	1.9 fps	2.9 fps	1.8 fps	0.7 fps	5.9 fps
Maximum	3.5 fps	9.2 fps	6.9 fps	4.3 fps	12.6 fps
Mean	2.9 fps	4.7 fps	4.2 fps	3.0 fps	9.1 fps
σ	0.6 fps	1.6 fps	2.6 fps	1.0 fps	3.3 fps
Mean + 1σ	3.5 fps	6.3 fps	6.8 fps	4.0 fps	12.4 fps
Mean − 1σ	2.3 fps	3.1 fps	1.6 fps	2.0 fps	5.8 fps

2.6.3 Reading a BTW map

BTW maps are provided in **Appendix C**. As previously stated, the modeling approach produces ***minimum*** evacuation speeds that must be maintained along the entire route to safety. Actual travel speeds on any evacuation route will require either variable expenditure of energy to maintain a constant speed in all conditions, or higher speeds in easier terrain (flat paved streets) to compensate for slower speeds in more difficult terrain (e.g., steep slopes or sand).

BTW map colors represent the speed that must be **maintained** from each location all the way to safety. If an evacuee slows down for some portion of the route, he/she must account for the time deficit by traveling faster than the required speed for the remainder of the route. We stress this point because the map can be misleading: as a route approaches safety the roads along which one travels show a slower BTW speed, but an evacuee cannot slow down. The slower speed is only relevant for someone starting evacuation from that closer location.

2.7 Socioeconomic analysis

Exposure analyses involve tallying buildings that are within a tsunami hazard zone and then associating the buildings with population data and, ultimately, BTW walking speeds. This is an alternative approach to assessing risk when detailed loss estimations are not readily available (e.g., Hazus results [Federal Emergency Management Agency, 2017]) to quantify what is and what is not at risk.

A key piece of the risk assessment is the study area building inventory. This inventory consists of all buildings larger than 500 square feet (152 square meters), as determined from existing building footprints or tax assessor data. **Figure 2-6** shows an example of buildings that are exposed to different tsunami scenarios, and **Figure 2-7** shows an example of occupancy types of coastal Lane County's building inventory used in the exposure analyses. For population purposes, we focus primarily on residences.

Figure 2-6. Tsunami inundation scenarios and building exposure example in Florence (M. C. Williams, DOGAMI written commun., 2018).

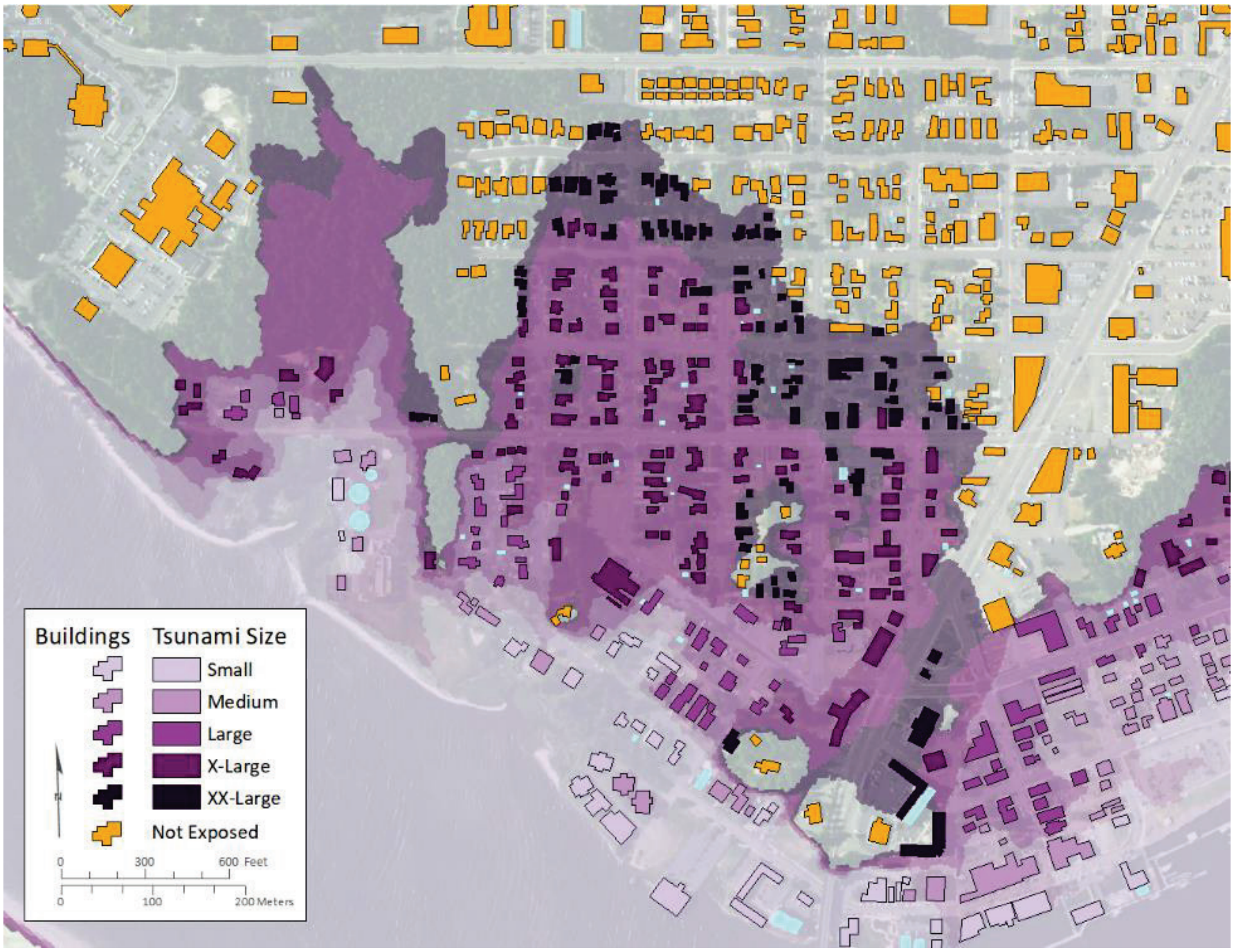


Figure 2-7. Building occupancy types, portion of City of Florence (M. C. Williams, DOGAMI, written commun., 2018).

Within the building inventory, the population of permanent residents reported per census block was distributed evenly among residential buildings (U.S. Census Bureau, 2010a). The authors of the report did not examine the impacts to the non-permanent population (e.g., tourists), whose total numbers fluctuate seasonally. Due to lack of information within the population sources (assessor and census), this distribution also includes vacation homes, which in many coastal communities make up some of the total residential building stock. American FactFinder (U.S. Census Bureau, 2010b) estimates that approximately 3% of residential buildings in coastal Douglas County and 8% in coastal Lane County are vacation rentals.

Using this distribution, we estimated the number of permanent residents that could be affected by an Medium, Large, and XXL CSZ tsunami. We then assigned buildings within the XXL tsunami zone with BTW walking speeds and analyzed population distributions with respect to how fast they must travel to survive. Socioeconomic analysis results are presented in section 3.3.

3.0 RESULTS AND DISCUSSION

Results from our tsunami evacuation and BTW analyses are presented separately for each community. In general, we find that the public are able to escape a maximum-considered Cascadia tsunami from all major population areas in Reedsport and Florence with most locations requiring minimum walking speeds of 4 fps (***walk***). The exception is a portion of Winchester Bay where the public are dependent on the Salmon Harbor Bridge to reach safety. We identify several other areas that will be challenging for evacuation, including the Umpqua Dunes (**Figure 3-1**), Siuslaw South Jetty (**Figure 3-11**), and the Baker and Sutton Beach trails (**Figure 3-11**). Although these popular recreational sites have few permanent residents, the sites experience several thousand (transient) people on a busy summer weekend (oral communication with Douglas County Emergency Manager Wayne Stinson and City of Florence Planning Director Wendy Campbell, 2018).

BTW evacuation modeling results will be presented for the Reedsport project area, then the Florence project area. Socioeconomics results will be discussed jointly and are presented in section **3.3**. For each project area we first examine tsunami wave arrival times, then discuss the detailed evacuation modeling results for each community within XXL tsunami zone. When applicable, hypothetical scenarios such as bridges failures and liquefaction are included.

Unless otherwise noted, all scenarios include a 10-minute delay before commencing evacuation to account for the expected disorientated state of the public following the severe earthquake shaking, and the time required to exit buildings. This delay was reduced to 5 minutes for the Umpqua Dunes Rec Area (Reedsport) and the South Jetty, Baker, and Sutton Beach (Florence) areas because people in these locations will already be outdoors when the earthquake strikes. Although they may remain in place for the 3–5 minutes of earthquake shaking before beginning their evacuation, the additional ~5 minute-delay to exit a building is not necessary. **Table 3-1** represents a summary of the range of speeds and their conversions that will be used throughout the remainder of this report.

One important note—it is inevitable that following a disaster other factors will contribute to impede travel times. This modeling does not account for these ancillary effects. As a result, ***the public should maintain the overarching goal of immediately evacuating following the earthquake, and moving as rapidly as possible in order to ensure they reach safety with ample time to spare.***

Table 3-1. Pedestrian evacuation speed categories and their conversions.

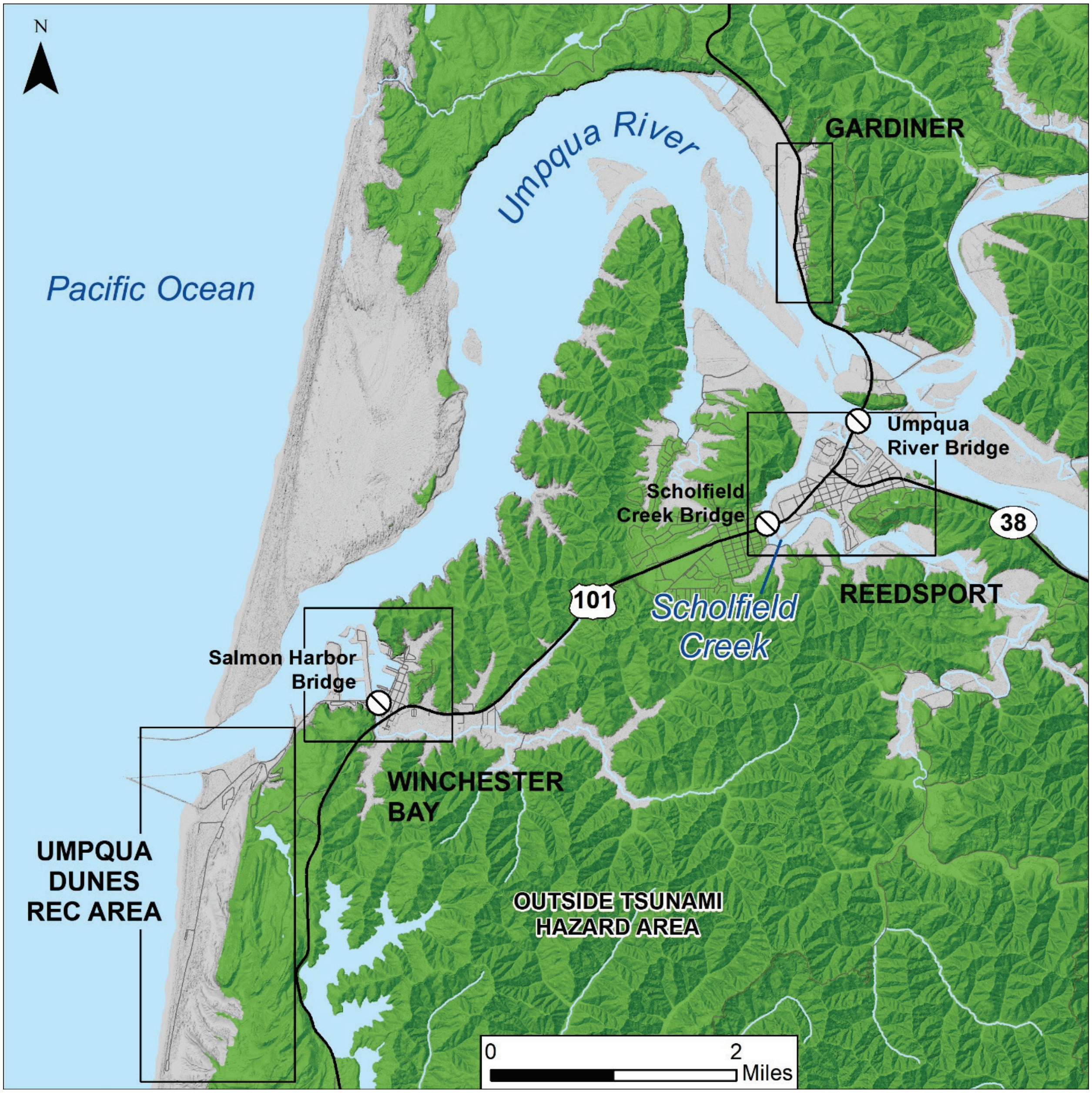
Description	Feet per Second (fps)	Miles per Hour (mph)	Minutes per Mile
Slow walk	>0–2	>0–1.4	>44
Walk	2–4	1.4–2.7	44–22
Fast walk	4–6	2.7–4.1	22–14.7
Jog	6–8	4.1–5.5	14.7–11
Run	8–10	5.5–6.8	11–8.8
Sprint	10–14.7	6.8–10	8.8–6.0
Unlikely to survive	>14.7	>10	<6.0

Note: walking at speeds of 2–4 fps is considered a reasonable measure for the elderly and for adults who may be mobility impaired (see Figure 6 of Fraser and others, 2014).

3.1 Reedsport project area

The Reedsport project area includes City of Reedsport, Gardiner, Winchester Bay, and the Umpqua Lighthouse and Dunes Recreation ("Rec") Area (**Figure 3-1**).

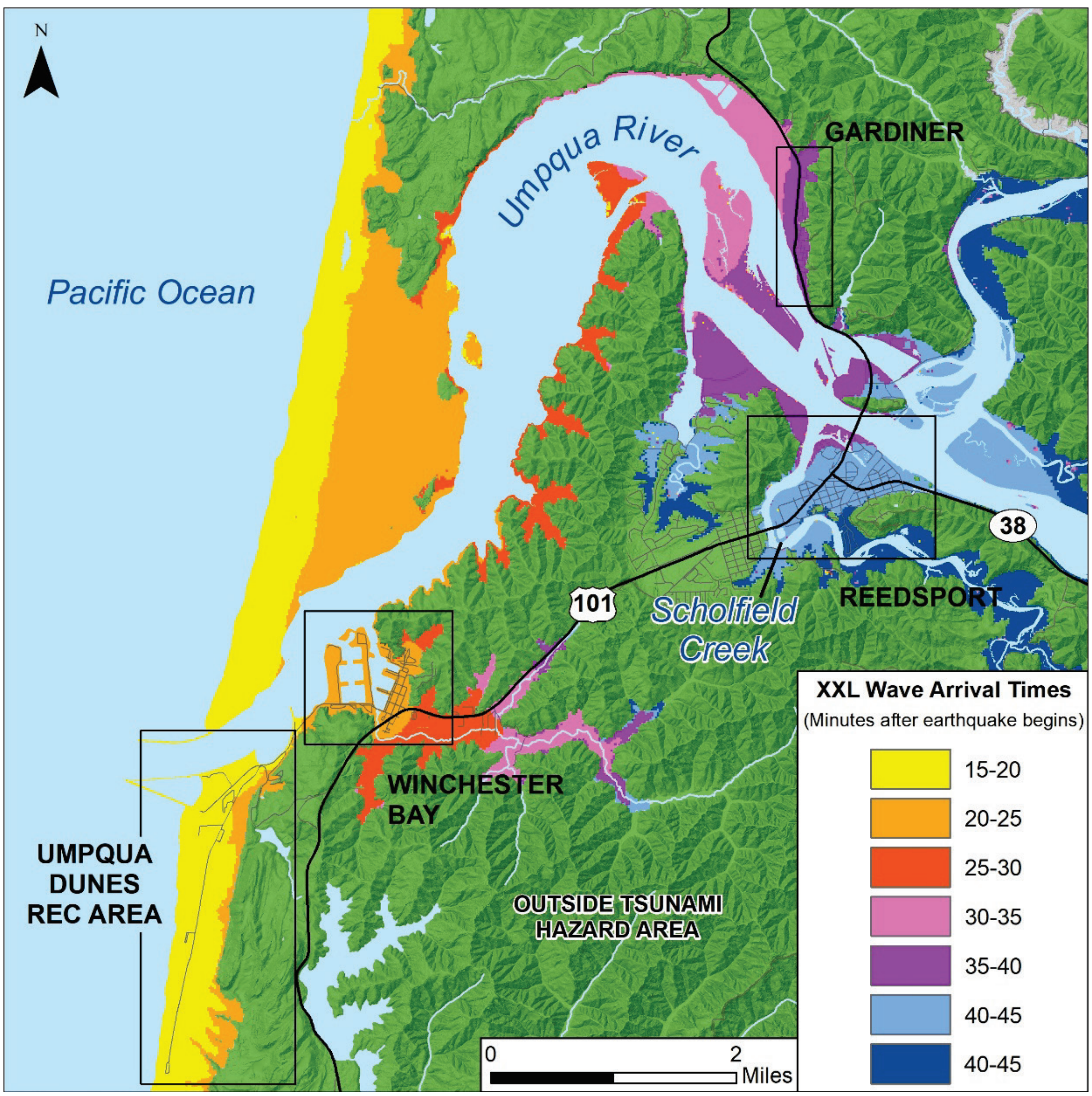
Figure 3-1. Area map of the Umpqua River estuary including the communities of Reedsport, Gardiner, Winchester Bay, and the Umpqua Dunes Recreation Area.



3.1.1 Tsunami wave arrivals

Figure 3-2 demonstrates the arrival times for an XXL tsunami in the Reedsport project area. The earliest wave arrivals are along the open coast; the tsunami reaches the beach ~16–18 minutes after the start of the earthquake shaking. By 22 minutes, the entire Umpqua Lighthouse and Dunes Rec Area is expected to be inundated. Winchester Bay is inundated at 24 minutes, the tsunami having entered the estuary mouth and overtopped of the Umpqua Spit. It takes an additional ~12 minutes for the tsunami to reach Gardiner, which is inundated by ~36 minutes after the earthquake. In 40 minutes the wave has reached Reedsport, and within about 5 minutes all of town is inundated, with the tsunami flooding both the Umpqua River and Scholfield Creek. The tsunami continues upriver past Reedsport, reaching its farthest upriver extent after about 2 hours at river mile 25, just before the town of Scottsburg (not shown in figure). Additional waves will continue to strike the coast and enter the estuary, causing water levels to fluctuate for up to 12 hours after the earthquake. Tsunami wave arrival time data are found in the Florence_Reedsport_Tsunami_Evacuation_Modeling geodatabase, TsunamiWaveArrival_XXL1 dataset.

Figure 3-2. Illustration of XXL tsunami wave arrivals after a Cascadia subduction zone earthquake for the Umpqua River estuary.



3.1.2 City of Reedsport

The city of Reedsport can be divided in two parts separated by Scholfield Creek. Everything east of the Hwy 101 bridge over Scholfield Creek ("Scholfield Bridge"), often called "lower Reedsport", is inundated in the XXL tsunami scenario, while "upper Reedsport" west of the Scholfield Bridge is on high ground, outside the XXL tsunami zone (**Figure 3-1**). The police station and city hall are within the inundated area while the hospital, fire station, and schools are safe. *For the remainder of the report, when we refer to "Reedsport" we will be referring to the inundated areas of Reedsport.*

We had some difficulty mapping where the levee and railroad "trails" connect with roads adjacent to East Railroad Ave, given that we are considering pedestrian evacuation only. While the resulting network may leave out several connections, we feel the roads and trails modeled provide sufficient detail and any "shortcuts" will only serve to make an evacuee's path shorter and faster than what is modeled for the community. We do not anticipate any shortcuts significantly changing evacuation flow zones or modeled BTW walking speeds.

Overall, the evacuation analyses show that there is significant high ground around the margins of Reedsport. Our modeling indicates the following:

1. Many evacuation routes are available to the public. This means evacuation to high ground can be achieved in a timely manner; and,
2. The modeled BTW pedestrian evacuation speeds for much of the community were determined to be low (***slow walk***), regardless of the potential for bridge failure or liquefaction. Because of this, no mitigation options were evaluated for Reedsport. As noted previously, these are minimum recommended speeds and the public should endeavor to evacuate as rapidly as possible.

3.1.2.1 Scenario 1—Existing road network/failure of Umpqua River Bridge and Scholfield Creek Bridge

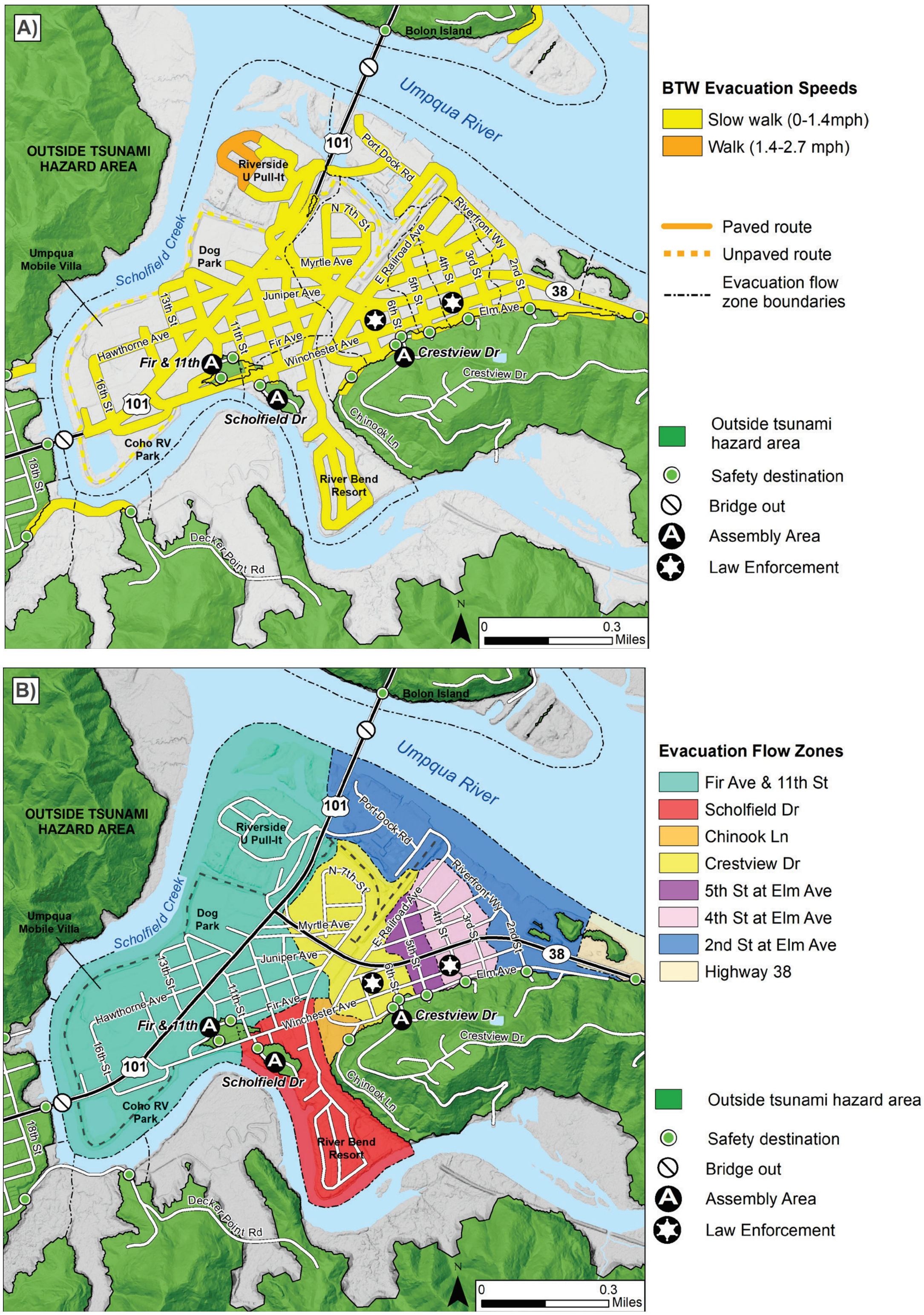
This scenario combines the results of two model runs: 1) assuming the existing road and bridge network remains intact, and 2) assuming the two bridges fail. Results from the first run indicate a natural divide between evacuation flow zones at both bridges, meaning no one needs to cross a bridge to reach the nearest high ground. Therefore Scenario 1 presents results for both "with" and "without" the Umpqua River Bridge and Scholfield Creek Bridge. Because both bridges are unlikely to withstand the shaking from a Cascadia earthquake, figures in this report include the "bridge out" symbol.

Figure 3-3 shows the least-cost (path) distance modeling for lower Reedsport. The purpose of this modeling is to identify and define detailed evacuation routes, which ultimately are used to define the evacuation flow zones in each sub-community. Each of the evacuation flow zones defines an area being evacuated and the associated nearest destination point(s) of safety (defined by bright green circles) located outside the inundation zone. The solid green color outside the tsunami inundation zone indicates "safety" in a maximum considered XXL local tsunami event.

Figure 3-3A shows that evacuation in Reedsport looks extremely positive. Because tsunami wave arrival times for the neighborhood are on the order of ~40–45 minutes (**Figure 3-2**) and most locations are relatively close to evacuation destinations (i.e., safety), virtually the entire area is characterized with a **minimum** evacuation speed of ***slow walk***, with the only exception being the Riverside junkyard, which is characterized as ***walk***.

Figure 3-3B shows that Reedsport is characterized by eight evacuation community flow zones (corridors). The primary source of high ground is along Elm Ave, which runs along the base of Crestview Heights. Five north-south roads intersect Elm and reach safety in this area (2nd St, 4th St, 5th St, Crestview Dr, and Chinook Ln), defining the five main flow zones for the areas south of Highway 101 and east of N 9th St. One additional flow zone in this area encompasses a small section of Highway 38 that quickly rises out of the inundation zone as the highway exits town. There are also two "islands" of high ground: 1) by Fir Ave and N 11th St, and 2) Scholfield Dr. Hwy 101 and the central part of town evacuates to the Fir and 11th island, while the River Bend Mobile Resort evacuates to the Scholfield Dr island. The final safety destination encompasses the very western edge of Reedsport, evacuating 16th St and the levee trail along Scholfield Creek west across the Scholfield Bridge to safety just on the other side, if the bridge is available; if not, evacuees go to the "islands." Note that the Umpqua River bridge connecting Reedsport to Bolon Island is a natural break between evacuation communities, meaning no one in Reedsport needs to cross the Umpqua River bridge to reach their nearest high ground. **Figure B-1** shows the detailed evacuation route map for Reedsport. **Figure A-1** presents the 4-fps evacuation time map for Reedsport. **Figure C-1** presents the BTW map for the City of Reedsport. Walking speeds on the roads and trails as well as evacuation flow zone data are found in the Florence_Reedsport_Tsunami_Evacuation_Modeling geodatabase, BridgesOut_XXL1 feature dataset.

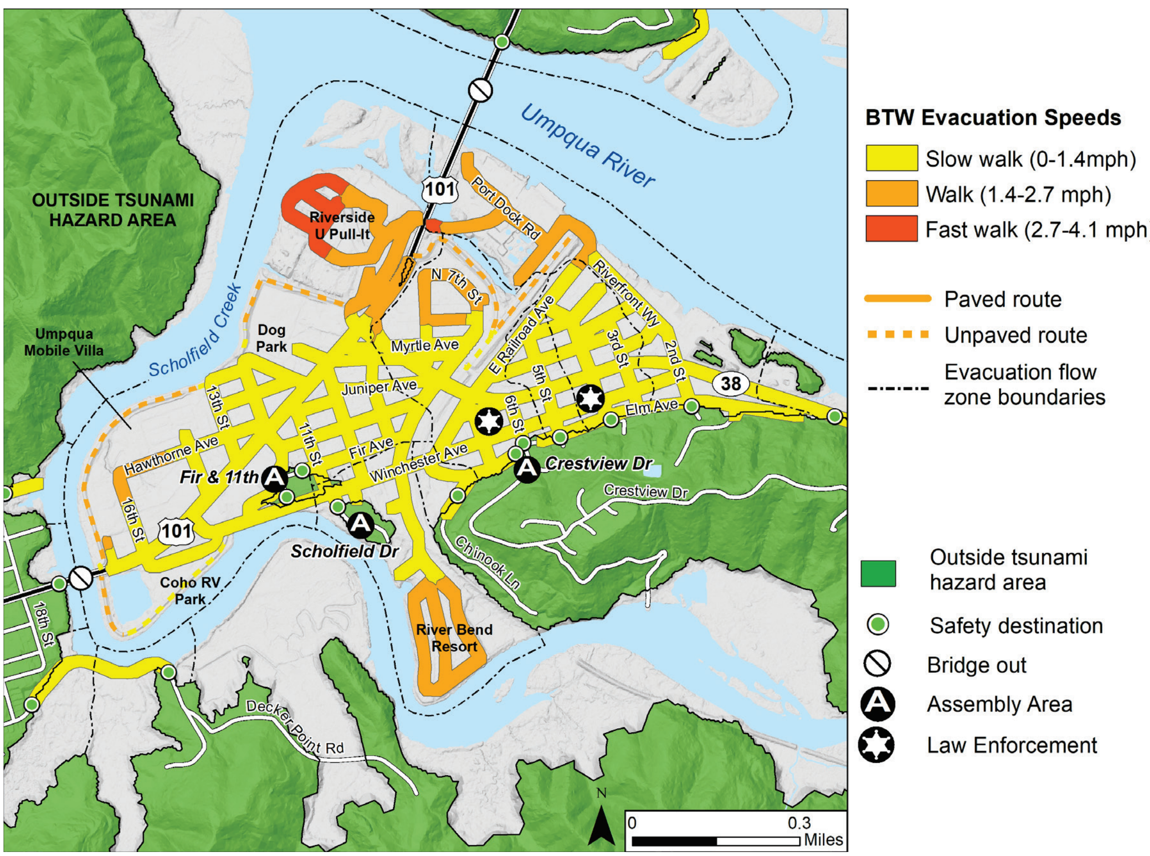
Figure 3-3. Beat the Wave modeling for Reedsport assuming bridges over the Umpqua River and Scholfield Creek have failed. Modeling results are identical if the bridges remain intact, meaning that the bridges are unnecessary to successful evacuation of the area. A) BTW minimum walking speeds and B) evacuation flow zones only.



3.1.2.2 Scenario 2—Liquefaction

Because Reedsport is built largely on fill, liquefaction is likely to influence evacuation travel to high ground. To that end, we considered a scenario where all roads and trails were modeled with a loose sand land cover value. This approach slows modeled pedestrian evacuation speed, simulating the difficulty evacuees might encounter when trying to walk across roads covered with sand and mud from sand boils and other liquefaction features (e.g., **Figure 2-1**). No routes were blocked. **Figure 3-4** shows that the majority of town remains unchanged with a modeled BTW speed of ***slow walk***. Exceptions to that include several sections of the levee trail, N 7th St, and the River Bend Mobile Resort which increase to ***walk*** and part of the Riverside U Pull-It yard which increases from ***walk*** to ***fast walk***. Evacuation flow zones are virtually unchanged from Scenario 1 (**Figure 3-3B**). While this is only a first-order look at how liquefaction could impact evacuation, these results reaffirm that high ground is close enough that even with additional evacuation challenges, safety is attainable for most people.

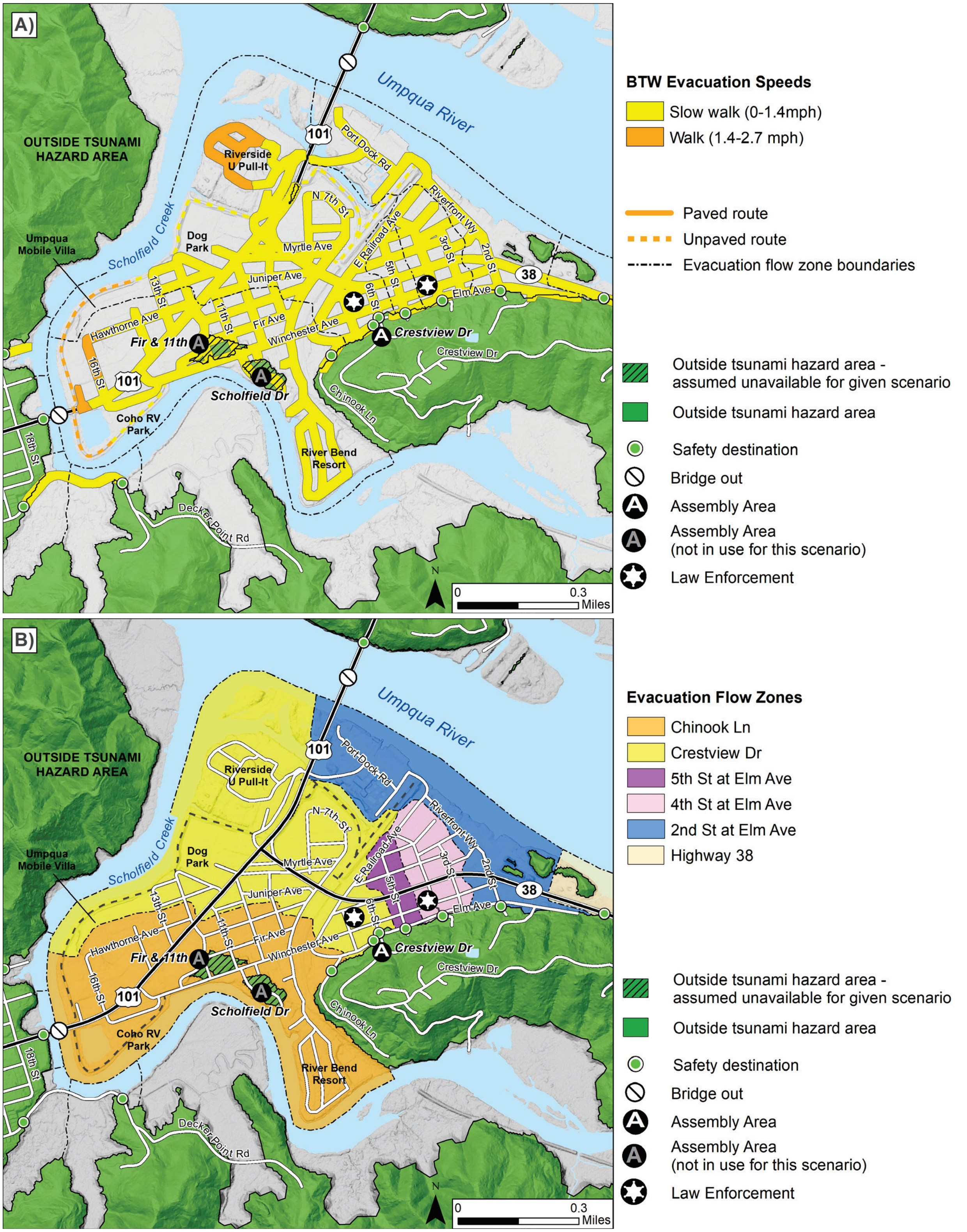
Figure 3-4. Beat the Wave minimum walking speeds for Reedsport assuming liquefaction blankets the roads with loose sand and mud, making travel more difficult. Bridges remain unavailable and evacuation flow zones remain unchanged from Scenario 1 (Figure 3-8B).



3.1.2.3 Scenario 3—"Islands" of safety

Although we believe the two "islands" of high ground in Reedsport will survive the earthquake shaking and are sufficiently large enough to accommodate the number of people who would potentially evacuate to them, questions have been raised about how long it would take to evacuate to a larger section of high ground in the vicinity of Elm Ave. We are providing this scenario to assist decision making for individuals interested in this alternative. **Figure 3-5A** reveals that when both islands are excluded as evacuation destinations, the only area where modeled BTW speeds increase is on the very western edge of lower Reedsoprt, including the levee trail along Scholfield Creek and parts of 16th St and Hawthorne Ave, where speed increases from ***slow walk*** to ***walk***. The remainder of the island flow zone areas remain ***slow walk***. Accordingly, evacuation to Elm St is also feasible under this scenario. **Figure 3-5B** depicts the merging of the island flow zones with Crestview Dr, meaning Crestview Dr is now the safety destination for a much larger section of Reedsport.

Figure 3-5. Beat the Wave modeling for Reedsport assuming evacuees bypass the two "islands" of high ground inside of the inundation zone and evacuate to Chinook Ln instead. A) BTW minimum walking speeds and B) evacuation zone zones only. Out of commission



3.1.2.4 Discussion

Overall, the evacuation landscape in the city of Reedsport is very positive. The prevalence of high ground and reasonably dense network of paved paths results in minimum evacuation speeds categorized as ***slow walk*** virtually everywhere. Although the Umpqua River Bridge and Scholfield Creek Bridge are unlikely to survive the earthquake shaking, our results show that there is no need to use them for evacuation purposes. This does not discount their importance for post-event recovery and community connectivity.

Similar to the 'bridge out' scenario, the incorporation of liquefaction did not significantly alter BTW evacuation results. This suggests that evacuation difficulty is low enough to allow for travel across more difficult surfaces. Regardless of mitigation considerations, wayfinding efforts including adequately spaced signage, battery operated lighting, evacuation drills, and many other actions are essential to survival.

3.1.3 Gardiner

The unincorporated community of Gardiner sits on a narrow strip of land between the Umpqua River and the Oregon Coast Range (**Figure 3-1**). While the entire community, including one rural fire station, is within the XXL inundation zone, there is abundant high ground nearby. As mentioned previously, despite being located ~8 river miles upstream of the Umpqua river mouth, the tsunami reaches Gardiner ~35 minutes following the start of earthquake shaking. Due to the community's small size and prevalence of high ground, the only vulnerability considered was liquefaction.

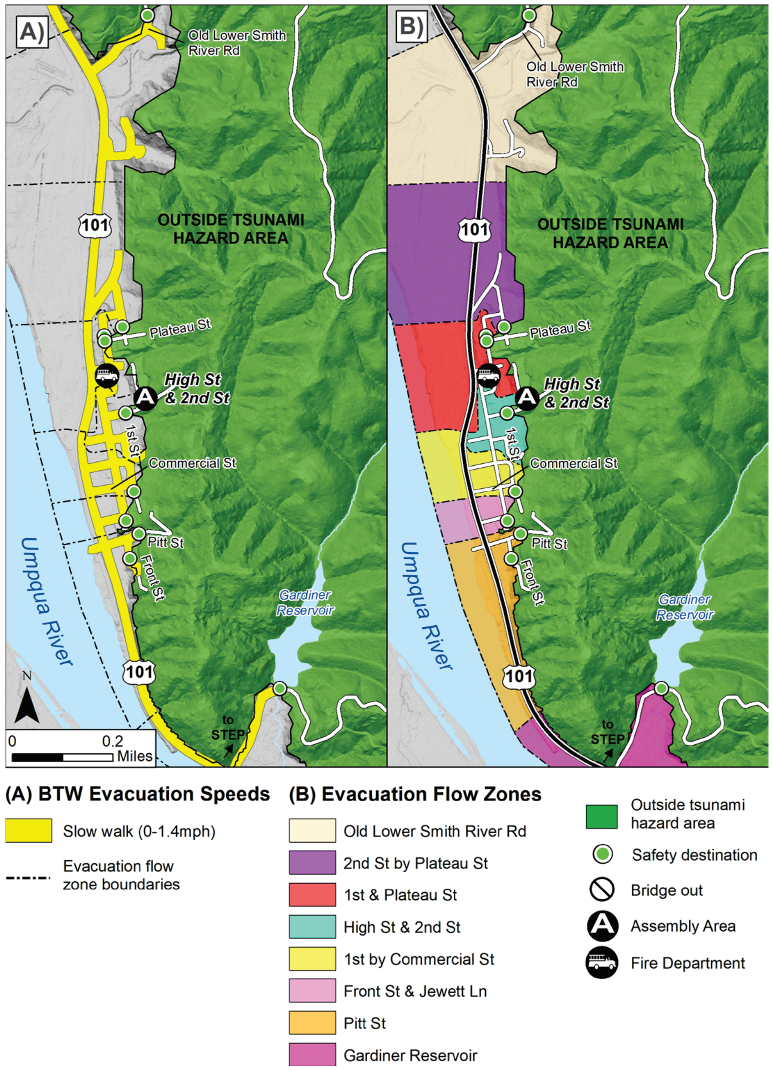
No mitigation options were evaluated although it is possible that some landsliding could impede evacuation in portions of the Gardiner community. Because there are many unmarked roads, driveways and backyards that reach high ground, many routes are readily available without great cost in terms of time or distance. Nevertheless, the hardening of a particular route may be desirable for long-term resilience.

3.1.3.1 Scenario 1—Existing road network/liquefaction effects

Because tsunami wave arrival times for the Gardiner neighborhood is on the order of ~35 minutes (**Figure 3-2**) and most locations are relatively close to evacuation destinations, the entire area is characterized with a **minimum** evacuation speed of ***slow walk*** (**Figure 3-6A**). **Figure 3-6B** illustrates the eight evacuation flow zones for the area, six of which encapsulate the community of Gardiner, while **Figure B-2** includes a detailed evacuation route map and evacuation time map based on a standard 4-fps speed (**Figure A-2**). **Figure C-2** presents a BTW map for Gardiner. Walking speeds on the roads and trails as well as evacuation flow zone data can be found in the Florence_Reedsport_Tsunami_Evacuation_Modeling geodatabase, BridgesOut_XXL1 feature dataset.

As with Reedsport, Gardiner's position at river level suggests a high probability that its roads will be affected by liquefaction. Due to the close proximity of high ground to the entire community, however, results are unchanged from **Figure 3-6**.

Figure 3-6. Beat the Wave modeling for Gardiner assuming the existing road network remains intact. A) BTW minimum walking speeds and B) evacuation zone zones only.



3.1.3.2 Discussion

As expected, Gardiner has extremely low evacuation difficulty due to its close proximity to high ground. There is no reliance on bridges and even the added complication of liquefaction does not significantly alter the modeled results. Nevertheless, wayfinding is still essential to survival. These runs assume an evacuee does not take a wrong turn, which essentially increases route distance and time and increases the possibility of being overcome by the tsunami. Landslides may be an issue in this area because of the steep slopes directly behind town. However, because of the abundance of streets leading out of the inundation zone, we feel there many routes to allow for evacuation to high ground even if the route is not on the intended street.

3.1.4 Winchester Bay

Winchester Bay is an unincorporated community at the mouth of the Umpqua River (**Figure 3-1**). Because of its proximity to the river mouth, tsunami wave arrival times are on the order of 20 minutes (**Figure 3-2**). Despite its small residential population, the community is a popular tourist attraction, which makes it especially important to ensure safe evacuation. Nearly all residences as well as Salmon Harbor Marina's East Basin sits adjacent to Highway 101 with high ground accessible both to the north and south (this area is referred to as "Winchester Bay" for the remainder of the section). Winchester Bay is home to a fire station and coast guard station. However, the Marina's West Basin, Winchester Bay RV Park, and Windy Cove Campground are separated from the rest of the community (and high ground) by the Salmon Harbor Bridge and a recently installed footbridge that crosses Winchester Creek. For the remainder of this section, we refer to this area as the "marina and campground." Windy Cove Campground and Salmon Harbor Rd are flanked by a steep, sometimes vertical cliff-face. Although this provides nearby high ground, much of the terrain is extremely difficult to access.

Due to the prevalence of high ground, BTW results for the community of Winchester Bay look generally good. The exception is for those recreating in the marina and campground area, who have farther to travel to reach safety. Due to the importance of the Salmon Harbor Bridge and our understanding that it may not survive the earthquake shaking, we considered a scenario without it, which forces evacuation of the marina and campground west to the lighthouse. As mentioned earlier, in addition to the main bridge, there is also a footbridge that crosses Winchester Creek. Our discussions with engineers in Douglas County Public Works revealed that although the main bridge is expected to fail, the footbridge itself is likely to survive. The biggest uncertainty surrounding the footbridge is if it will be subject to lateral spreading effects, such that the bridge comes off its foundation supports. Those results are not ideal, so we have modeled a mitigation scenario that includes a hypothetical earthquake-hardened trail behind the Windy Cove campground. Finally, we considered the effects of liquefaction on evacuation speeds.

3.1.4.1 Scenario 1—Existing road network

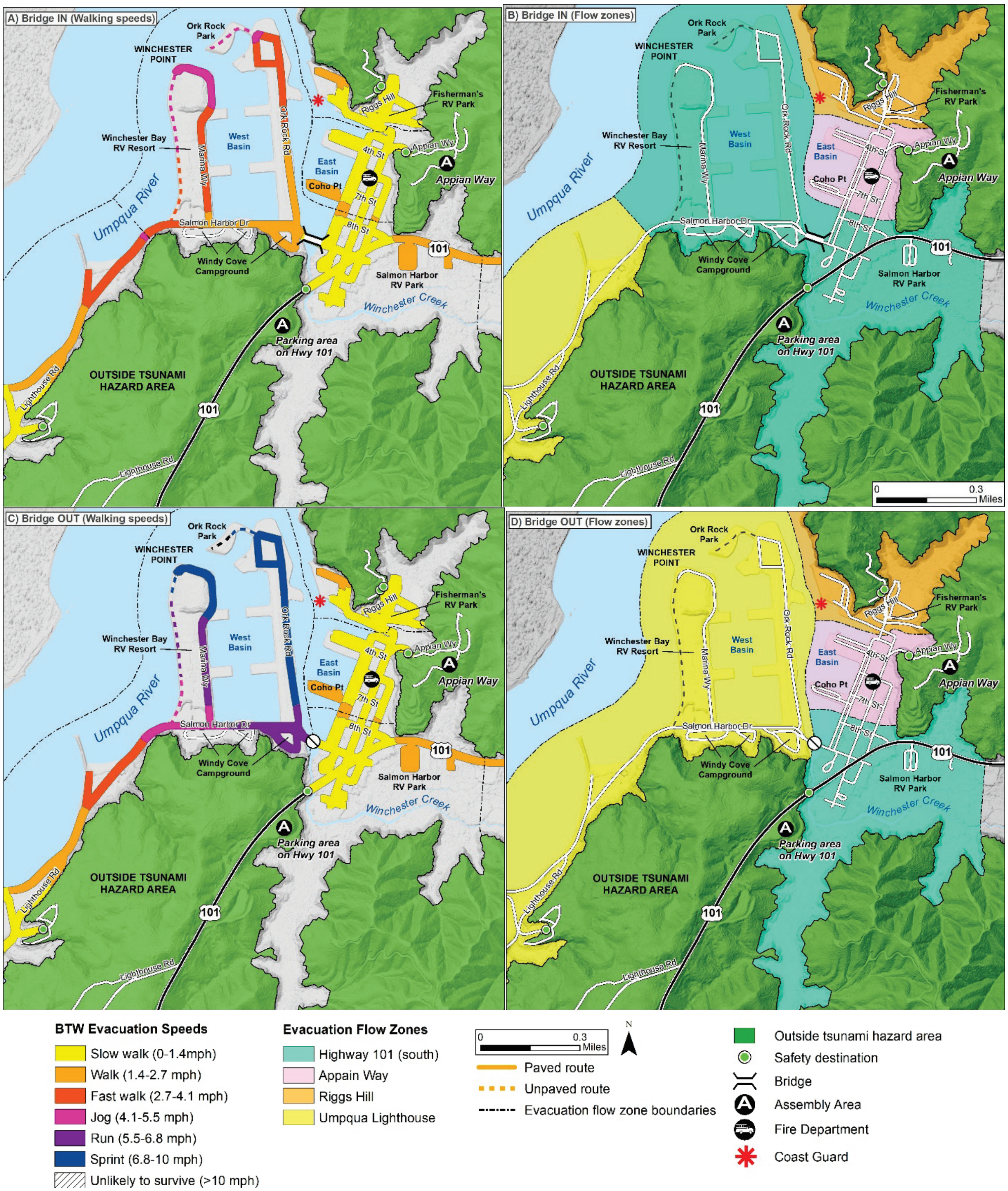
Figure 3-7A shows that virtually all of Winchester Bay with the East Basin can evacuate at a ***slow walk***, The Coast Guard station and Salmon Harbor RV Park require ***walk*** speeds. Even though this scenario assumes the Salmon Harbor Bridge remains intact, modeled BTW speeds still range from ***walk*** and ***fast walk*** at the Windy Cove campground to ***jog*** and ***run*** at the end of the marina. This is due to longer path distances to safety as well as earlier tsunami wave arrival times, which are on the order of ~20 minutes.

The very northern section of Winchester Bay, including the Coast Guard station, evacuates to the north via Riggs Hill (**Figure 3-7**B). The central part of town, including the East Basin down to 7th St, evacuates east up Appian Way, while the southern portion heads south on Highway 101. Highway 101 south of town is also the nearest safety destination for the marina and Windy Cove Campground. **Figure B-3**, **Figure A-3**, and **Figure C-3**, respectively, present the detailed evacuation route map, 4-fps evacuation time map, and BTW map. Walking speeds on the roads and trails as well as evacuation flow zone data can be found in the Florence_Reedsport_Tsunami_Evacuation_Modeling geodatabase, BridgesIn_XXL1_WinchesterBay Only feature dataset.

3.1.4.2 Scenario 2—Failure of Salmon Harbor Bridge

The Salmon Harbor Bridge is likely to fail during earthquake shaking. Although it may be possible for some to scramble across the creek and reach high ground on Highway 101 as shown in scenario 1 (**Figure 3-7**A, B), we considered a scenario restricting evacuation to the road network (**Figure 3-7**C, D). Figure 3-7C reveals that despite nearby high ground, the next nearest location where a road intersects with safety is at the lighthouse. Not only is this a significantly longer route, but it requires walking toward the oncoming tsunami (Figure 3-7**D**). Results shows that modeled BTW minimum walking speeds increase from ***walk***, ***fast walk***, and ***jog*** to ***jog***, ***run***, and ***sprint***. Results in Winchester Bay remain unchanged. **Figure B-4**, **Figure A-4**, and **Figure C-4**, respectively, present the detailed evacuation route map, 4-fps evacuation time map, and BTW map. Walking speeds on the roads and trails as well as evacuation flow zone data can be found in the Florence_Reedsport_Tsunami_Evacuation_Modeling geodatabase, BridgesOut_XXL1 feature dataset.

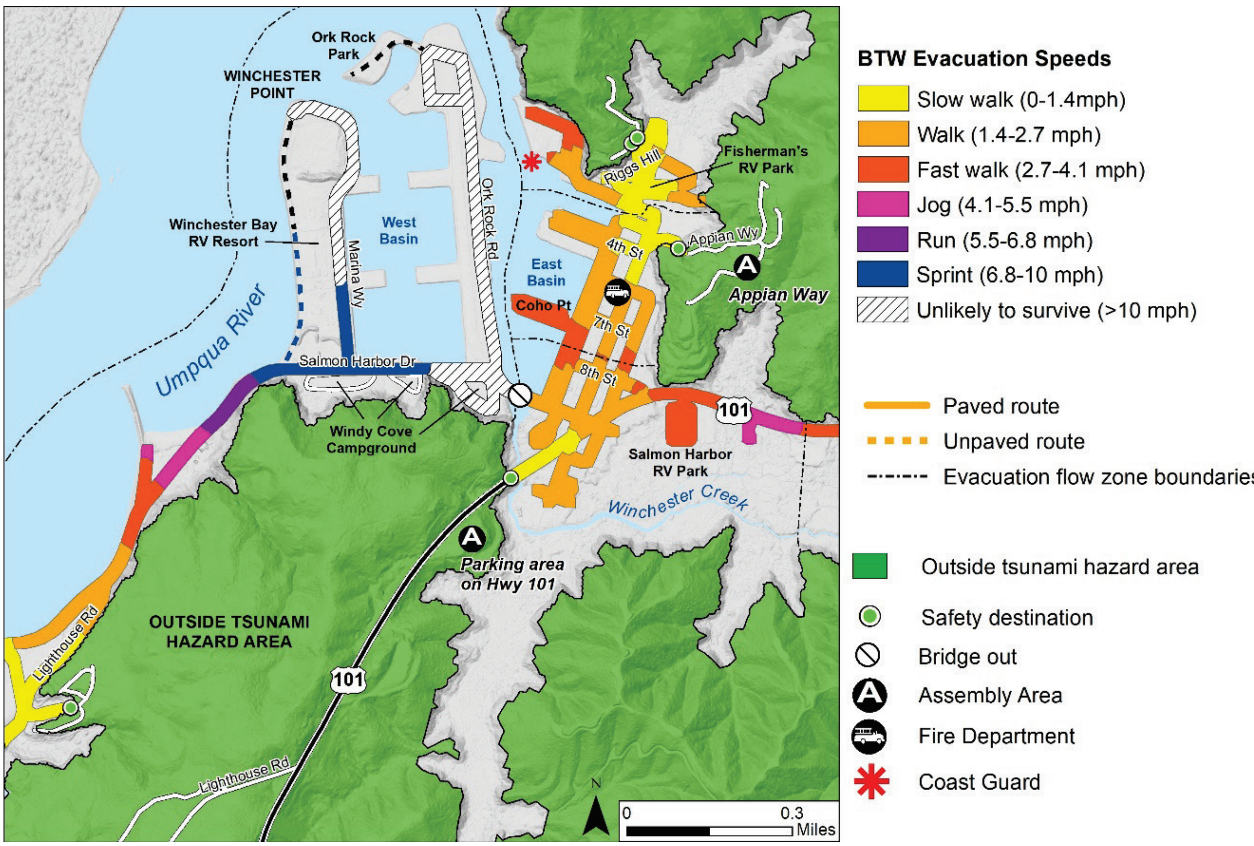
Figure 3-7. Beat the Wave modeling scenarios for Winchester Bay. Scenario 1 (top) assumes the existing road, trail, and bridge network remains intact; A) BTW minimum walking speeds and B) evacuation zone zones only. Scenario 2 (bottom) assumes the Salmon Harbor Bridge fails during the earthquake. For the area west of the bridge, if evacuees cannot reach safety on the east side of the bridge (Hwy 101), the nearest safety destination is now the Umpqua Lighthouse (via roads only); C) BTW minimum walking speeds and D) evacuation zone zones only.



3.1.4.3 Scenario 3—Liquefaction

Inclusion of liquefaction in our evacuation modelling yields worse results for the entire region, especially for areas west of the bridge around the West Basin. **Figure 3-8** shows that the marina goes from ***jog*** and ***run*** (scenario 1) to ***sprint*** and ***unsurvivable***. Most of Winchester Bay increases from ***slow walk*** to ***walk*** except for the East Basin and the Coast Guard station, which increase from ***walk*** to ***fast walk***. Evacuation flow zones remain unchanged (Scenario 1, **Figure 3-7**D). This scenario clearly highlights the importance of the Salmon Harbor Bridge for surviving a CSZ tsunami, and strongly suggests that the community evaluate the engineering viability of at least the existing footbridge (both the bridge foundation and effects associated with lateral spreading).

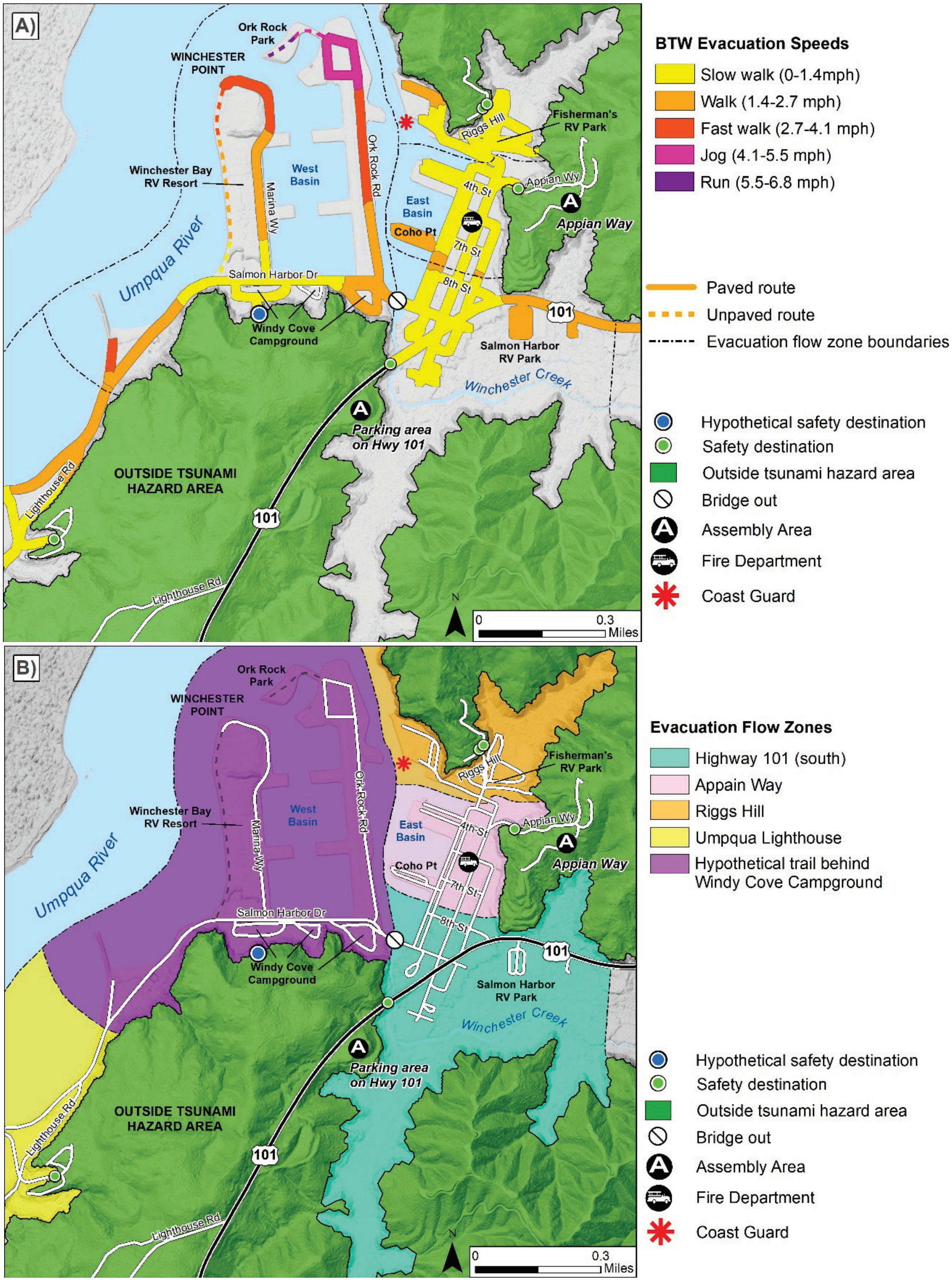
Figure 3-8. Beat the Wave minimum walking speeds for Winchester Bay assuming liquefaction blankets the roads with loose sand and mud, making travel more difficult. Bridge remains unavailable and evacuation flow zones remain unchanged from scenario 2 (Figure 3-7D).



3.1.4.4 Scenario 4—Construction of trail behind Windy Cove Campground

Due to the severity of scenarios 2 and 3, we felt strongly that the construction of a new trail providing access to safety should be considered for the area of high ground immediately south of the marina and campground. Several locations were considered for the hypothetical earthquake-hardened trail. The terrain south of the campground is very steep; ultimately, we settled on a spot with a slightly lower slope. However, due to the presence of dense vegetation along its course, this area will likely experience surficial debris runoff of upslope soil, rocks, and vegetation that shakes loose during the earthquake. Although trail construction anywhere in this area will be challenging, **Figure 3-9** showcases the dramatic improvements such a trail provides to local evacuation from this area. BTW speeds drop from predominantly ***run*** and ***sprint*** to ***walk***, ***fast walk*** and ***jog*** (**Figure 3-9A**). **Figure 3-9B** shows that everyone west of the bridge now evacuates to this hypothetical trail rather than to the lighthouse. A trail anywhere in this vicinity will yield similar results, in terms of both BTW walking speeds and flow zones. By providing an alternative route to traveling west to the lighthouse or scrambling across Salmon Harbor Creek to the east, the likelihood of survival for more evacuees increases.

Figure 3-9. Beat the Wave modeling for Winchester Bay assuming a hypothetical trail is built connecting the Windy Cove Campground with high ground immediately to the south. Bridge remains unavailable. A) BTW minimum walking speeds and B) evacuation zone zones only.



3.1.4.5 Discussion

Because the bridge over Winchester Creek has not been retrofitted to withstand an ~Mw 9.0 earthquake, it is possible that it will collapse during the shaking, effectively cutting off evacuation to Highway 101 to the southeast (**Figure 3-7**C, D). This loss critically affects residents and visitors at the Windy Cove Campground or in the Marina's West Basin area, such that their only way of escape is now to the southwest along Salmon Harbor Road/Lighthouse Road. Not only does this route take evacuees toward the ocean and approaching tsunami, but the road will likely be compromised by lateral spreading due to its proximity to the Umpqua River. Our analyses demonstrate that the speeds required to successfully "beat the wave" in this area reach as high as 10–15 fps (akin to a 8.8–6.0 min/mile pace), limiting evacuation success to only a few very fit adults. As a result, a portion of this population would not be able to reach safety in time and would be killed by the tsunami while evacuating.

Mitigation techniques considered included the construction of a new evacuation trail behind Windy Cove Campground (Scenario 4, **Figure 3-9**) and/or reinforcing the Salmon Harbor Bridge (effectively Scenario 1, Figure 3-7A, B)). Our analysis clearly demonstrates the benefits of both options. Both the establishment of a new trail or hardening the bridge would significantly decrease the public's evacuation times and the ***minimum*** evacuation speeds to reach safety.

The combined complication of liquefaction and bridge failure causes extreme evacuation difficulty west of the Salmon Harbor Bridge (Scenario 3, **Figure 3-8**). This result reinforces the necessity of providing access to nearby high ground, whether it be via a new trail or ensuring passage across the bridge to Highway 101.

3.1.5 Umpqua Lighthouse and Umpqua Dunes Recreation Area

The final region included in the Reedsport area of the study contains the Umpqua Lighthouse, Discover Point RV Park, Halfmoon Bay Campground, the south Umpqua jetties, and the vast, open sand dunes comprising the Bureau of Land Management's Umpqua Dunes Recreation Area (**Figure 3-1**), which is a part of the Oregon Dunes National National Recreation Area. Although the lighthouse itself is outside of the XXL inundation zone, the road leading up to it and the remaining locations listed are within the inundation zone. This area has the earliest wave arrivals of the project area, ~16-18 minutes, because it is on the open coast (**Figure 3-2**).

The northern part of this area contains a detailed network of paved roads and sandy trails leading to high ground at the lighthouse. The challenges to evacuation become more significant to the south in the open dune areas, where evacuees must decide whether to follow Salmon Harbor Rd north back to the lighthouse or strike out east across the dunes to reach high ground among the trees. We investigate both options to highlight the importance of this wayfinding decision. We also model a reduction in the 10-minute delay because people in this area are more likely to be outside or in a tent, which means their evacuation can generally start more quickly compared with people evacuating from buildings.

Overall results show that evacuees in areas nearest the lighthouse including Halfmoon Bay Campground can reach safety with reasonable BTW walking speeds. However, the farther south they are, the faster evacuees must travel.

3.1.5.1 Scenario 1—Existing road network, 10-minute delay

We begin with an initial look at the evacuation potential assuming everyone evacuates on the roads only (**Figure 3-10A**). The same 10-minute delay used in all previous scenarios is also assumed. This means the only safety destination for the region is the lighthouse. Modeled BTW minimum walking speeds show a rapid increase from ***slow walk*** near the lighthouse to ***fast walk*** at Halfmoon Bay Campground, ***jog*** at Day Use #1, and ***sprint*** at Day Use #2. At Day Use #3, the modeling suggests that a tsunami would be ***unsurvivable;*** there is a tsunami evacuation 'You Are Here' sign at Day Use #3 directing evacuation east across the dunes, not north to the lighthouse—therefore BTW results for this scenario at this location are somewhat misleading/extreme. **Figure B-2** includes a detailed evacuation route map, and **Figure A-2** provides an evacuation time map based on a standard 4-fps speed. **Figure C-5** presents a BTW map. Walking speeds on the roads and trails as well as evacuation flow zone data can be found in the Florence_Reedsport_Tsunami_Evacuation_Modeling geodatabase, BridgesOut_XXL1 feature dataset.

3.1.5.2 Scenario 2—5-minute delay

To better understand the effects of evacuation delay, we reduced the 10-minute evacuation departure delay to 5 minutes for rural areas where people are already outside, either in a tent or RV. Such an approach allows for a faster transition from waiting out the earthquake shaking to evacuating. **Figure 3-10B** demonstrates the resulting minimum walking speeds associated with a 5-minute evacuation delay, which decrease to ***fast walk*** at Day Use #1, ***run*** at Day Use #1, and still ***unsurvivable*** at Day Use #3. These results confirm the importance of evacuating as soon as possible after earthquake shaking begins.

3.1.5.3 Scenario 3—Existing road network with unmarked trails to the east (5-min delay)

While no other parking lot besides Day Use #3 directs evacuation to the east, we wanted to investigate the changes to BTW walking speeds if everyone heads east to their nearest high ground instead of traveling north to the lighthouse. All four trails included in this scenario (**Figure 3-10C**) are unmarked and besides Day Use #3, do not technically exist. However, the area consists of open sand, so no work besides signage would need to be done to direct people in this direction toward safety. The northernmost trail connects Halfmoon Bay Campground to a footpath at the base of the lighthouse, which leads straight to the lighthouse parking lot. The trails from each day use parking lot head due east across open sand to high ground. High ground roughly coincides with the tree line for all areas except for Day Use #3, where high ground is reached well before the tree line.

As expected, **Figure 3-10C** shows that walking speeds dramatically decrease from scenario 2 with the inclusion of these trails, especially to the south. Day Use #1 decreases from ***fast walk*** to ***walk***. Day Use #2 decreases from ***run*** to ***walk***, and Day Use #3 decreases from ***unsurvivable*** to ***fast walk***. Evacuation flow zones (dashed black lines) show that each new trail becomes its own safety destination, with the Halfmoon Bay Campground flow zone reflecting the trail to the base of the lighthouse, Day Use #1 heading toward the trail to Lake Marie, and Day Use #2 and #3 to unmarked high ground. These results clearly demonstrate that, in much of the area, heading east across the dunes is a better decision than heading toward the lighthouse.

Figure 3-10. Beat the Wave minimum walking speeds for the Umpqua Lighthouse and Oregon Dunes National Rec Area. A) Scenario 1: Assumes evacuation is restricted to roads only, meaning the entire area evacuates to the lighthouse. The standard 10-minute evacuation delay is used. B) Reducing the evacuation delay from 10 minutes down to 5 minutes, and C) Scenario 3: Evacuation to the east from Salmon Harbor Rd in addition to the 5-minute delay.

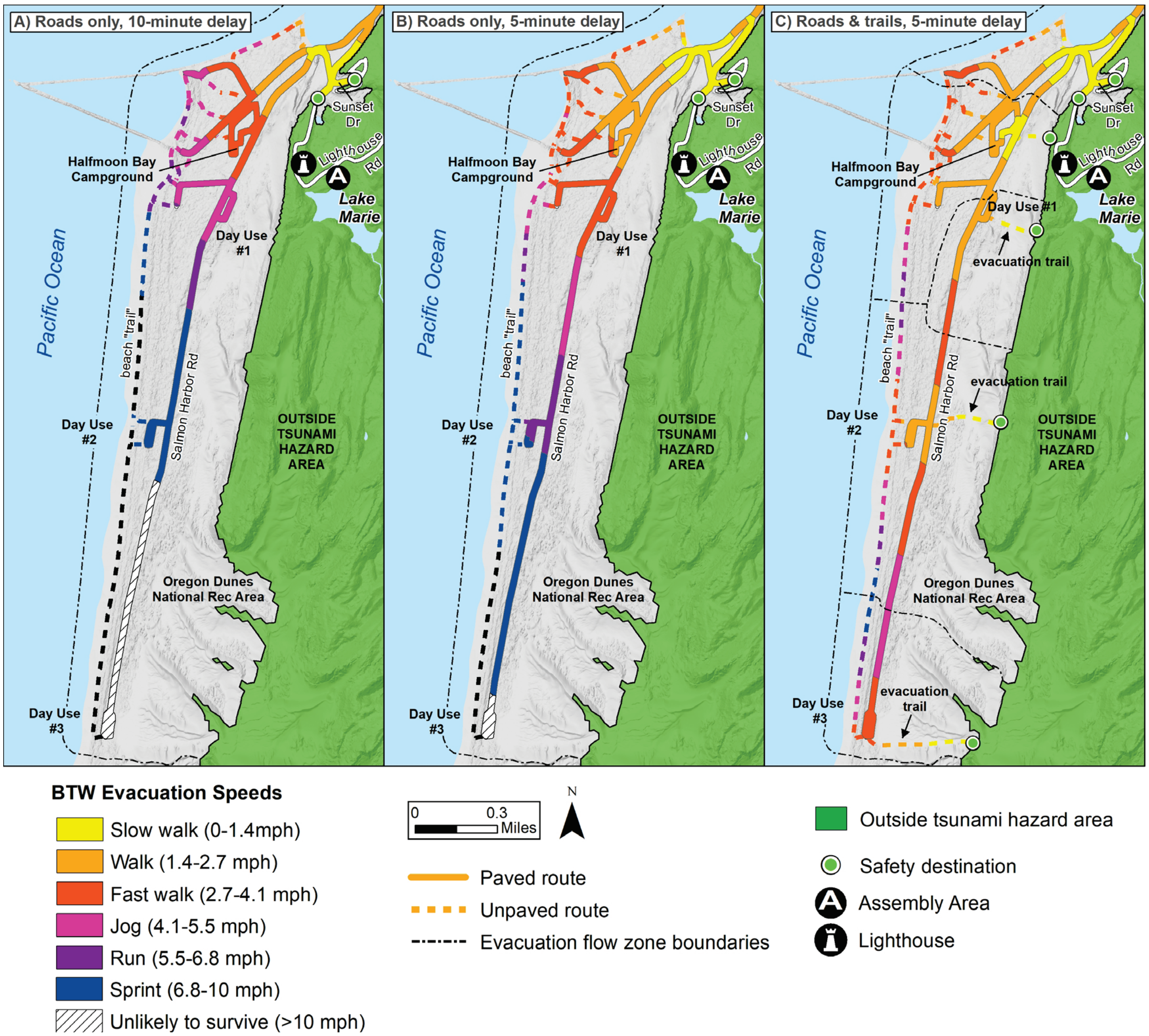


Table 3-2 summarizes BTW walking speeds for Umpqua Lighthouse and Dunes Recreation Area scenarios 1, 2, and 3 at several areas of interest, demonstrating the reduction in walking speeds that occur with a quicker start to evacuation and trails to the east. **Figure B-2**, **Figure A-2**, and **Figure C-5**, respectively, present the detailed evacuation route map, 4-fps evacuation time map, and BTW map.

Table 3-2. Comparison of BTW walking speeds from various locations along Salmon Harbor Road for the three scenarios considered: 10-minute delay versus 5-minute delay to the start of evacuation, and evacuating to the lighthouse versus east across the dunes.

	Evacuate to Lighthouse		Evacuate Across Dunes		
Area of interest	**Distance to Safety (miles)**	**BTW Speed, 10-Minute Delay**	**Distance to Safety (miles)**	**BTW Speed, 10-Minute Delay**	**BTW Speed, 5-Minute Delay**
Halfmoon Bay Campground	0.6	walk	0.2	walk	walk
Day Use #1	0.9	fast walk	0.2	walk	walk
Day Use #2	1.8	run	0.3	fast walk	walk
Day Use #3	2.8	unlikely to survive	0.4	jog	fast walk

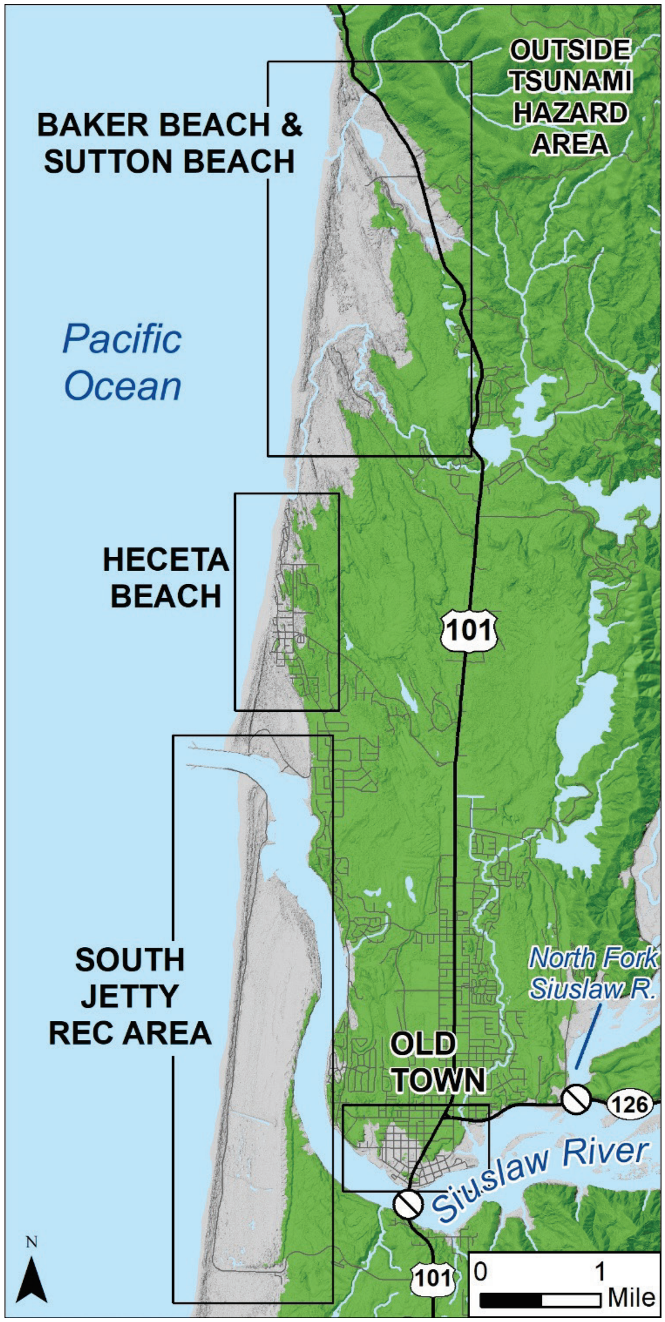
3.1.5.4 Discussion

As with all remote open-coast areas, evacuation can be difficult due to extreme distances to high ground, lack of paths to reach it, and loose sandy surfaces that are difficult to walk on. Although relatively few people live here, summer tourists can number in the thousands, and that makes wayfinding all the more important: visitors will likely be confused about which way to go. We presented scenario 1, roads-only, to emphasize the evacuation difficulty associated with the message that everyone should head toward Umpqua Lighthouse. **Figure 3-10** and **Table 3-2** illustrate how BTW walking speeds are much slower if evacuees choose to head east across the open dunes for most of Salmon Harbor Road. A DOGAMI "You Are Here" tsunami evacuation map at Day Use #3 tells people to evacuate to the east; however, Day Use #2 and other locations to the north direct people to the lighthouse. We strongly urge Douglas County to direct evacuation east across the dunes and put trail markers of some kind in the sand to guide evacuees.

3.2 Florence project area

The Florence project area includes Old Town Florence, Heceta Beach, South Jetty Recreation ("Rec") Area, and Baker and Sutton Beach trails (**Figure 3-11**). Results will be discussed separately for each area.

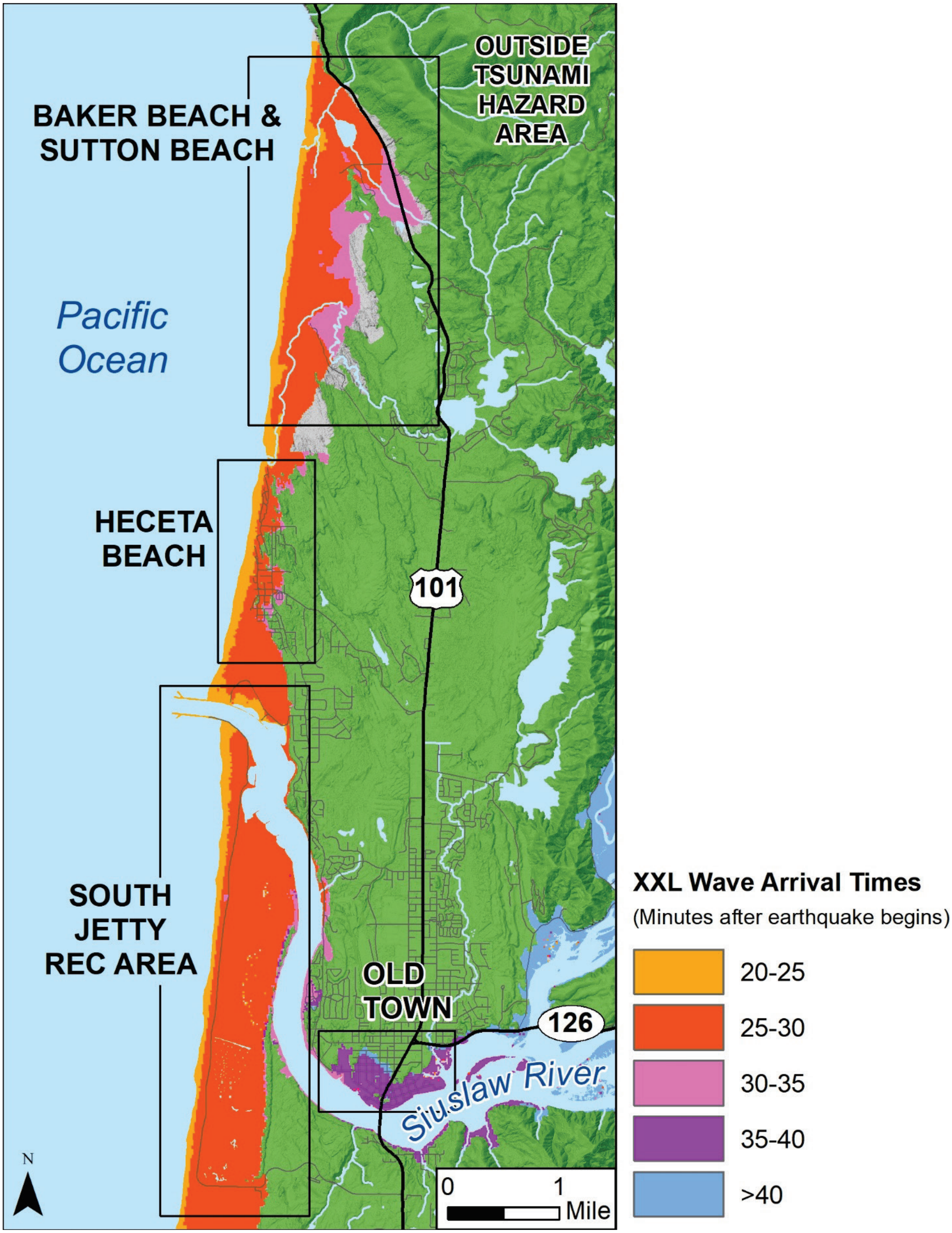
Figure 3-11. Area map of the Siuslaw River estuary including the communities of Old Town Florence, Heceta Beach, South Jetty Recreational Area and the Baker Beach and Sutton Beach trail network.



3.2.1 Tsunami wave arrival

Figure 3-12 shows that tsunami inundation pattern in the Florence project area is similar to that of Reedsport, with the primary population center being several miles up-river and having significantly later arrival times. This contrasts with the South Jetty Rec Area on the open coast to the south, where wave arrival times range from 20 to 30 minutes. Not surprisingly, the earliest wave arrivals are on the open coast some ~22 minutes after the start of the earthquake. By 28 minutes, the entire South Jetty Rec Area is inundated; Heceta Beach to the north is fully inundated by ~30 minutes after the earthquake. Highway 101 adjacent to Baker and Sutton Beaches is inundated by ~35 minutes. The tsunami reaches Old Town Florence up the Siuslaw River at 35 minutes, and within ~5 minutes the Old Town is inundated. The tsunami continues upriver beyond Florence, reaching its farthest extent near river mile 20 (just upstream of Mapleton), some 2 hours after the earthquake occurred. Additional waves will continue to strike the coast and enter the estuary, causing water levels to fluctuate for up to 12 hours. Tsunami wave arrival time data can be found in the Florence_Reedsport_Tsunami_Evacuation_Modeling geodatabase, TsunamiWaveArrival_XXL1 dataset.

Figure 3-12. Illustration of XXL tsunami wave arrivals after a Cascadia subduction zone earthquake for the Florence project area.



3.2.2 Old Town Florence

Much of the city of Florence is outside of the XXL tsunami hazard zone. The exception is Old Town, which sits on the north bank of the Siuslaw River about 2 river miles upstream of the Pacific Ocean (**Figure 3-11**). High ground can be found immediately north of Old Town (by 9th St) as well as at two small "islands" of high ground adjacent to Hwy 101 and just north of the Siuslaw River Bridge. There are a few other smaller islands of high ground that do not intersect any roads and were therefore not considered for this study. One of three area fire stations is located within the XXL inundation zone, while the hospital, city hall, police station, public works, and all schools are all located outside of the XXL inundation zone. The Siuslaw River Bridge connects Florence with Glenda to the south, crossing the Siuslaw River. Hwy 126 crosses the North Fork Siuslaw River to the east of Old Town, heading toward Mapleton.

Overall results for Old Town are positive due to the community's proximity to high ground. Neither the Siuslaw River Bridge nor the Hwy 126 bridge were found to play a role in evacuation; therefore we present one scenario that represents both "with" and "without" bridges (figures do not the show Hwy 126 bridge but this area is included in the digital data). Liquefaction was considered due to the likelihood of its occurrence in Old Town; however, results are essentially unchanged due to the fact that high ground is close by. No mitigation options were evaluated for Florence.

3.2.2.1 Scenario 1—Existing road network/failure of Siuslaw River Bridge and Hwy 126 N Fork Bridge

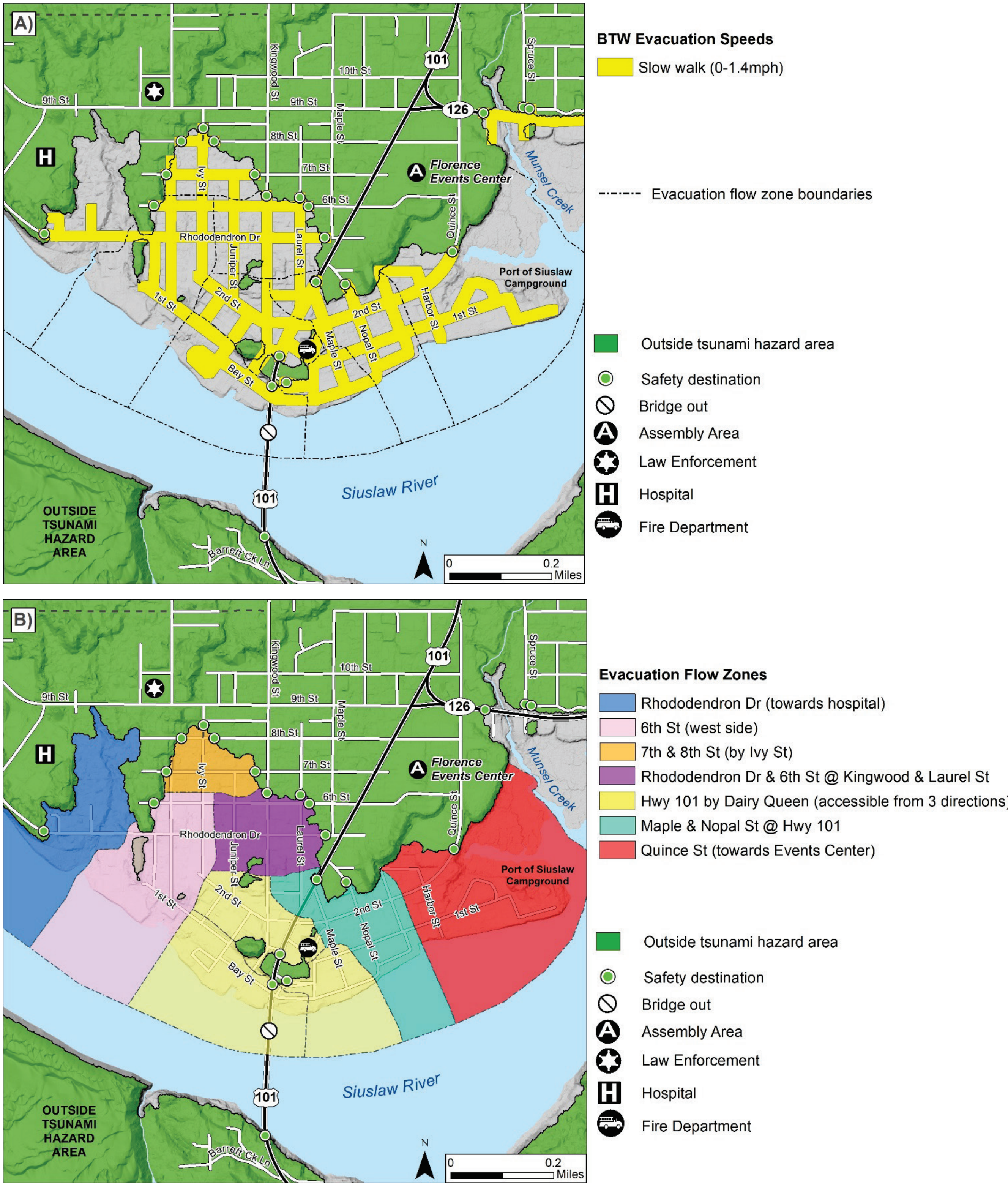
This scenario presents the identical results from two model runs: 1) assuming the existing road and bridge network remains intact, and 2) assuming the Siuslaw River Bridge fails. Results from the first run indicate a natural divide between evacuation flow zones at both bridges, meaning no one needs to cross a bridge to reach their nearest high ground. Therefore, scenario 1 presents the identical results for both "with" and "without" the Siuslaw River Bridge and Hwy 126 over N Fork Siuslaw River. Because it is likely that neither bridge will survive the earthquake shaking, figures include the "bridge out" symbol.

Figure 3-13A demonstrates that all of Old Town can evacuate to high ground at a **minimum** speed classified as ***slow walk***. **Figure 3-13**B indicates that many roads intersect with high ground along the northern margin of the inundation zone in this area including:

- Rhododendron Dr near the hospital,
- 8th and Ivy in the far north,
- Highway 101 by Maple St, and
- Quince St in the east.

The "island" of high ground on Hwy 101 by Old Town Way is the evacuation destination for a significant area of Old Town. **Figure B-5**, **Figure A-4**, and **Figure C-6**, respectively, present the detailed evacuation route map, 4-fps evacuation time map, and BTW map. Digital data depicting walking speeds on the roads and trails as well as evacuation flow zone data can be found in the Florence_Reedsport_Tsunami_Evacuation_Modeling geodatabase, BridgesOut feature dataset.

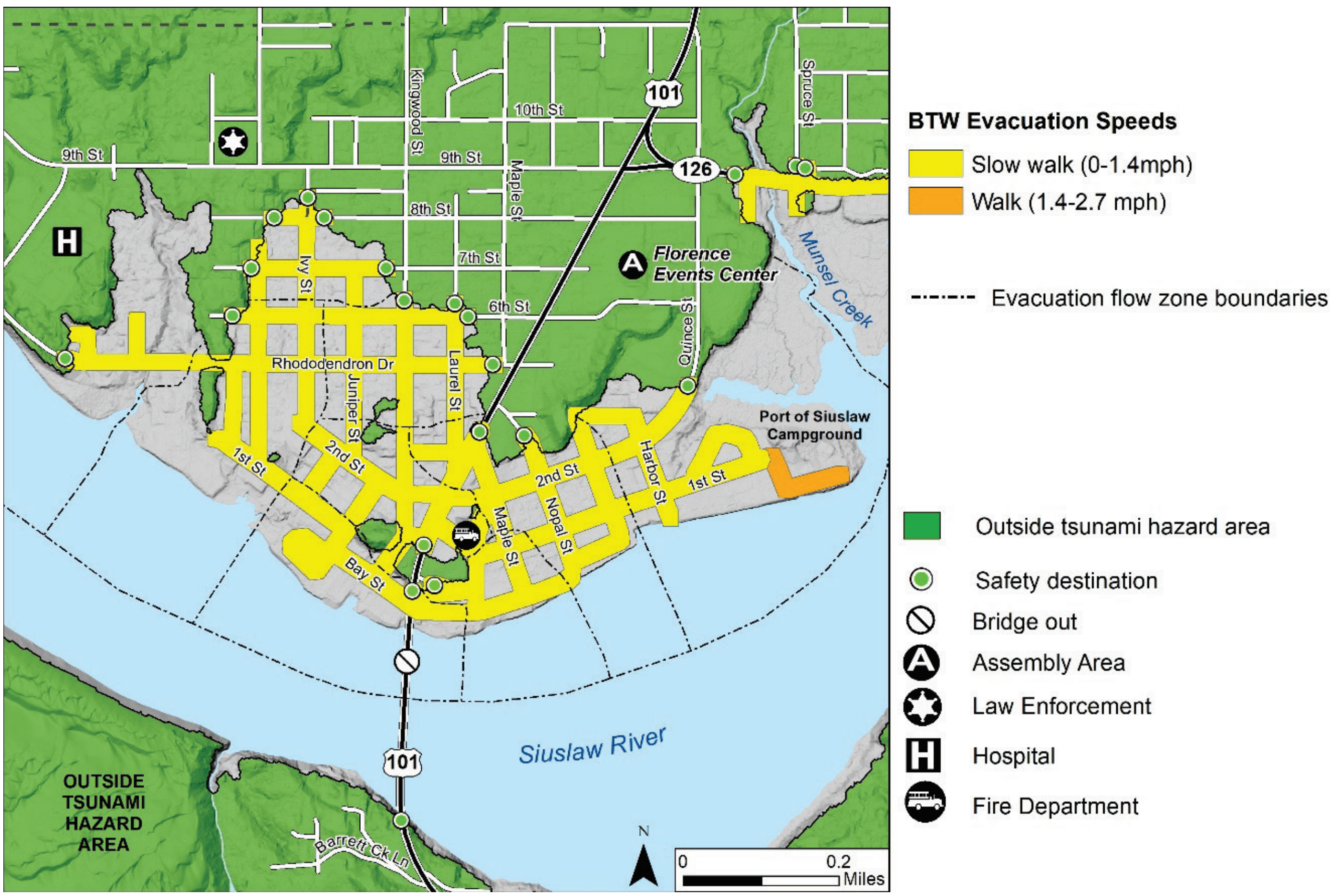
Figure 3-13. Beat the Wave modeling for Old Town Florence assuming the Siuslaw River Bridge has failed. Results are identical if the bridge is kept in, meaning that the bridge is unnecessary to successful evacuation of the area. A) BTW minimum walking speeds and B) evacuation flow zones only.



3.2.2.2 Scenario 2—Liquefaction

As previously discussed, liquefaction-induced sand boils are a likely result of earthquake shaking in low-lying areas of the coast, Old Town Florence included. **Figure 3-14** shows results from a scenario where all paved roads are reclassified as loose sand. The results indicate that BTW speeds are virtually unchanged from scenario 1 (**Figure 3-13**A) with only the very outer edge of the Port of Siuslaw Campground increasing in BTW speed from ***slow walk*** to ***walk***; evacuation flow zones are also unchanged from scenario 1 (**Figure 3-13**B). While there will be other challenges to evacuation not accounted for in this modeling exercise (i.e., downed power lines, lateral spreading, etc.), it is reassuring to know that even with more difficult terrain, high ground is attainable.

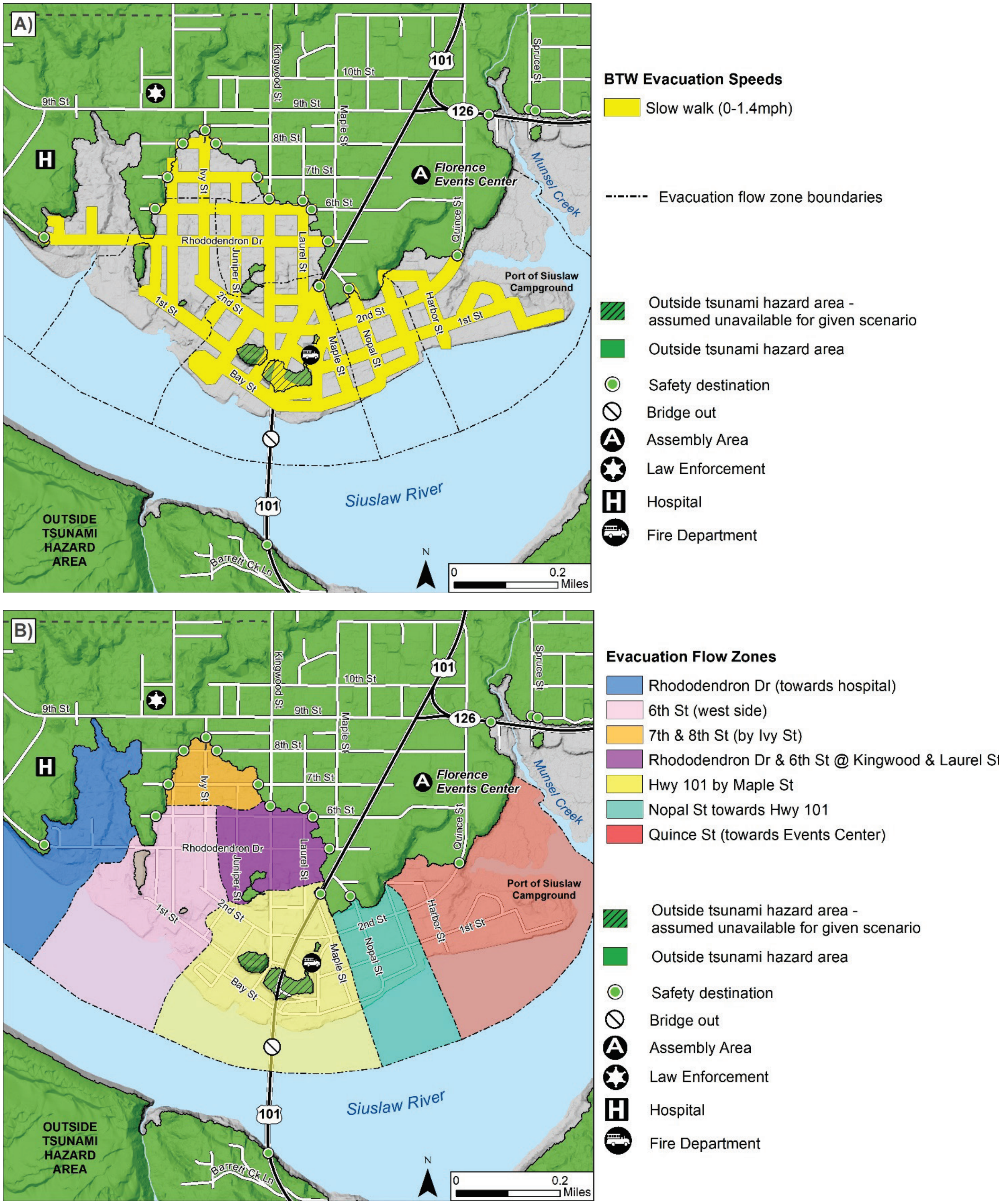
Figure 3-14. Beat the Wave minimum walking speeds for Old Town Florence assuming liquefaction blankets the roads with loose sand and mud, making travel more difficult. Bridge remains unavailable and evacuation flow zones remain unchanged from Scenario 1 (Figure 3-13B).



3.2.2.3 Scenario 3—"Islands" of safety

Similar to Reedsport, we evaluated the effects of excluding the "island" of high ground next to Old Town. While this island is likely to survive the earthquake shaking and, importantly, is big enough to accommodate a large number of people evacuating from Old Town, the community explicitly wanted an assessment of evacuation speeds required to reach safety along the north edge of town. **Figure 3-15**A shows that modeled BTW walking speeds remain unchanged, with all areas of Old Town able to reach Highway 101 by Maple St at a ***slow walk***. **Figure 3-15**B shows that the island safety destination is now gone (green hatch zone) and instead the public evacuate northward toward the Hwy 101 and Maple St intersection. Thus, the only change is a slight increase in the "Hwy 101 by Maple St" evacuation zone (compare Figure 3-15B with **Figure 3-13**B).

Figure 3-15. Beat the Wave modeling for Old Town Florence assuming evacuees bypass the "island" of high ground inside of the inundation zone and evacuate to Hwy 101 at Maple St instead. A) BTW minimum walking speeds and B) evacuation zone zones only.



3.2.2.4 Discussion

The evacuation landscape of Old Town Florence is nearly identical to that of Reedsport. Our analyses show a very positive situation with proximity to high ground and a prevalence of paved paths, resulting in the entire community being able to reach safety based on a **minimum** ***slow walk*** speed. Similar to Reedsport, the presence of bridges in Florence are not critical for evacuation purposes. Because there is high ground on both sides of the Siuslaw River Bridge as well as the Hwy 126 bridge over the North Fork Siuslaw River, there is no difference in the modeled results between "with" and 'without" bridge scenarios. Liquefaction effects were also found to have a nominal effect on evacuation speeds, with only the Port of Siuslaw Campground showing a BTW speed increase to ***walk***. Finally, the exclusion of evacuation "islands" of high ground next to Highway 101 just north of the Siuslaw River Bridge resulted in no change to the required evacuation speeds.

3.2.3 Heceta Beach

Although much of the Heceta Beach community is located inside the XXL tsunami hazard zone, high ground is close by and is accessible via many streets (**Figure 3-16**). Overall results for Heceta Beach are also positive due to the proximity of high ground. There are no bridges or landslide issues that could block or disrupt safe evacuation. As a result, we did not evaluate any additional mitigation options. Liquefaction was considered due to the likelihood of its occurrence in this area.

3.2.3.1 Scenario 1—Existing road and trail network

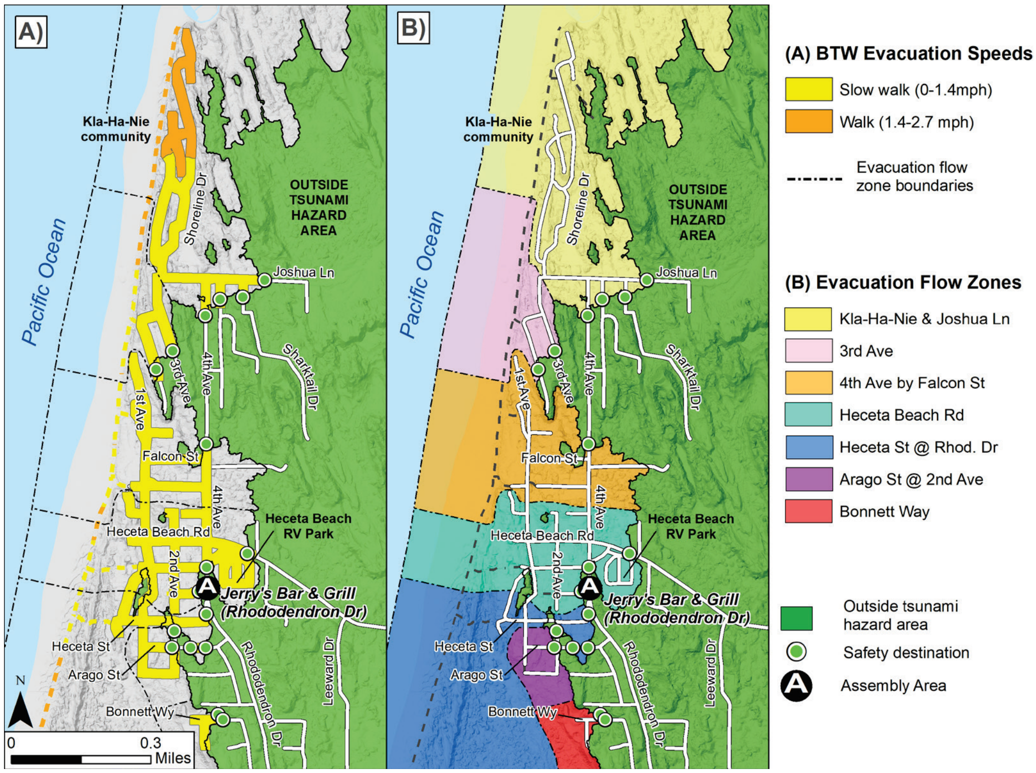
With the assumption that the existing road and trail network remains intact after the earthquake, evacuation to high ground in Heceta Beach is considered straightforward. **Figure 3-16**A shows that evacuees in virtually every location in the area are able to reach high ground at a ***slow walk*** with the exception of those in the Kla-Ha-Nee neighborhood located at the north end of Heceta Beach. Residents there must travel at a **minimum** ***walk*** speed. There appears to be a foot path connecting this area with nearby high ground. However, we were unable to verify the footpath's existence and excluded it from our modeling. If this trail is available, our results in this location are likely too conservative.

Evacuation flow zones for Heceta Beach are shown in **Figure 3-16**B. Due to the high density of streets that intersect high ground, some of the smaller evacuation flow zones were combined; however, every road that reaches safety has a green dot. As always, we recommend that individuals practice their evacuation route to find out which route works best for them. In general:

- The northern area, including Joshua Ln and Kla-Ha-Nee, evacuates east on Joshua Ln.
- Driftwood Shores evacuates to 4th Ave via Falcon St.
- Heceta Beach Rd reaches safety near the Heceta beach RV Park,
- The majority of the areas south of Heceta Beach Rd reaches safety on Rhododendron Dr by Jerry's Bar and Grill. Several other roads reach high ground to the south including Arago St and Bopnett Wy.

Figure B-6, **Figure A-5**, and **Figure C-7**, respectively, present the detailed evacuation route map, 4-fps evacuation time map, and BTW map. Walking speeds on the roads and trails as well as evacuation flow zone data can be found in the Florence_Reedsport_Tsunami_Evacuation_Modeling geodatabase, BridgesOut feature dataset.

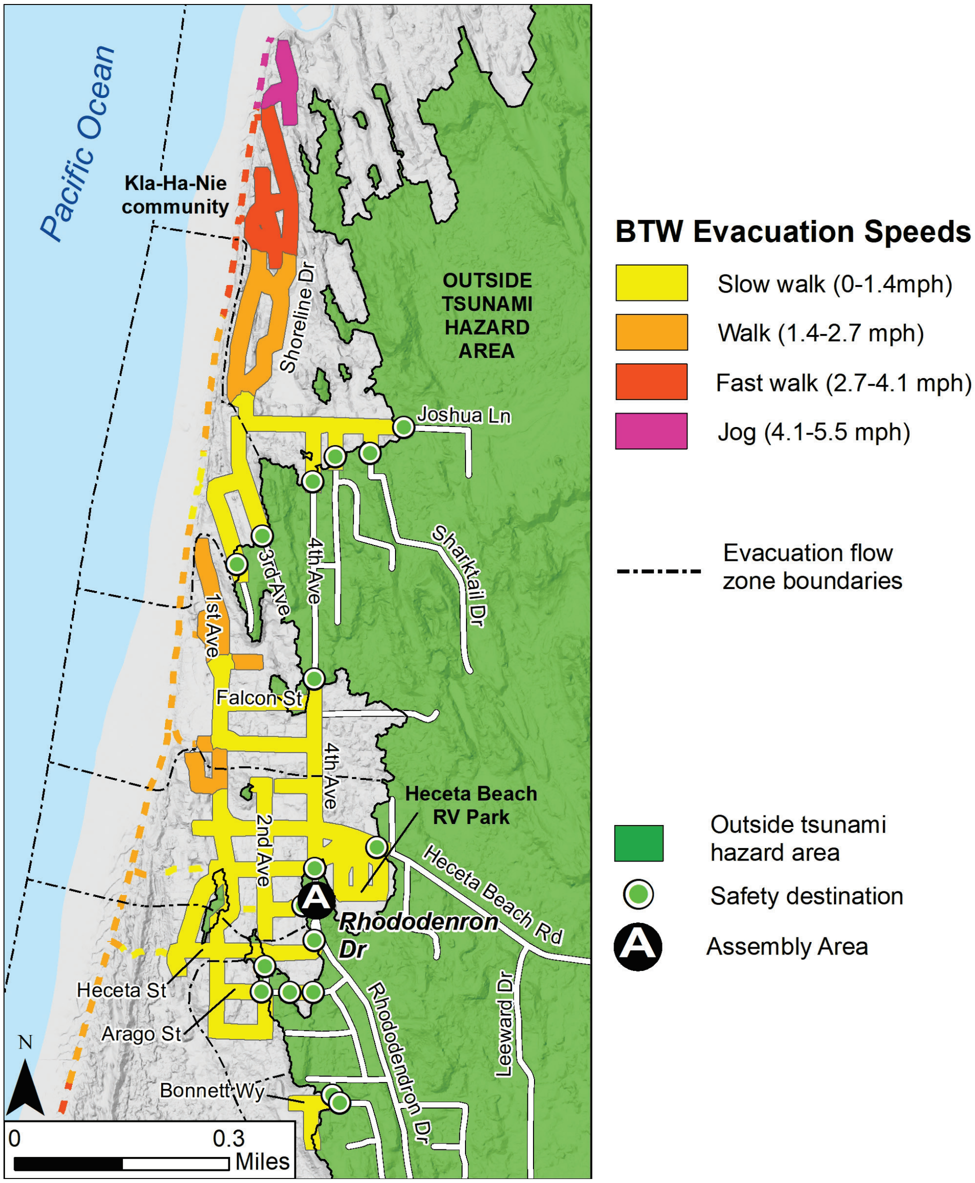
Figure 3-16. Beat the Wave modeling for Heceta Beach assuming the existing road network remains intact. A) BTW minimum walking speeds and B) evacuation zone zones only.



3.2.3.2 Scenario 2—Liquefaction

Heceta Beach is highly susceptible to earthquake-induced liquefaction (Burns and others, 2016). For this scenario, the road network was classified as loose sand. The results are presented in **Figure 3-17**. As can be seen in the figure, evacuation remains feasible for most neighborhoods with the **minimum** BTW speeds based around a ***slow walk***. However, beach trails increase to ***walk***, while the Kla-Ha-Nee neighborhood increases to ***walk*** at the south end and ***jog*** at the north end. The inclusion of a footpath at the north end of this neighborhood to nearby high ground will likely help to lower the evacuation speeds to ***slow walk***. Evacuation flow zones remain unchanged from scenario 1 (**Figure 3-16**B).

Figure 3-17. Beat the Wave minimum walking speeds for Heceta Beach assuming liquefaction blankets the roads with loose sand and mud, making travel more difficult. Evacuation flow zones remain unchanged from scenario 1 (Figure 3-16B).



3.2.3.3 Discussion

Unlike Florence, Heceta Beach is on the open coast and has less time to reach safety. The tsunami is expected to arrive some 20–25 minutes after the earthquake. Despite this, the BTW evacuation model results are encouraging, with evacuees on nearly every street able to reach high ground at **minimum** speeds based around a ***slow walk***. The exception is at the north end of the Kla-Ha-Nie community, where residents must travel faster, at a ***walk***, in order to reach safety in time to "beat the wave." The inclusion of a footpath connecting the north end of the Kla-Ha-Nie community with high ground immediately to its east, would almost certainly reduce the necessary travel speeds needed to reach safety.

Because there is no need to model vertical evacuation at Heceta Beach, the main vulnerability we evaluated further was liquefaction. Unlike for Florence, we do see a slight increase in the required BTW evacuation speeds: speed increases at the south end of the Kla-Ha-Nie community to ***walk***, while evacuation speeds in the north increase to a ***fast walk*** and ***jog***.

Wayfinding is especially important here, because streets in this area undulate, making it unclear which way to go and, importantly, how far to evacuate along a road before the road dips back into the inundation zone. In particular, 4th Ave goes in and out of the inundation zone several times.

3.2.4 South Jetty Rec Area

The south jetty area, also known as the Siuslaw River Spit, is 4 miles long and has only one way out via Sand Dunes Rd. There are additional trails south of the road that reach high ground. However, we will focus our discussion on the spit itself (**Figure 3-11**; complete results including the trails are available in the geodatabase). This area experiences the earliest wave arrivals in the project area because it is on the open coast, between 20 and 22 minutes (**Figure 3-12**). As with the Umpqua Dunes area, we consider a 5-minute evacuation delay in addition to the standard 10-minute to account for the fact that people will be outside when the earthquake begins.

Safety can be reached on Sand Dunes Rd about 0.8 miles east of Day Use #1, near the Sand Camping Access parking lot. Additional high ground runs north-south about 0.5 miles east of the road along the western bank of the Siuslaw River. No official trails connect Sand Dunes Rd to this high ground, which starts to thin around Day Use #3 and disappears by Day Use #4.

Overall results are similar to what we see in other remote coastal areas, including the Umpqua Dunes, namely, that much faster travel speeds are needed to reach safety, safety destinations are limited, and land cover conditions (i.e., loose sand and wetlands) can make evacuation difficult. The lack of high ground on the spit means there are not a lot of options for mitigation aside from a vertical evacuation structure, which is considered in scenario 3. Liquefaction was not considered, mostly because our modeled results indicated that evacuating in time to beat the tsunami wave will be extremely challenging out on the spit.

3.2.4.1 Scenario 1—Existing road and trail network

Figure 3-18A shows results for a scenario including the existing road and trail network and a 10-minute evacuation delay. The BTW walking speed at Day Use #1 is ***fast walk***, and by Day Use #3 an evacuee would need to maintain a ***sprint*** to reach high ground in time to survive. By Day Use #4 and beyond one is ***unlikely to survive*** (on foot). High ground on Sand Dunes Rd is the only safety destination for the region.

Figure B-7, **Figure A-6**, and **Figure C-8**, respectively, present the detailed evacuation route map, 4-fps evacuation time map, and BTW map. Walking speeds on the roads and trails as well as evacuation flow zone data can be found in the Florence_Reedsport_Tsunami_Evacuation_Modeling geodatabase, BridgesOut_XXL1 feature dataset.

3.2.4.2 Scenario 2—5-minute delay

As for Umpqua Dunes Rec Area, we ran a simulation using a 5-minute evacuation delay to reflect the likelihood that evacuees are probably able to travel sooner because they will be outside at the time of the earthquake. As can be seen in **Figure 3-18**B, the resulting BTW speeds are reduced everywhere. In particular, two of the day use areas that were previously classified as ***unlikely to survive*** (#4 and #5) are now re-classified to a ***sprint***. Evacuation flow zones remain unchanged from scenario 1 (black dashed lines in Figure 3-18A, B). Evacuation will remain a challenge, but our results suggest that it is survivable as long as evacuation begins immediately.

3.2.4.3 Scenario 3—Vertical evacuation structure, 5-min delay

Because people recreating out on the spit are *unlikely to survive* a CSZ event, due to the required fast travel speeds needed to beat the wave (even with a shorter evacuation delay), we evaluated the effect of constructing a vertical evacuation structure at Day Use #4. This location was chosen because it is approximately midway down the spit. As expected, BTW speeds are dramatically reduced by this hypothetical structure with no section of road classified as ***sprint*** or ***unlikely to survive*** (**Figure 3-18**C). **Table 3-3** compares BTW speeds at key locations with and without a VE structure.

Using our XXL evacuation model results, we estimate that the design elevation must exceed the maximum tsunami flood elevation of ~12 m (40 ft) (a maximum flow depth of ~10 m [33 ft]) (Priest and others, 2013a). Furthermore, the structure would need to be of a sufficient strength to withstand the tsunami current flow and be large enough to accommodate the estimated number of evacuees in the immediate area (defined as the flow zone surrounding the structure in **Figure 3-18**C).

Figure 3-18. Beat the wave minimum walking speeds for the South Jetty Area. A) assuming the existing road network remains intact, B) reducing the evacuation delay to 5-minutes, and C) a hypothetical vertical evacuation structure at Day Use #4. Black dashed lines indicate trails 'unlikely to survive (>10 mph).

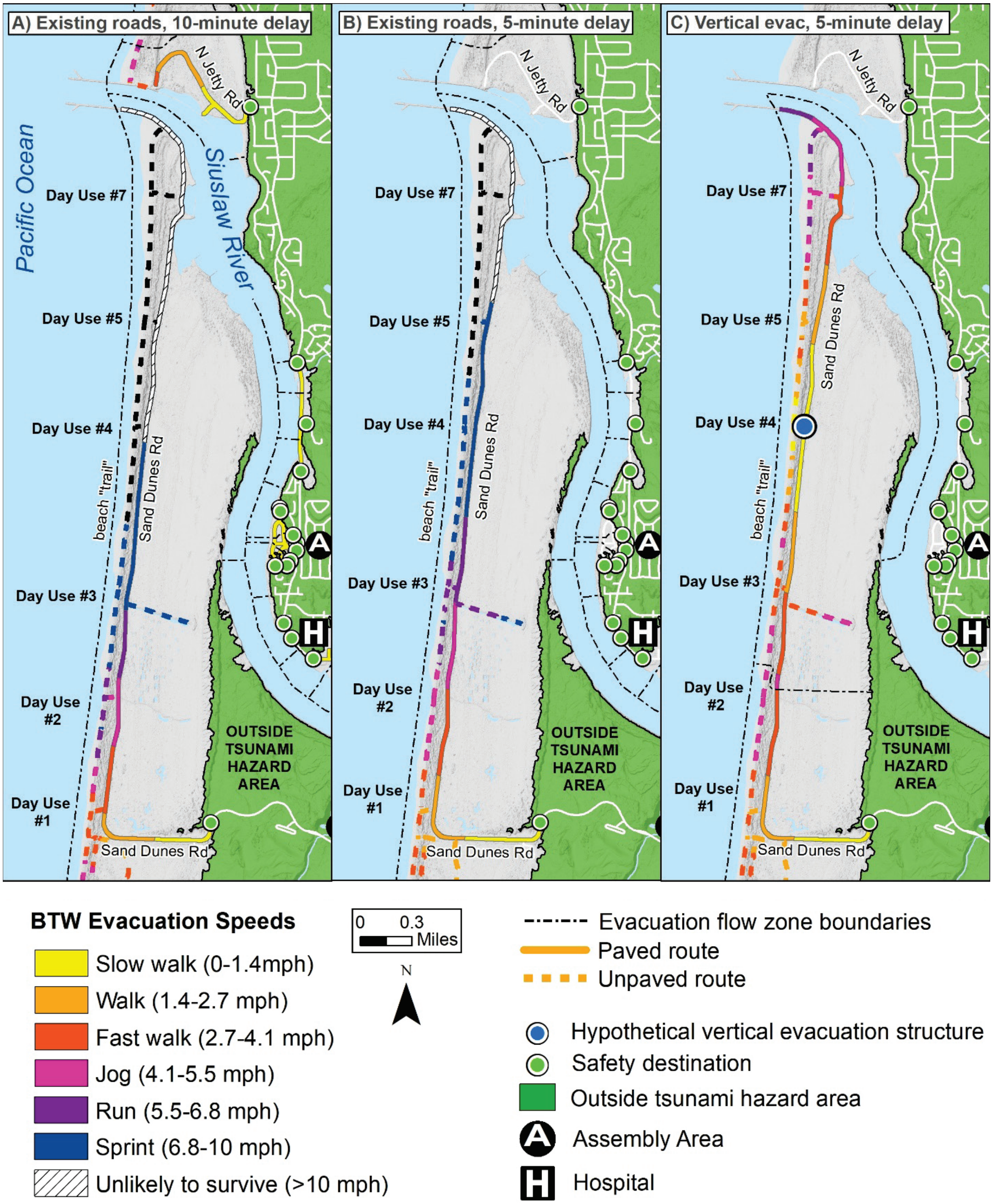


Table 3-3. Comparison of Beat the Wave walking speeds from various locations along Sand Dunes Road with and without a hypothetical vertical evacuation (VE) structure at Day Use #4. Both scenarios use a 5-minute delay.

	Evacuate to Sand Dunes Rd		Evacuate to VE at Day Use #4	
Area of interest	**Distance to Safety (miles)**	**BTW Speed, 5-Minute Delay**	**Distance to Safety (miles)**	**BTW Speed, 5-Minute Delay**
South jetty	4.7	Unlikely to survive	1.6	Jog
Day Use #7	4.4	Unlikely to survive	1.4	Fast walk
Day Use #5	3.7	Sprint	0.6	Walk
Day Use #4	3.0	Sprint	0	Slow walk
Day Use #3	2.1	Run	0.9	Walk
Day Use #2	1.5	Fast walk	*	*
Day Use #1	0.8	Walk	*	*

* Day Use #1 and #2 do not evacuate to hypothetical vertical evacuation structure

3.2.4.4 Discussion

The South Jetty has significant evacuation challenges, as is typical of spits along the Oregon coast. There is only one safety destination for the entire ~4 mile stretch, and it is on the access road (Sand Dunes Rd) located at the south end of the recreational area. Although reducing the initial evacuation delay from 10 minutes to 5 minutes does improve the situation, evacuees at the northern half of the spit must maintain a ***sprint*** to reach safety. For this northern reach, the only mitigation option is construction of a vertical evacuation structure. Our modeling (compare **Figure 3-18**A and B with **Figure 3-18**C) shows the dramatic improvement such a structure would have for this area: the fastest required evacuation speed is reduced from a ***sprint*** to a ***jog***, while evacuees in most other areas would require an evacuation speed classified as ***fast walk*** or slower in order to reach a vertical evacuation structure at Day Use #4 or, alternatively, high ground located to the south on Sand Dunes Rd. These analyses presuppose that any vertical evacuation structure have adequate capacity for the population served and is designed and constructed to remain intact and accessible after the earthquake shaking while also resisting tsunami forces and scour. The significant height of the structure, potential large footprint, and large cost are likely to be a deterrent. Costs versus benefits must be carefully evaluated among all these options, including the possibility of designing a structure built to withstand a smaller tsunami, such as that modeled in the DOGAMI L1 (Large) scenario, characterized by significantly shallower flow depths.

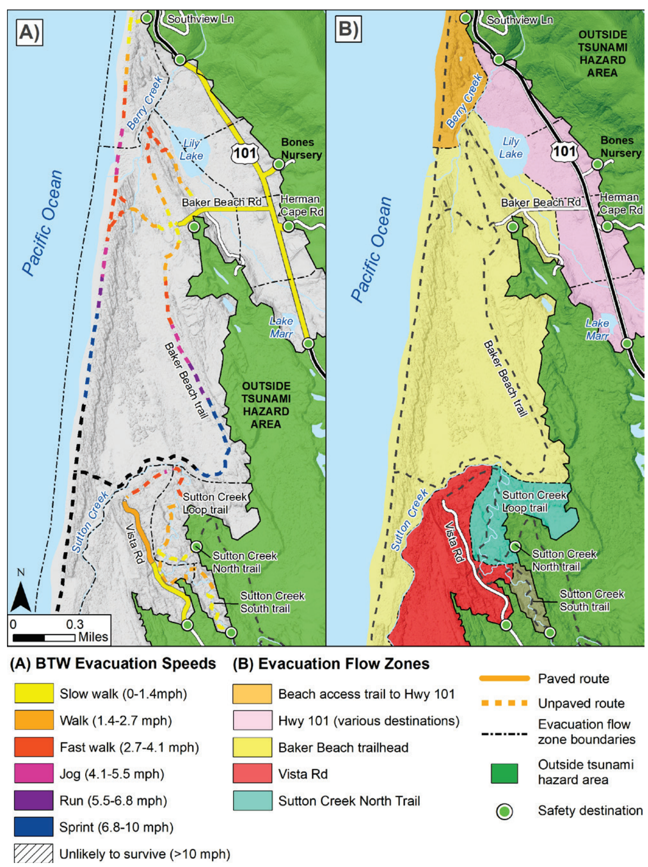
3.2.5 Sutton and Baker Beach and trails

The final region included in the Florence project area encompasses the Sutton Beach and Baker Beach trail network and beaches area (**Figure 3-11**), which has tsunami arrival times of ~20–25 minutes (**Figure 3-12**). Trailheads are accessed via Baker Beach Rd or Vista Dr (Holman Vista), with Sutton Creek separating the two areas. The largest concentration of people in this area is likely to be based at Sutton Campground. However, because the campground is located outside the tsunami zone, campers there are safe from the effects of a tsunami. Nevertheless, these people may recreate out on the beach and hence would be impacted by a tsunami. Because there is no concentration of people within the inundation zone, we did not consider any hypothetical mitigation options. We did, however, reduce the evacuation delay to 5-minutes because people in this area are expected to be outside when the earthquake strikes.

3.2.5.1 Scenario 1—Existing road and trail network, 10-minute delay

Figure 3-19A shows that modeled BTW walking speeds for this area range from ***slow walk*** at the Baker Beach trailhead, which is very near a high dune, to ***unsurvivable*** for some parts of the trail system. The Holman Vista parking lot, at the end of Sutton Outlet Rd, is classified as a ***fast walk***. The short section of Hwy 101 that is within the XXL inundation zone has several safety destinations nearby and is predominantly within ***slow walk*** with a short section of ***walk***. Note that not all trails were included for clarity in the final map products. Evacuation flow zones are shown in **Figure 3-19**B. The northernmost safety destination is a beach access trail that reaches Hwy 101 by Southview Ln. The nearest safety destination for most of the Baker Beach trail system is the Baker Beach trailhead. For those on the Sutton Beach trail system, high ground can be found on Vista Rd or along the Sutton Creek trail. **Figure B-8** presents the detailed evacuation route map and evacuation time map based on the standard 4-fps speed (**Figure A-7**). Walking speeds on the roads and trails as well as evacuation flow zone data can be found in the Florence_Reedsport_Tsunami_Evacuation_Modeling geodatabase, BridgesOut feature dataset.

Figure 3-19. Beat the wave modeling for trails in the Baker Beach and Sutton Beach areas. A) BTW minimum walking speeds and B) evacuation flow zones only. Not all trails were included in the modeling for clarity.

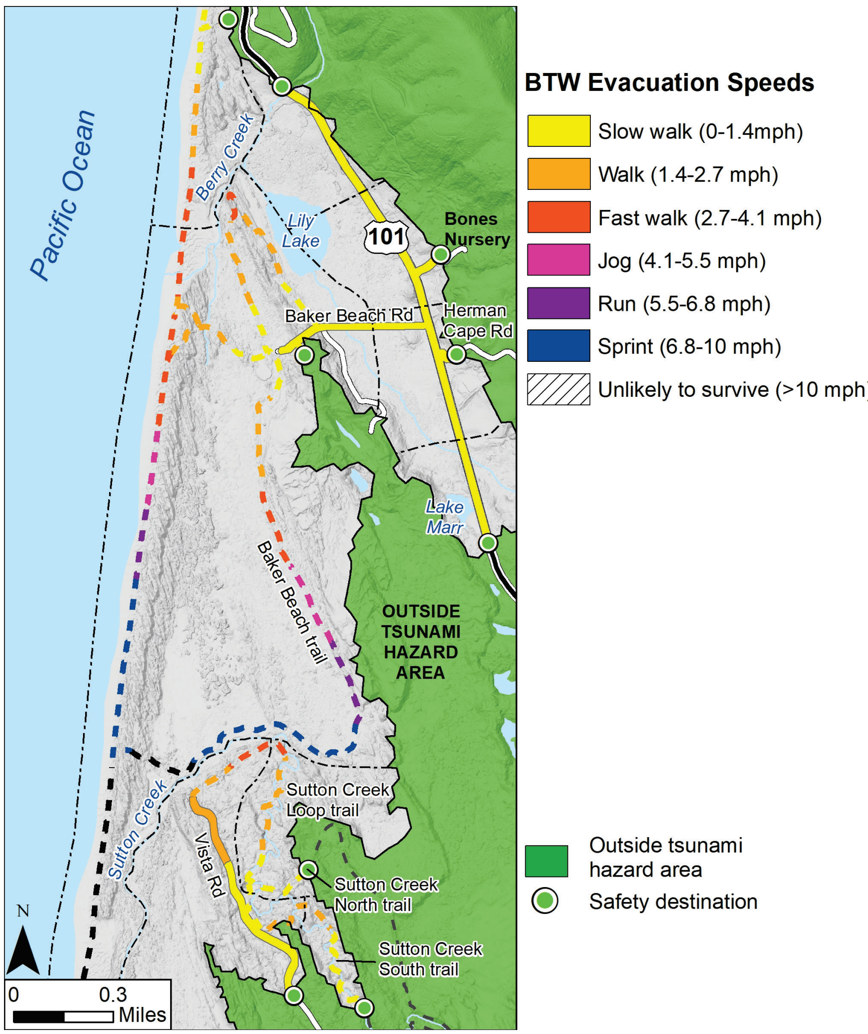


3.2.5.2 Scenario 2

3.2.5.3 —5-minute delay

While a 5-minute reduction in evacuation delay reduces minimum walking speeds, the changes are not appreciable in most places except the farthest reaches of the trail network (**Figure 3-20**). Baker Beach trailhead and Holman Vista day use remain ***slow walk*** and ***walk***, respectively. However, the amount of trail classified as unsurvivable is reduced by 1,000 to more than 2,000 feet in places. Evacuation flow zones are unchanged from scenario 1 (**Figure 3-19**B).

Figure 3-20. Beat the wave modeling for trails in the Baker Beach and Sutton Beach areas with a 5-minute evacuation delay. A) BTW minimum walking speeds and B) evacuation flow zones only.



3.2.5.4 Discussion

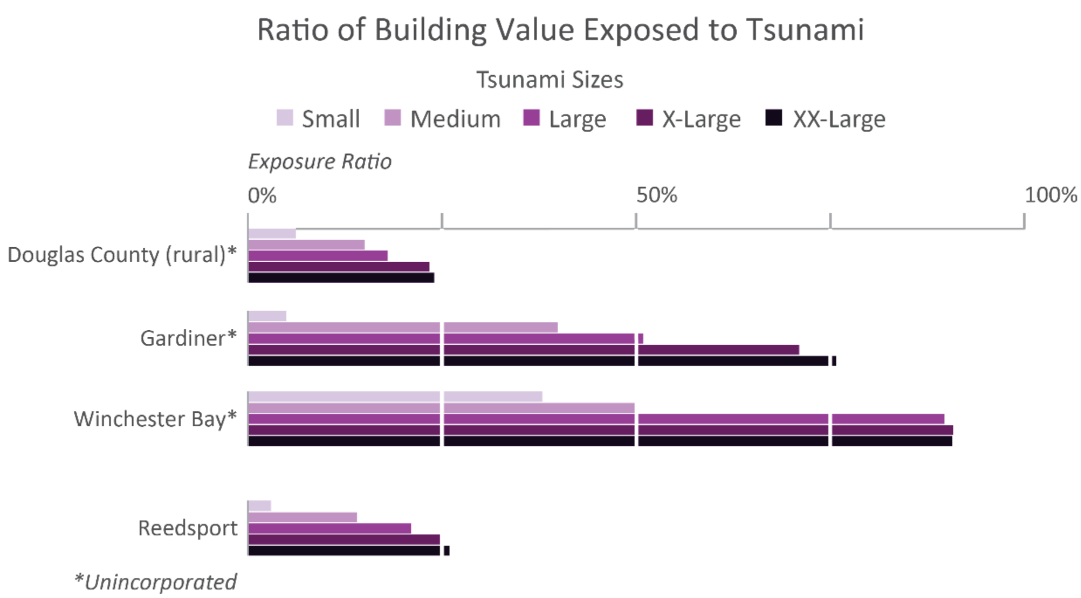
This area is remote and far from high ground, difficult to traverse due to significant amounts of loose sand, and disorienting due to the many dunes. We did not consider any infrastructure mitigation options for this region because we did not think any were justified, given the remoteness and relatively small number of visitors. However, signage to inform visitors of their nearest high ground is imperative for their survival.

3.3 Socioeconomic analysis

3.3.1 Reedsport project area

Much of the development in coastal Douglas County is close to the Pacific Ocean or adjacent to the Umpqua River, resulting in high risk from tsunamis. Up to 1,770 permanent residents could be impacted from a CSZ tsunami, requiring services like medical care and shelter (M. C. Williams, written commun., 2018). Visitors and employees were not included in this analysis. **Figure 3-21** shows the exposure, in building value, by community. Winchester Bay experiences the most significant exposure, with 50% or more of the building value affected for all but the Small tsunami scenario. Gardiner also has an elevated risk due to its proximity to the river. Reedsport has a much lower risk due to its distance upriver.

Figure 3-21. Tsunami inundation exposure for coastal Douglas County communities.



Many of the area's critical facilities are outside XXL tsunami inundation zone. The exceptions are:

- Reedsport
    - Douglas County Sheriff's Office (within DOGAMI's Small and Medium scenarios, outside Large, Extra-large and XXL, i.e. "Medium")
    - Reedsport Police Department (Medium)
    - Reedsport Fire Station 1 (Medium)
- Gardiner
    - Rural Fire Protection District Station (Medium)
- Winchester Bay
    - Rural Fire Protection District Station (Small)
    - Coast Guard Station (Small)

Although it is good that the schools and hospital are outside the XXL tsunami inundation zone, the fact that all area fire stations as well as law enforcement are inside the Medium zone is cause for concern. We recommend the city and county consider alternative locations for these and other facilities deemed critical.

People over the age of 65 or under the age of 18 are classified as vulnerable age groups. Populations over the age of 65 may depend on others or on assistive devices to fulfill the activities of daily living. Children rely on caregiving adults, while elderly populations may have transportation and mobility limitations. Additionally, individuals living with a disability may require more services regarding hazard preparation, mitigation, repairs, and outreach efforts. Because of these factors, these age groups will likely be unable to sustain speeds of ~2–4 fps or greater for very long when evacuating (Wood and others, 2015). By identifying where these populations are, and comparing them to BTW walking speed maps, we can identify areas that need improvements.

It is encouraging that evacuees on nearly every street in Reedsport, Gardiner, and Winchester Bay can evacuate at 0–2 fps (***slow walk***). An analysis of population groups with respect to BTW speeds is shown in **Table 3-4**. Results show that Winchester Bay has the highest number of people at risk of being unable to evacuate, but even there only 5% of that population group (5 people total) are at risk. BTW speeds were assigned using the "bridges out" scenario (scenario 1 for Reedsport and Gardiner; scenario 2 for Winchester Bay).

Results do not necessarily reflect the higher BTW speeds west of the Salmon Harbor Bridge in Winchester Bay due to the lack of permanent residences in the area. The high number of visitors to this area (overnight camping at Windy Cove Campground, Marina RV Park, and Halfmoon Bay Campground) would likely increase the number of vulnerable people.

Table 3-4. Coastal Douglas County socioeconomic Beat the Wave analysis using the "bridges out" scenario.

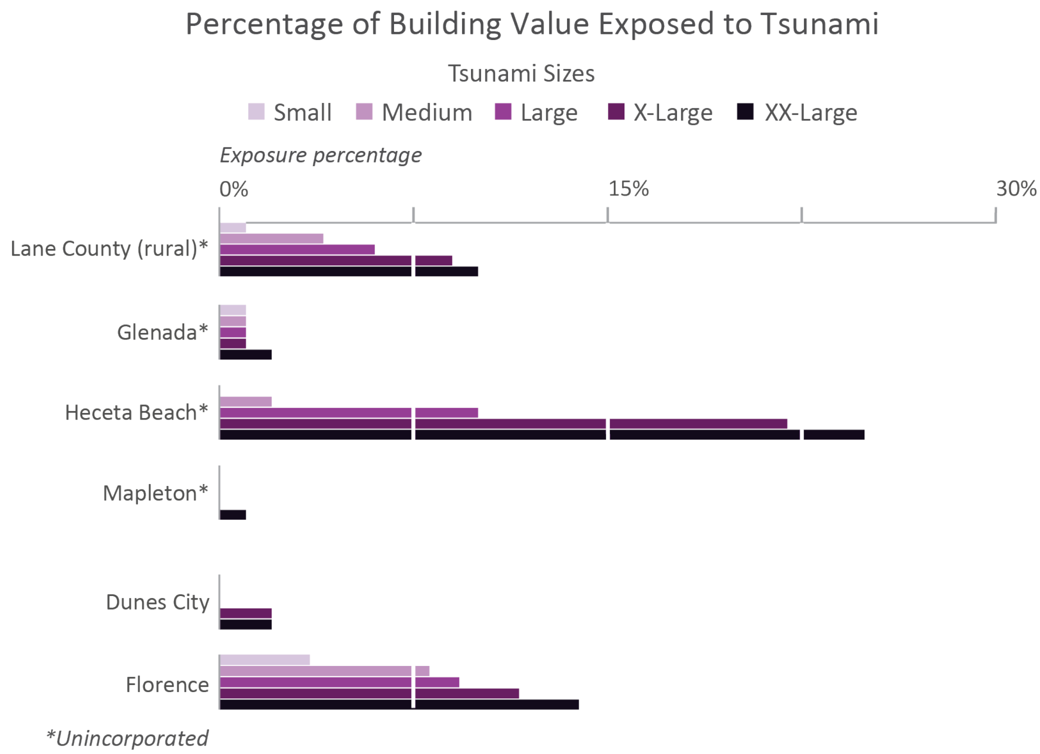
Community	Total Population	Population within Medium	Population within Large	Population within XXL	Population within XXL that must travel faster than 2 fps	Population over 65 or under 18 that must travel faster than 2 fps
Reedsport	4,215	560 (13%)	1,035 (25%)	1,175 (28%)	0 (0%)	0 (0%)
Gardiner	248	124 (50%)	152 (61%)	209 (84%)	0 (0%)	0 (0%)
Winchester Bay	295	154 (52%)	239 (81%)	243 (82%)	19 (8%)	5 (5%)

Medium, Large, and XXL indicate tsunami inundation scenarios for a locally generated tsunami from a Cascadia subduction zone (CSZ) earthquake: XXL (100%), L (95%), and M (79%) (Priest and others, 2013b).

3.3.2 Florence project area

Much of the City of Florence is on high ground outside the XXL tsunami inundation zone. Exceptions are Old Town, which is adjacent to the Siuslaw River, and Heceta Beach, which is on the open coast. Around 1,000 permanent residents could be impacted from a CSZ tsunami, requiring services like medical care and shelter (M. C. Williams, written commun., 2018). Visitors and employees were not included in this analysis. **Figure 3-22** shows the exposure, in building value, by community. Heceta Beach experiences the most significant exposure, with ~25% of the building value affected for an XXL tsunami; however, that drops to almost 10% by the Large scenario. The tsunami affects only ~15% of the total building value in Florence and the percentage drops rapidly when considering smaller tsunami scenarios (drops in half, to ~7%, for the Medium scenario).

Figure 3-22. Tsunami inundation exposure for coastal Lane County communities. Note that the exposure axis stops at 30%.



All but one critical facility in the Florence area is outside the XXL tsunami inundation zone. The exception is the Siuslaw Valley Fire and Rescue Station 2, which is inside XXL but outside XL and very near high ground.

People over the age of 65 or under the age of 18 are classified as vulnerable age groups. Populations over the age of 65 may depend on others or on assistive devices to fulfill the activities of daily living. Children rely on caregiving adults, while elderly populations may have transportation and mobility limitations. Additionally, individuals living with a disability may require more services regarding hazard preparation, mitigation, repairs, and outreach efforts. Because of these factors, these age groups will likely be unable to travel faster than 4 fps when evacuating. By identifying where these populations are, and comparing them to BTW walking speed maps, we can identify areas that need improvements.

Nearly every street can evacuate at 0–2 fps (***slow walk***). An analysis of population groups with respect to BTW speeds is shown in **Table 3-5**. Results show that Heceta Beach has the highest number of people at risk of being unable to evacuate, but even there only 7% of that population group (67 people total) are at risk. BTW speeds were assigned using Heceta Beach scenario 1, which assumes the "existing road and trail network remains intact". Because there are no bridges in the community, these results are the same as "bridges out" scenarios elsewhere in the Florence study area.

Results do not reflect the higher BTW speeds for the South Jetty Rec Area due to the lack of permanent residences. The high number of visitors to this area would likely increase the number of vulnerable people.

Table 3-5. Coastal Lane County socioeconomic Beat the Wave analysis using the "bridges out" scenario.

Community	Total Population	Population within Medium	Population within Large	Population within XXL	Population within XXL that must travel faster than 2 fps	Population over 65 or under 18 that must travel faster than 2 fps
Florence	8,466	156 (2%)	332 (4%)	860 (10%)	0 (0%)	0 (0%)
Heceta Beach	1,558	5 (0.3%)	45 (3%)	189 (12%)	19 (10%)	67 (7%)

Medium, Large, and XXL indicate tsunami inundation scenarios for a locally generated tsunami from a Cascadia subduction zone (CSZ) earthquake: XXL (100%), L (95%), and M (79%) (Priest and others, 2013b).

4.0 CONCLUSIONS AND RECOMMENDATIONS

The investigation accomplished the primary objective: to provide a quantitative assessment of evacuation difficulty in coastal Lane and Douglas Counties, including the communities of Florence and Reedsport. The investigation implemented the Beat the Wave (BTW) approach to evacuation analysis developed by Priest and others (2015a,b), with a major refinement in that we can now account for variable speeds along a route due to differences in the route characteristics (e.g., flat vs. steep, sand vs. paved). As a result, the BTW approach accomplishes in a single map what would require multiple maps in other approaches such as that of Wood and Schmidtlein (2012). In contrast, the single-evacuation-speed approach of Wood and Schmidtlein (2012) is more practical for regional analyses or where wave arrival times are not known.

The results of this study demonstrate that evacuation of the incorporated communities in response to a maximum considered (XXL) Cascadia Subduction Zone tsunami is attainable with one notable exception. The exception is in Winchester Bay (the area west of the Salmon Harbor Bridge containing Windy Cove Campground and the Marina's RV Park and boat moorage) where the bridge is expected to fail during the earthquake, potentially eliminating their key evacuation route. Without suitable mitigation efforts directed at reinforcing the bridge or constructing a new trail, we anticipate some potential loss of life because the time required to "beat the wave" to safety in this area is too long relative to the arrival time of the tsunami.

Of additional concern are the high evacuation speeds needed in the open-coast recreational areas of the South Jetty and Umpqua Dunes Recreation Areas. For the latter, we feel that signage directing evacuation across open sand to nearby high ground is preferable to taking the road all the way to the Umpqua Lighthouse. For the South Jetty, a vertical evacuation structure is the only viable mitigation option because there is no other natural high ground in the area. A large enough structure (e.g., a berm or building) capable of holding the estimated number of people in the relevant evacuation flow zone would need to be built to a sufficient height. We recommend further evaluation in order to assess the cost/benefits of each of these options.

The socioeconomic analysis provides reassurance that the prevalence of nearby high ground in Reedsport and Florence will allow even the most vulnerable permanent residents to survive. Visitors and employees were not included in this analysis. We anticipate the incorporating visitors into an analysis for places like the Umpqua Dunes and South Jetty Recreation Areas would bring to light the need for additional mitigation efforts in these locations due to high BTW speeds. We hope to incorporate visitors and employees as well as account for second homes, vacation rentals, and hotel/motels in future analyses.

Regardless of walking speeds, physical limitations, and mitigation considerations, wayfinding through adequately spaced signage, battery operated lighting, and other means is essential to survival. Even in areas where safety is nearby and all populations appear likely to survive, confusion about where to go will make the difference between life and death. Clear and visible signage placed in key locations is extremely important, especially for areas likely to experience large numbers of visitors. We also encourage individuals to practice their evacuation route to determine what works for them. It is only through quick, instinctive evacuation that lives will be saved. This can be achieved through ongoing education programs with a focus on regular community-wide evacuation drills (e.g., Connor, 2005).

5.0 ACKNOWLEDGMENTS

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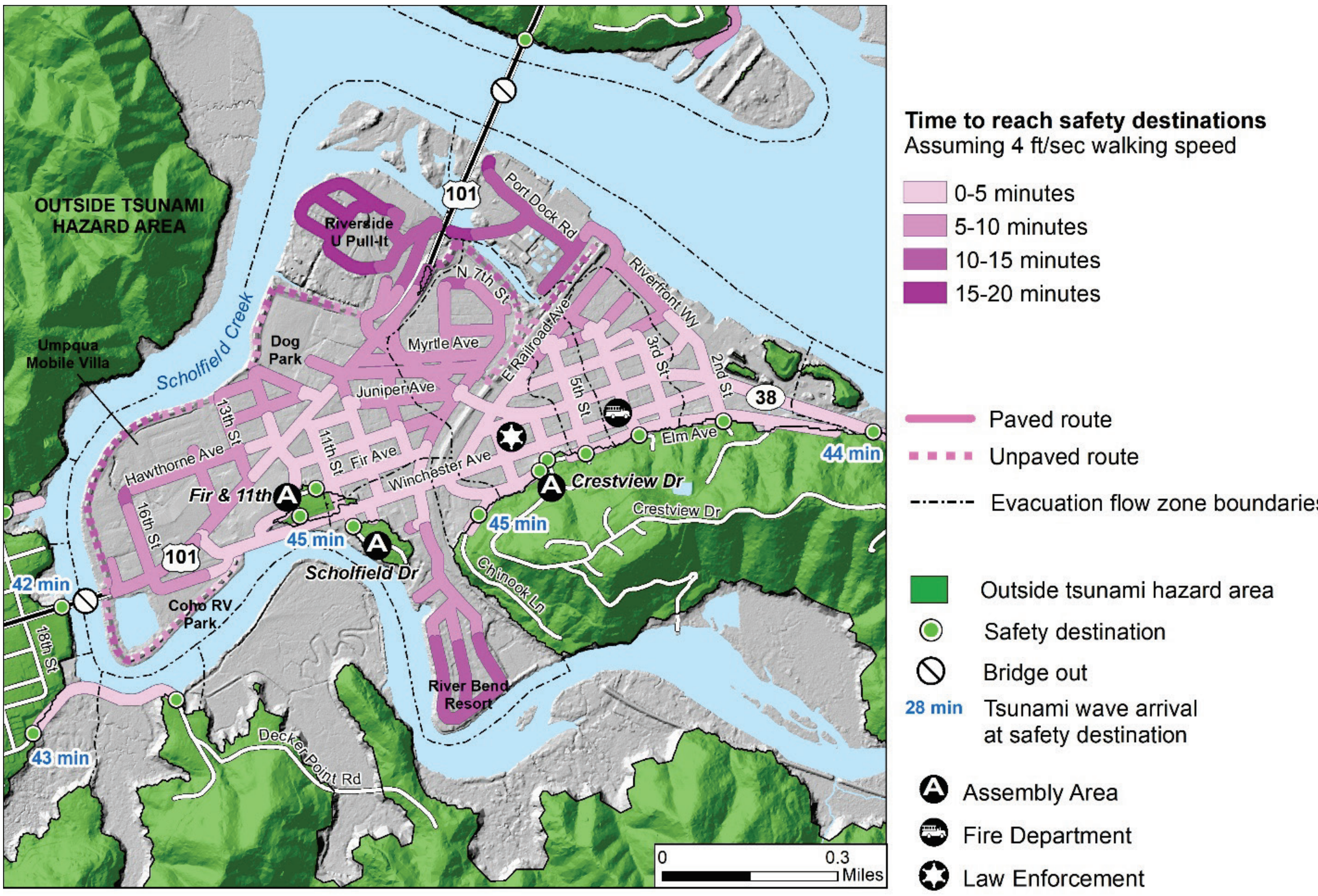
APPENDIX A. EVACUATION TIME MAPS

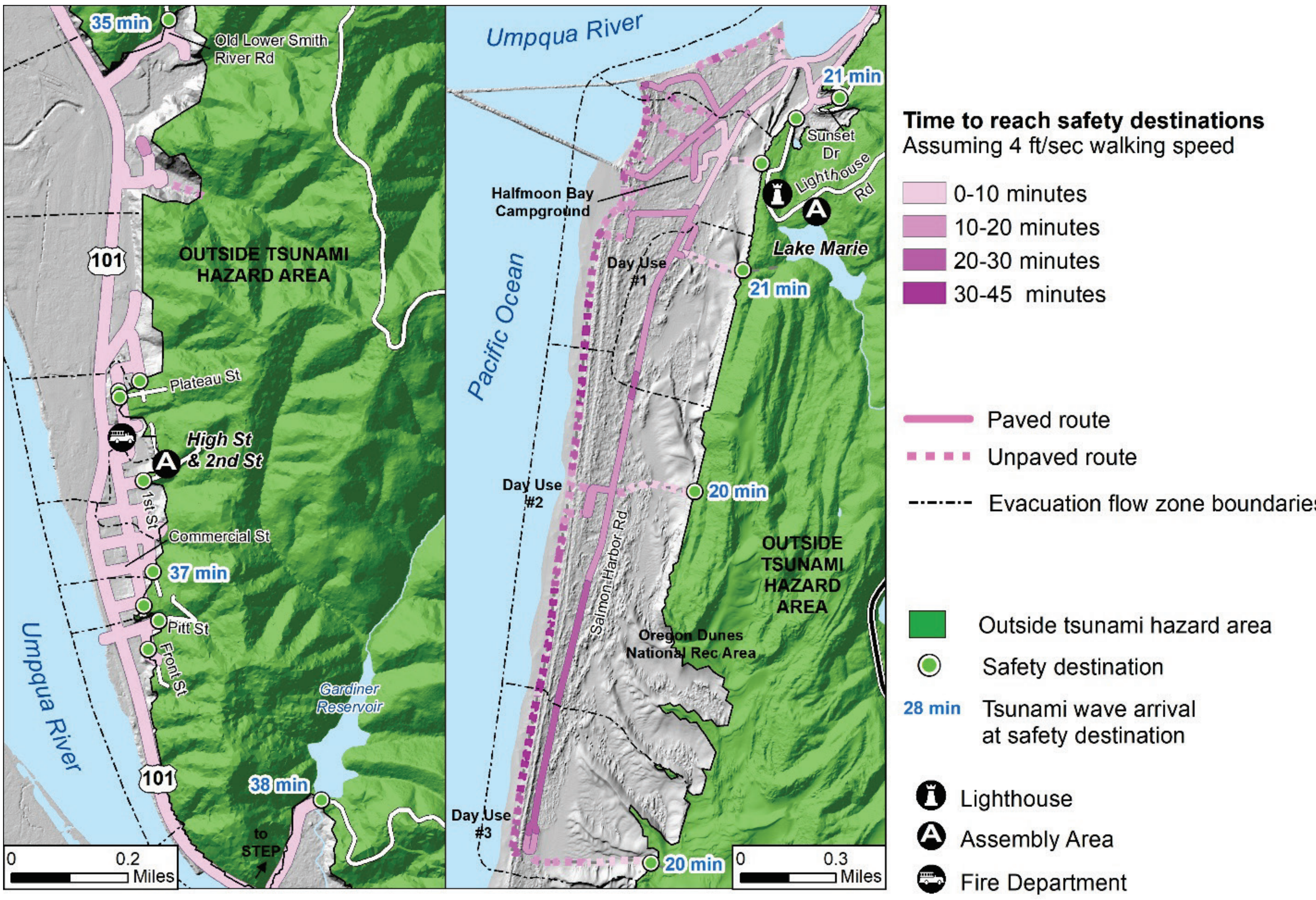
A.1 City of Reedsport

Figure A-1. Evacuation time map based on a standard 4-fps speed for the City of Reedsport using Scenario 1: With and without the Umpqua River Bridge and Scholfield Creek Bridge (results unchanged). These data can also be found in the Florence_Reedsport_Tsunami_Evacuation_Modeling geodatabase, BridgesOut_XXL1 feature dataset, EvacuationTime feature classes.



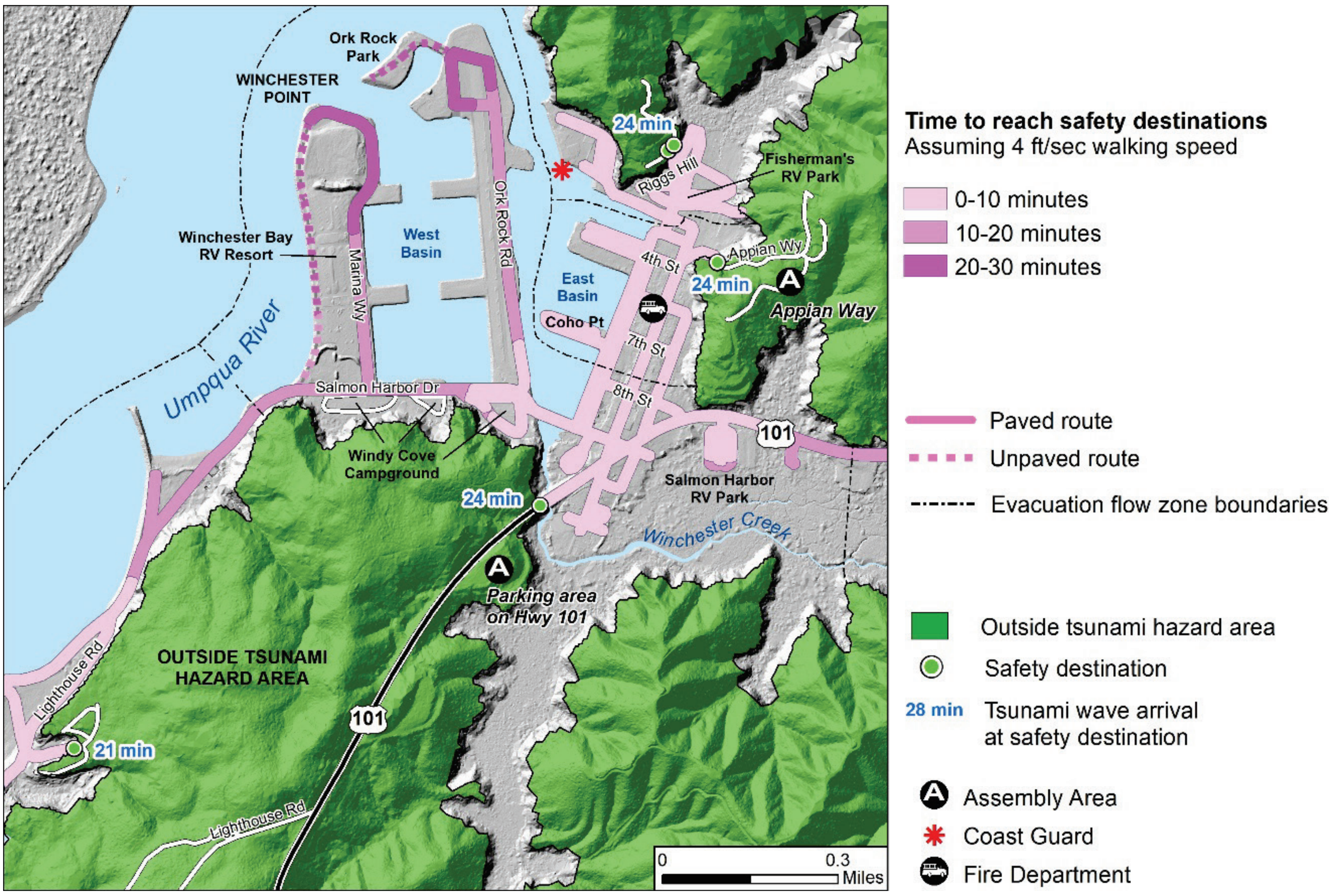
A.2 Gardiner and Umpqua Dunes Recreation Area

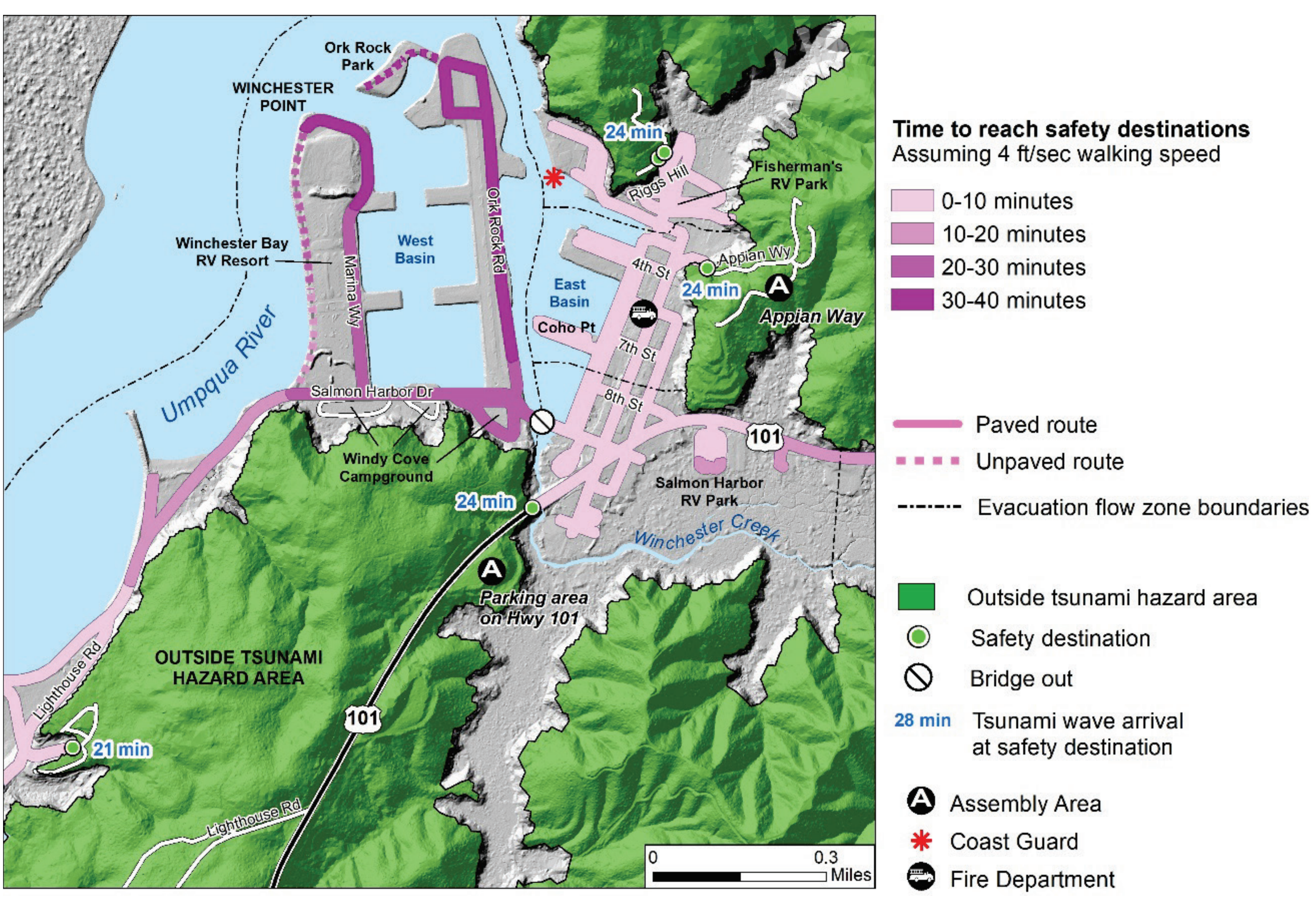
Figure A-2. Evacuation time map based on a standard 4-fps speed for A) Gardiner (using Scenario 1) and B) the Umpqua Dunes Rec Area (using Scenario 3, with trails). These data can also be found in the Florence_Reedsport_Tsunami_Evacuation_Modeling geodatabase, BridgesOut_XXL1 feature dataset, EvacuationTime feature classes.



A.3 Winchester Bay

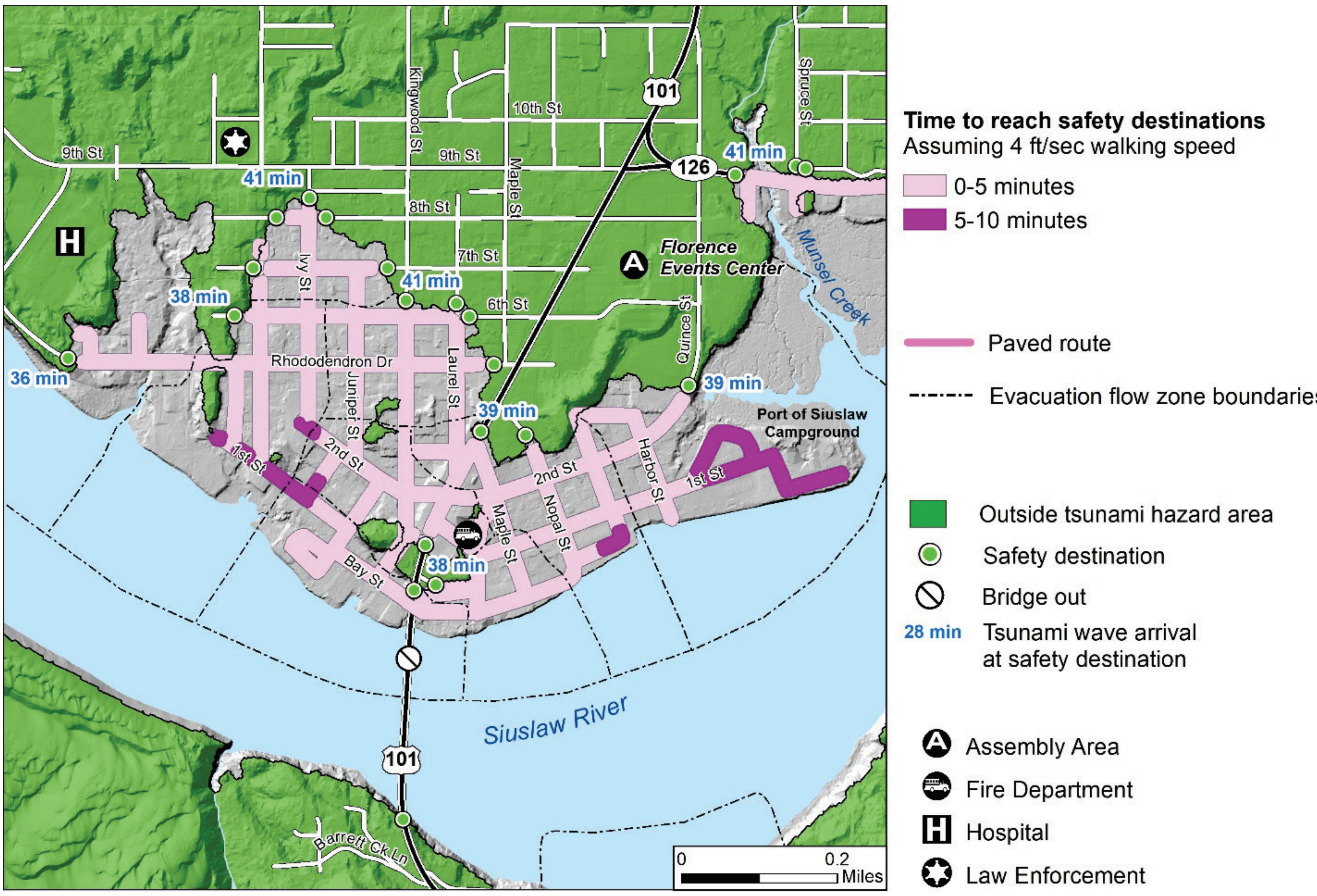
Figure A-3. Evacuation time map based on a standard 4-fps speed for Winchester Bay using A) Scenario 1: existing road network, including the Salmon Harbor Bridge, intact, and B) failure of the Salmon Harbor Bridge. These data can also be found in the Florence_Reedsport_Tsunami_Evacuation_Modeling geodatabase, BridgesOut_XXL1 and BridgesIn_XXL1_WinchesterBayOnly feature datasets, EvacuationTime feature classes.





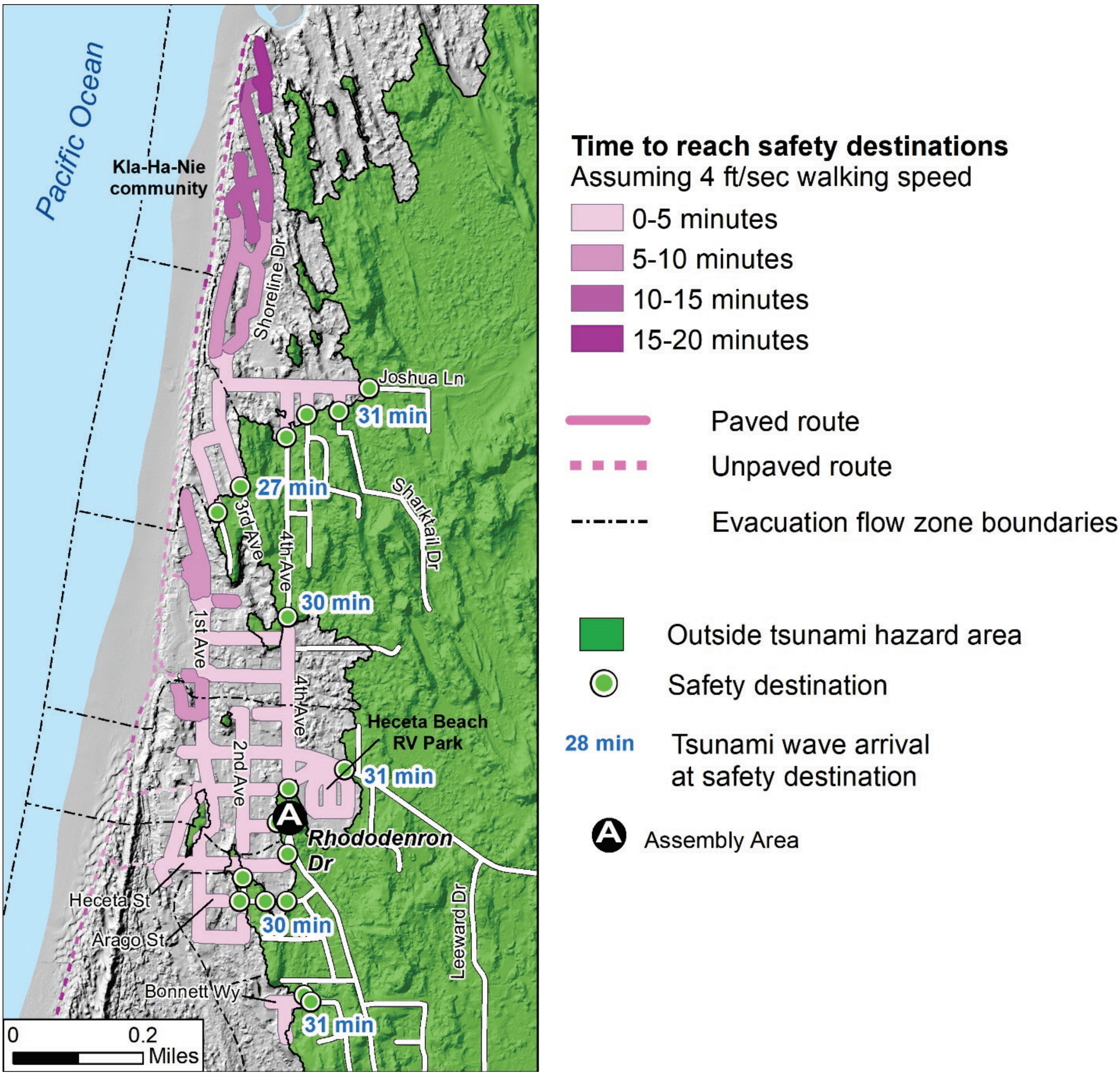
A.4 Old Town Florence

Figure A-4. Evacuation time map based on a standard 4-fps speed for the City of Florence, Old Town, using Scenario 1: With and without the Siuslaw River Bridge (results unchanged). These data can also be found in the Florence_Reedsport_Tsunami_Evacuation_Modeling geodatabase, BridgesOut_XXL1 feature dataset, EvacuationTime feature classes.



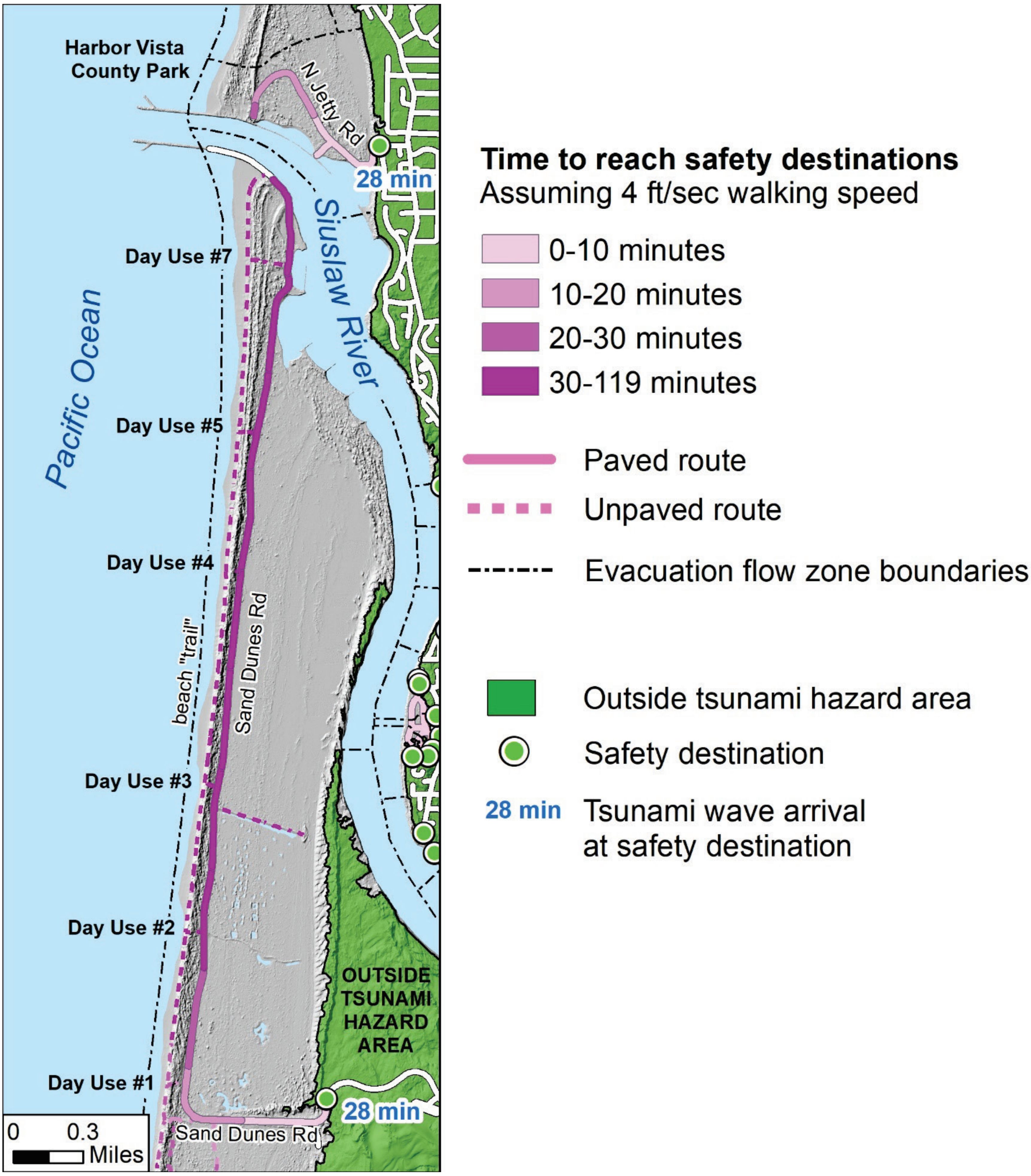
A.5 Heceta Beach

Figure A-5. Evacuation time map based on a standard 4-fps speed for the Heceta Beach community using Scenario 1: existing road network intact. These data can also be found in the Florence_Reedsport_Tsunami_Evacuation_Modeling geodatabase, BridgesOut_XXL1 feature dataset, EvacuationTime feature classes.



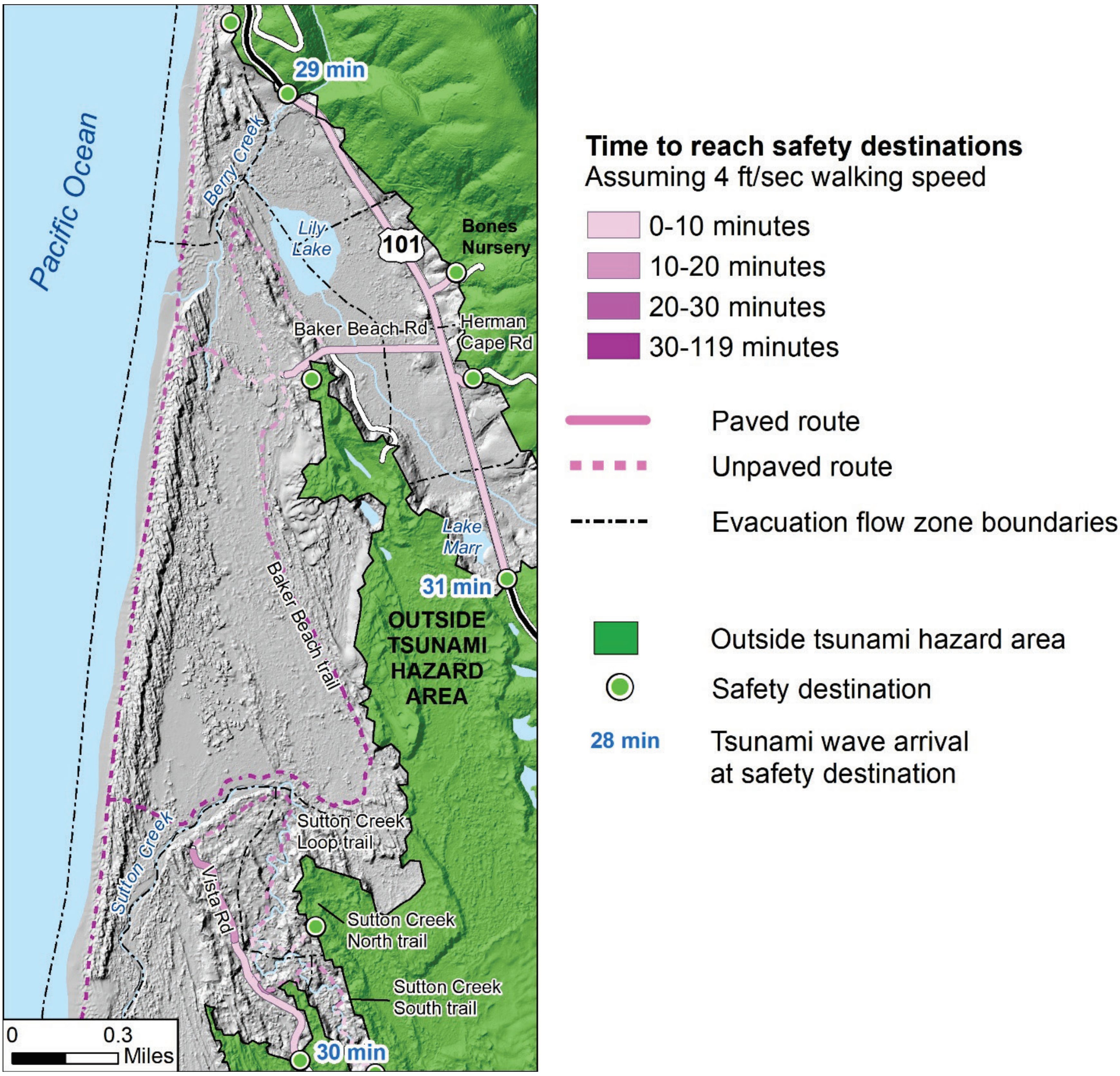
A.6 South Jetty Rec Area

Figure A-6. Evacuation time map based on a standard 4-fps speed for the South Jetty Recreation Area using Scenario 1: existing road network intact. These data can also be found in the Florence_Reedsport_Tsunami_Evacuation_Modeling geodatabase, BridgesOut_XXL1 feature dataset, EvacuationTime feature classes.



A.7 Baker Beach and Sutton Beach

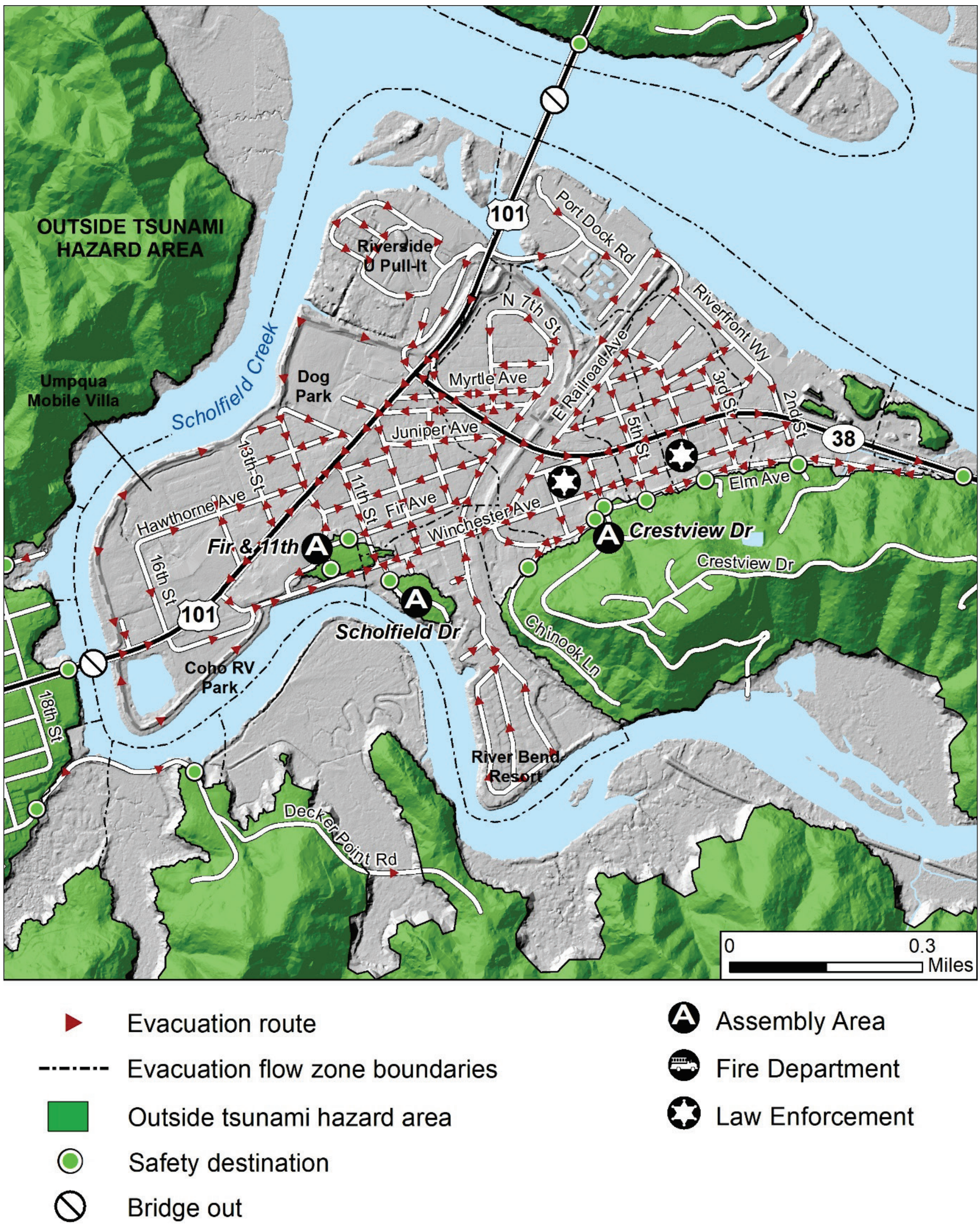
Figure A-7. Evacuation time map based on a standard 4-fps speed for the Baker Beach and Sutton Beach trail area using Scenario 1: existing road and trail network intact. These data can also be found in the Florence_Reedsport_Tsunami_Evacuation_Modeling geodatabase, BridgesOut_XXL1 feature dataset, EvacuationTime feature classes.



APPENDIX B. DETAILED EVACUATION ROUTE MAPS

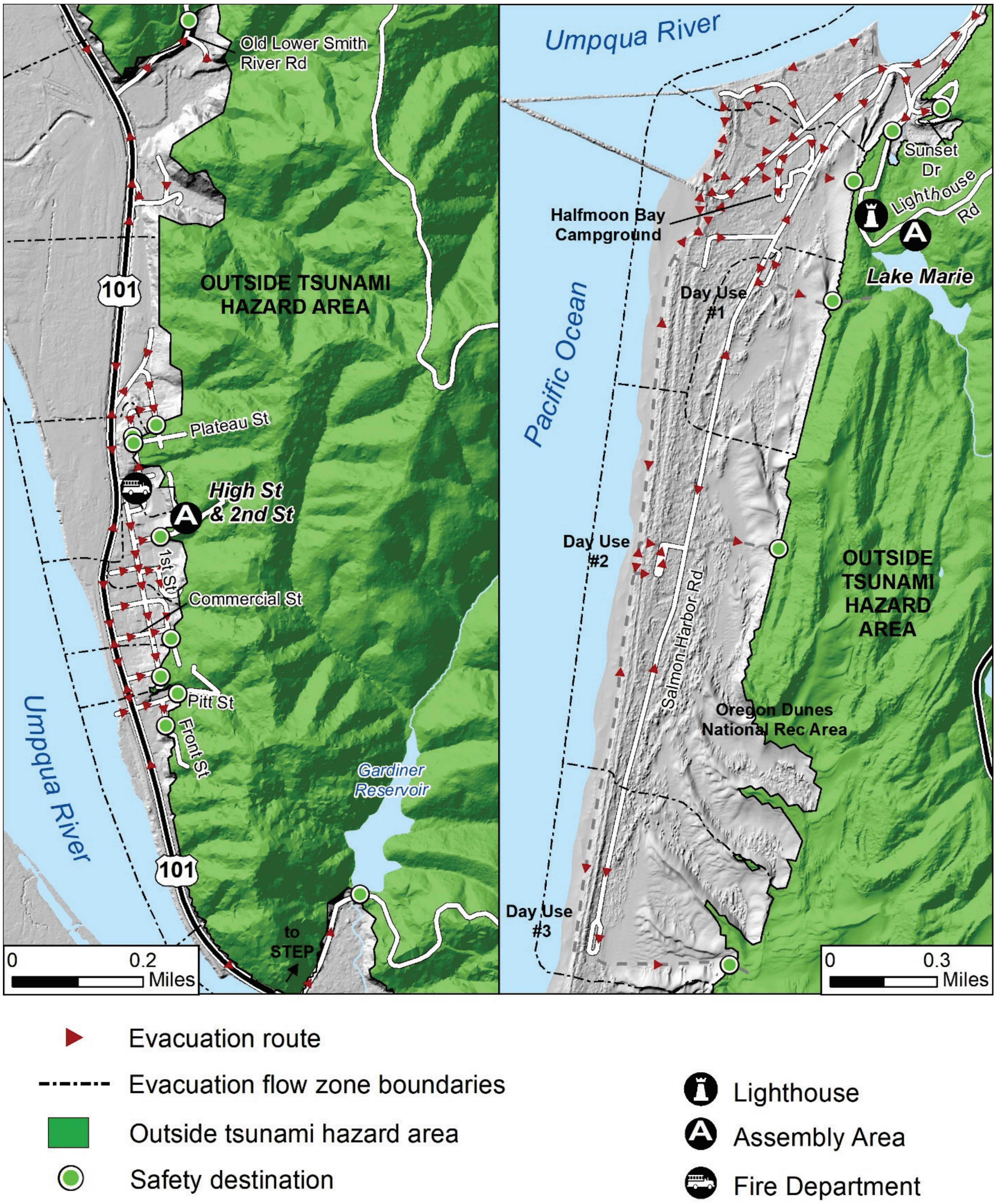
B.1 City of Reedsport

Figure B-1. Detailed evacuation routes for the City of Reedsport using Scenario 1: With and without the Umpqua River Bridge and Scholfield Creek Bridge (results unchanged). These data can also be found in the Florence_Reedsport_Tsunami_Evacuation_Modeling geodatabase, BridgesOut_XXL feature dataset, EvacuationRoutes and EvacuationFlowZones feature classes.



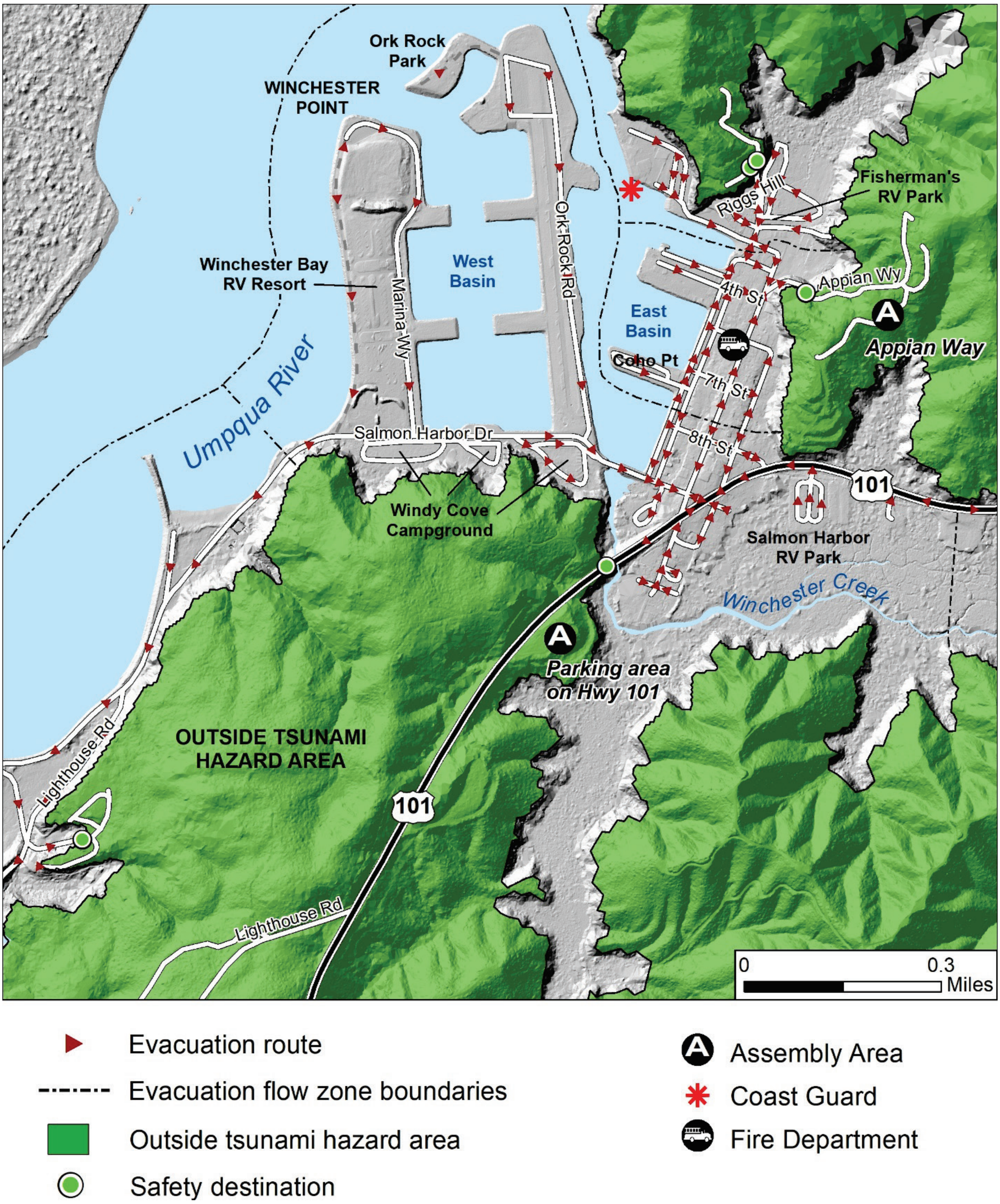
B.2 Gardiner and Umpqua Dunes Recreation Area

Figure B-2. Detailed evacuation routes for left) Gardiner (using Scenario 1) and right) the Umpqua Dunes Rec Area (using Scenario 3, with trails). These data can also be found in the Florence_Reedsport_Tsunami_Evacuation_Modeling geodatabase, BridgesOut_XXL1 feature dataset, EvacuationRoutes and EvacuationFlowZones feature classes.



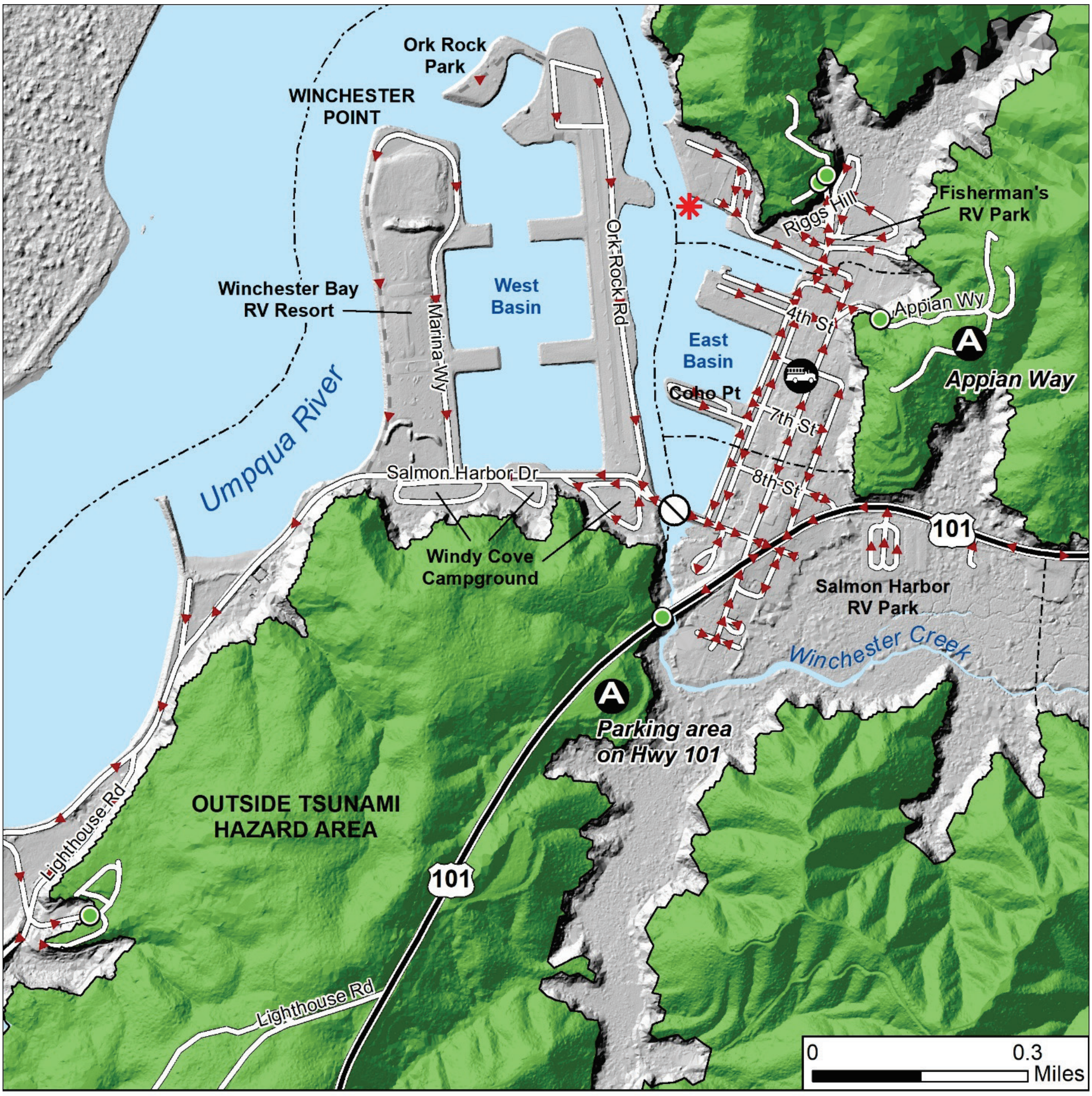
B.3 Winchester Bay – with Salmon Harbor Bridge

Figure B-3. Detailed evacuation routes for Winchester Bay using Scenario 1: existing road network, including the Salmon Harbor Bridge, intact. These data can also be found in the Florence_Reedsport_Tsunami_Evacuation_Modeling geodatabase, BridgesIn_XXL1_WinchesterBayOnly feature dataset, EvacuationRoutes and EvacuationFlowZones feature classes.



B.4 Winchester Bay – without Salmon Harbor Bridge

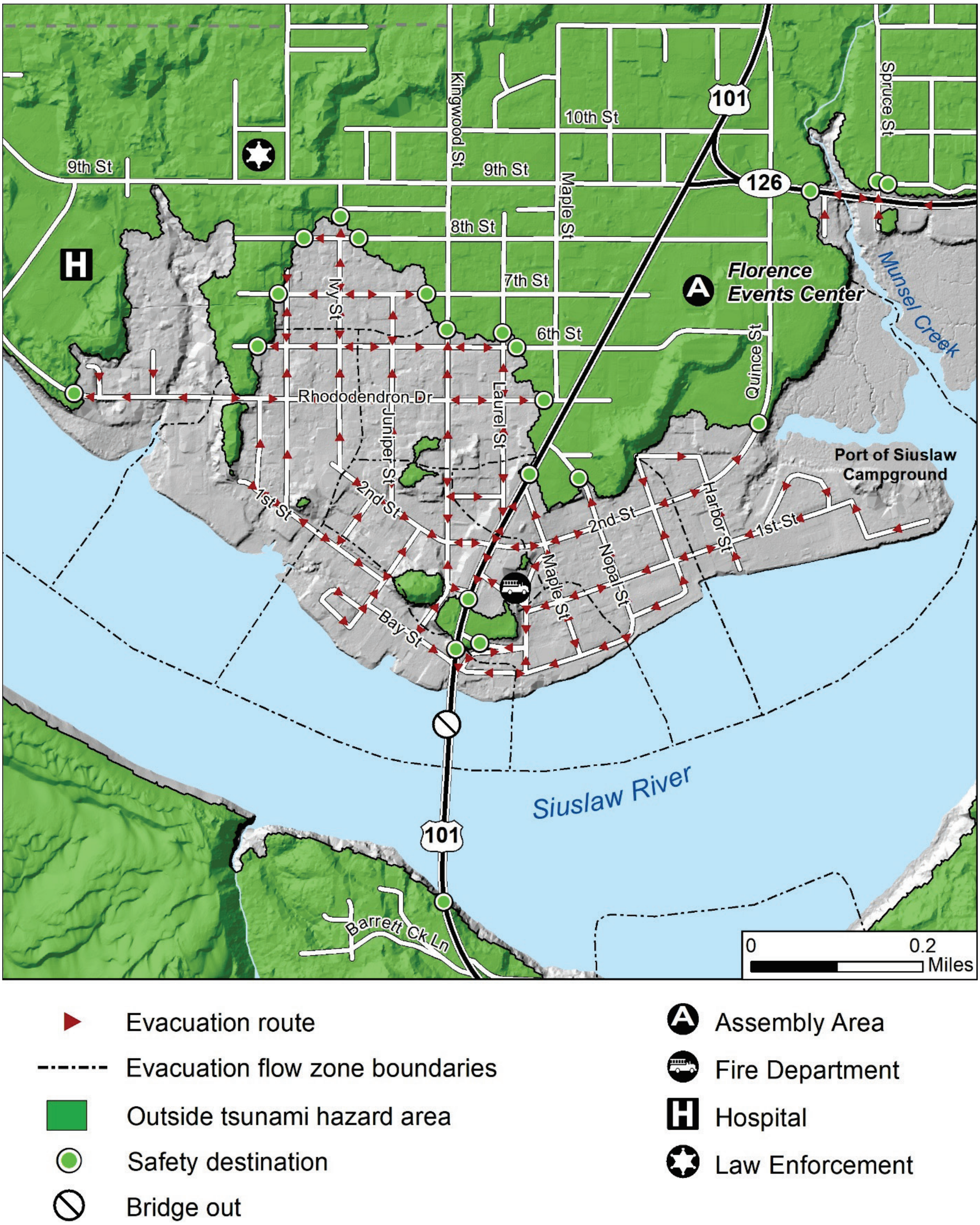
Figure B-4. Detailed evacuation routes for Winchester Bay using Scenario 2: Failure of the Salmon Harbor Bridge due to earthquake shaking. These data can also be found in the Florence_Reedsport_Tsunami_Evacuation_Modeling geodatabase, BridgesOut_XXL1 feature dataset, EvacuationRoutes and EvacuationFlowZones feature classes.



- Evacuation route
- Evacuation flow zone boundaries
- Outside tsunami hazard area
- Safety destination
- Bridge out
- Assembly Area
- Coast Guard
- Fire Department

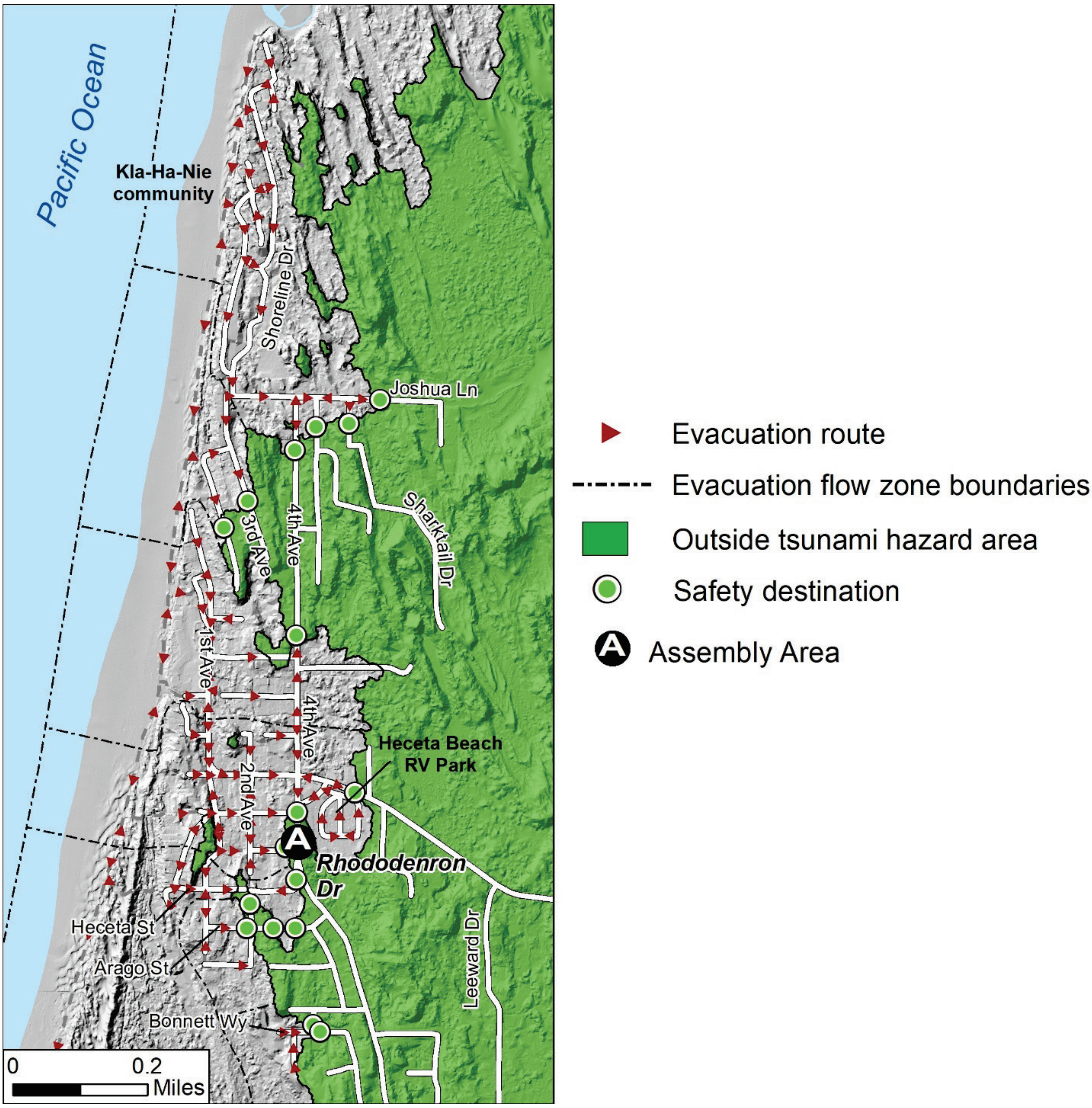
B.5 Old Town Florence

Figure B-5. Detailed evacuation routes for the City of Florence, Old Town, using Scenario 1: With and without the Siuslaw River Bridge (results unchanged). These data can also be found in the Florence_Reedsport_Tsunami_Evacuation_Modeling geodatabase, BridgesOut_XXL1 feature dataset, EvacuationRoutes and EvacuationFlowZones feature classes.



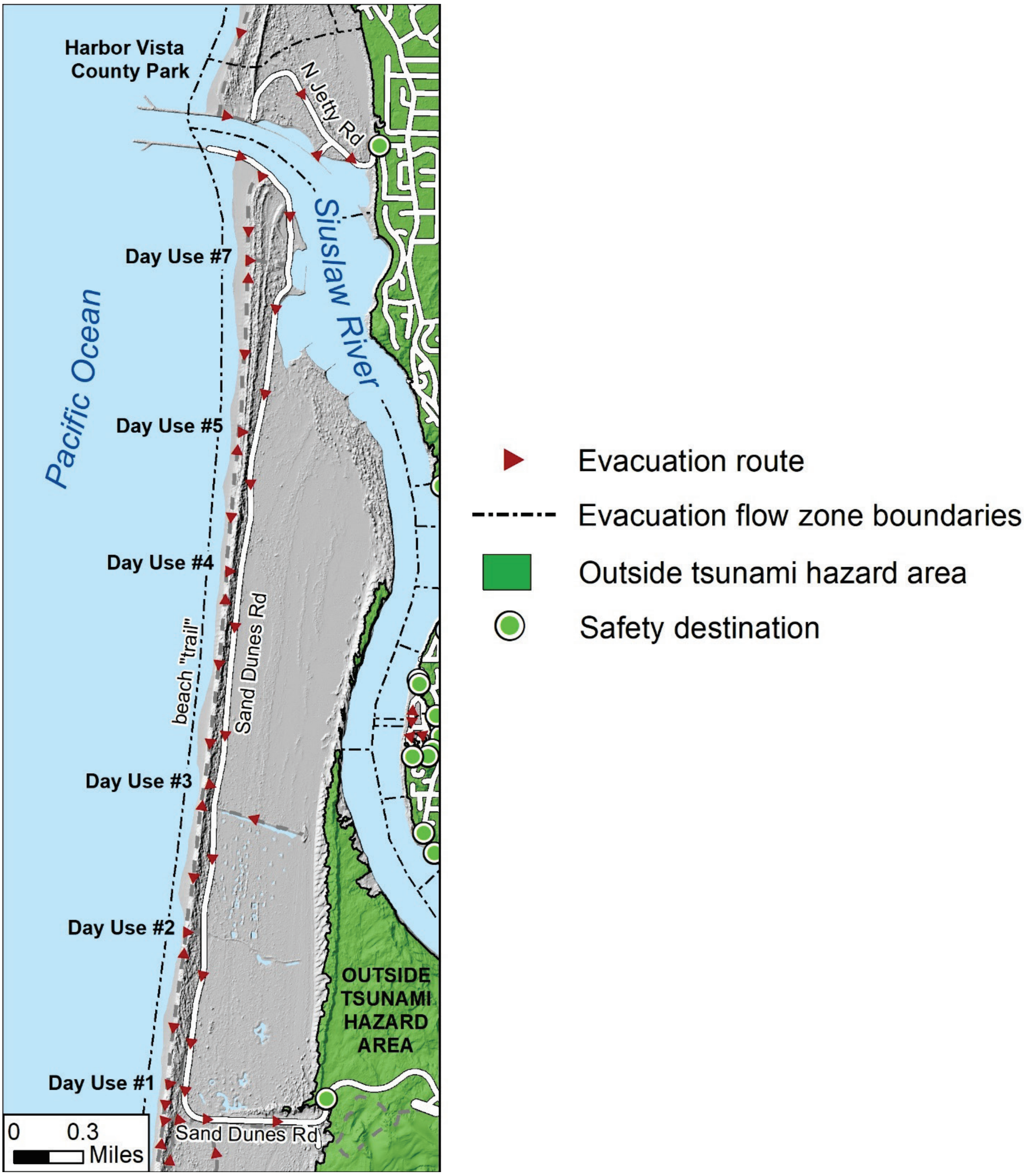
B.6 Heceta Beach

Figure B-6. Detailed evacuation routes for the Heceta Beach community using Scenario 1: existing road network intact. These data can also be found in the Florence_Reedsport_Tsunami_Evacuation_Modeling geodatabase, BridgesOut_XXL1 feature dataset, EvacuationRoutes and EvacuationFlowZones feature classes.



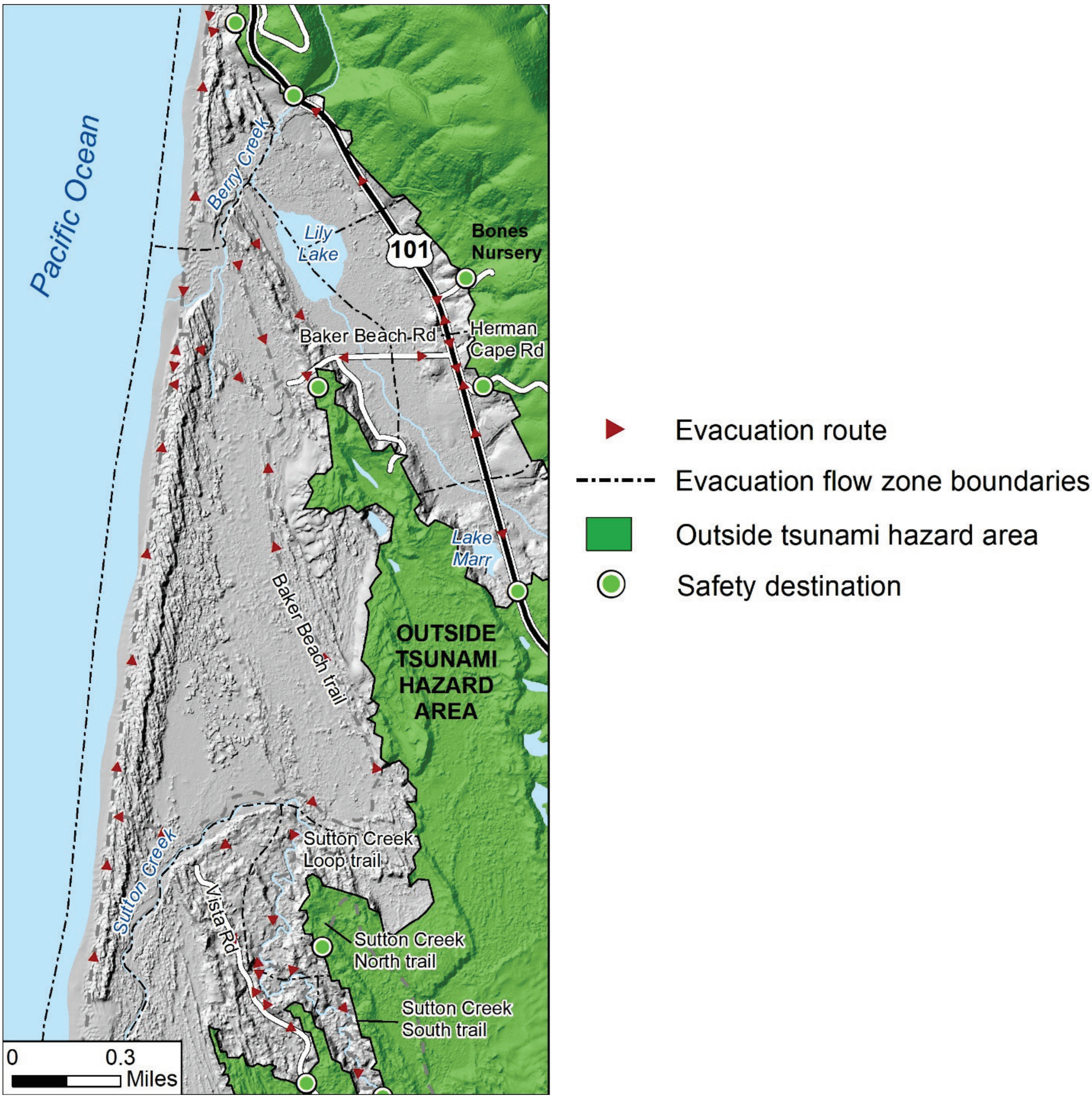
B.7 South Jetty Rec Area

Figure B-7. Detailed evacuation routes for the South Jetty Recreation Area using Scenario 1: existing road network intact. These data can also be found in the Florence_Reedsport_Tsunami_Evacuation_Modeling geodatabase, BridgesOut_XXL1 feature dataset, EvacuationRoutes and EvacuationFlowZones feature classes.



B.8 Baker Beach and Sutton Beach

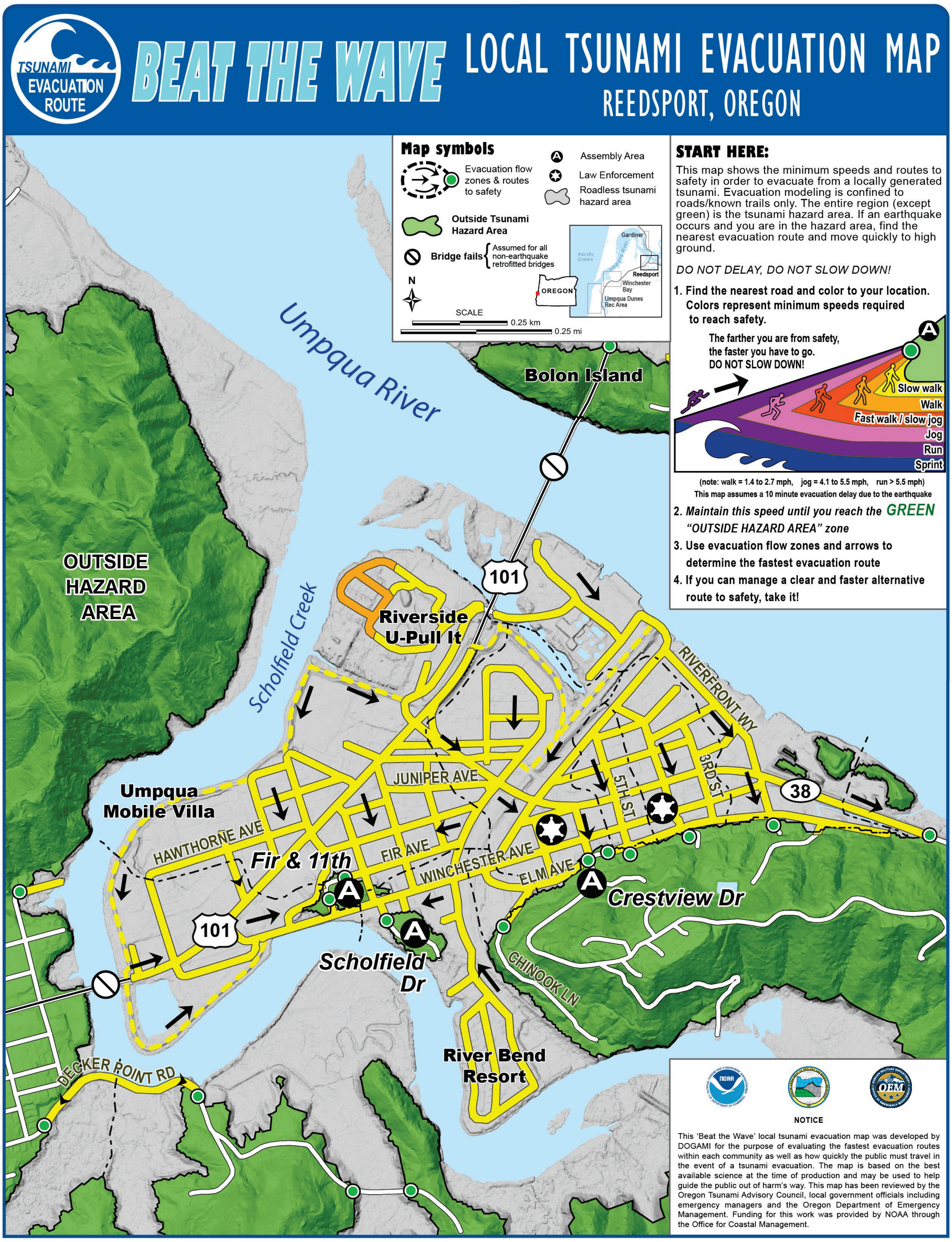
Figure B-8. Detailed evacuation routes for the Baker Beach and Sutton Beach trail area using Scenario 1: existing road and trail network intact. These data can also be found in the Florence_Reedsport_Tsunami_Evacuation_Modeling geodatabase, BridgesOut_XXL1 feature dataset, EvacuationRoutes and EvacuationFlowZones feature classes.



APPENDIX C. BEAT THE WAVE MAPS

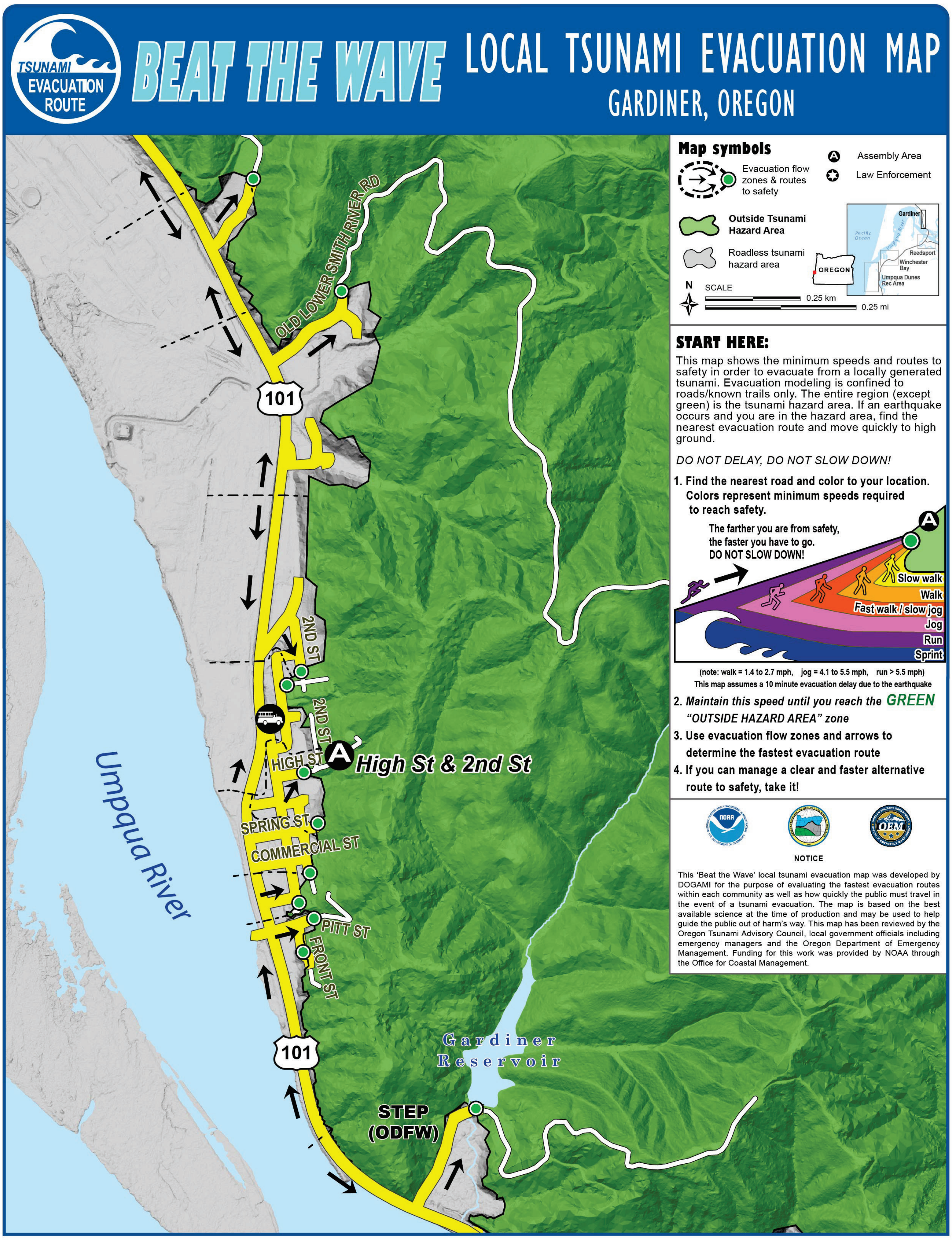
C.1 City of Reedsport

Figure C-1. Final Beat the Wave map for Reedsport.



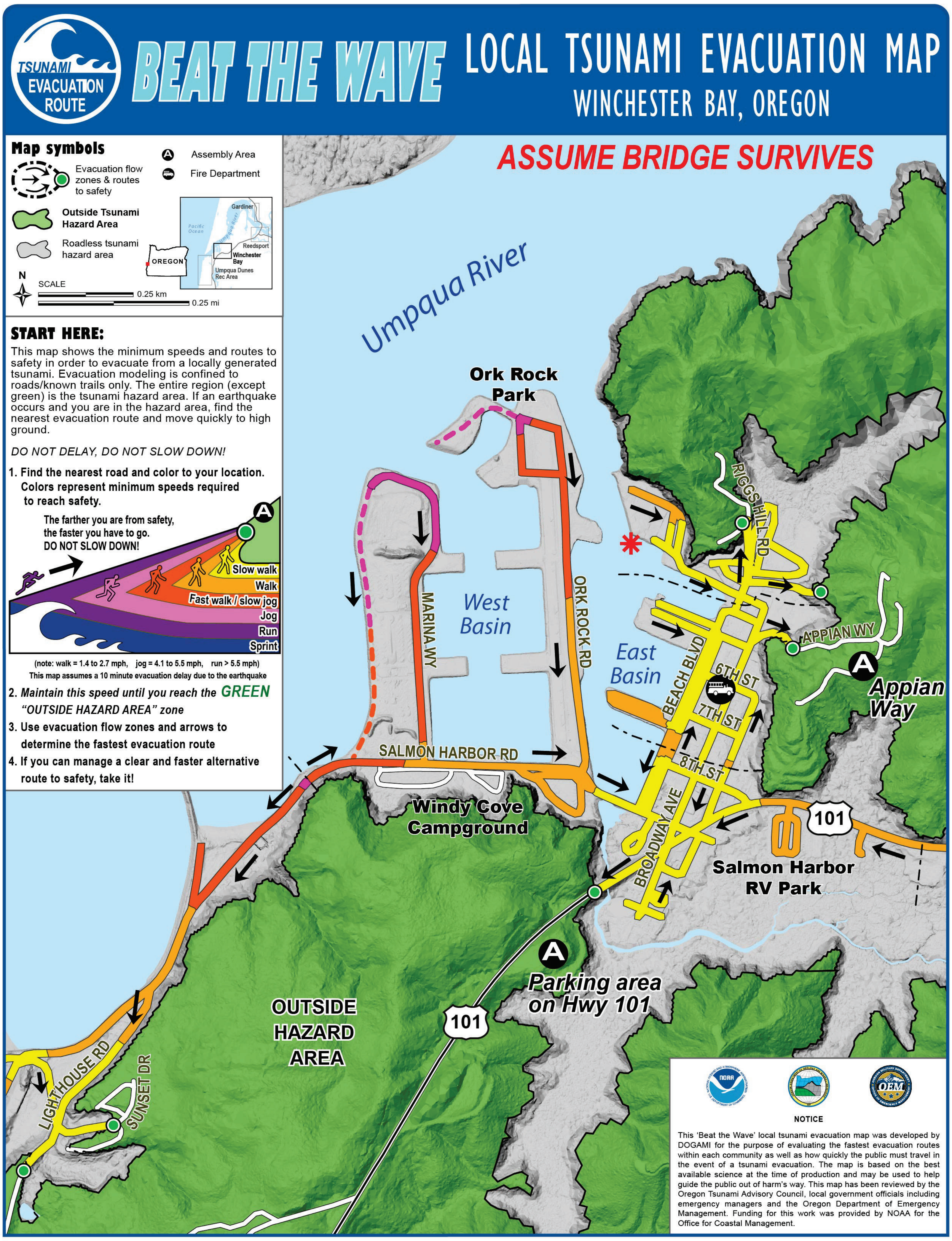
C.2 Gardiner

Figure C-2. Final Beat the Wave map for Gardiner.



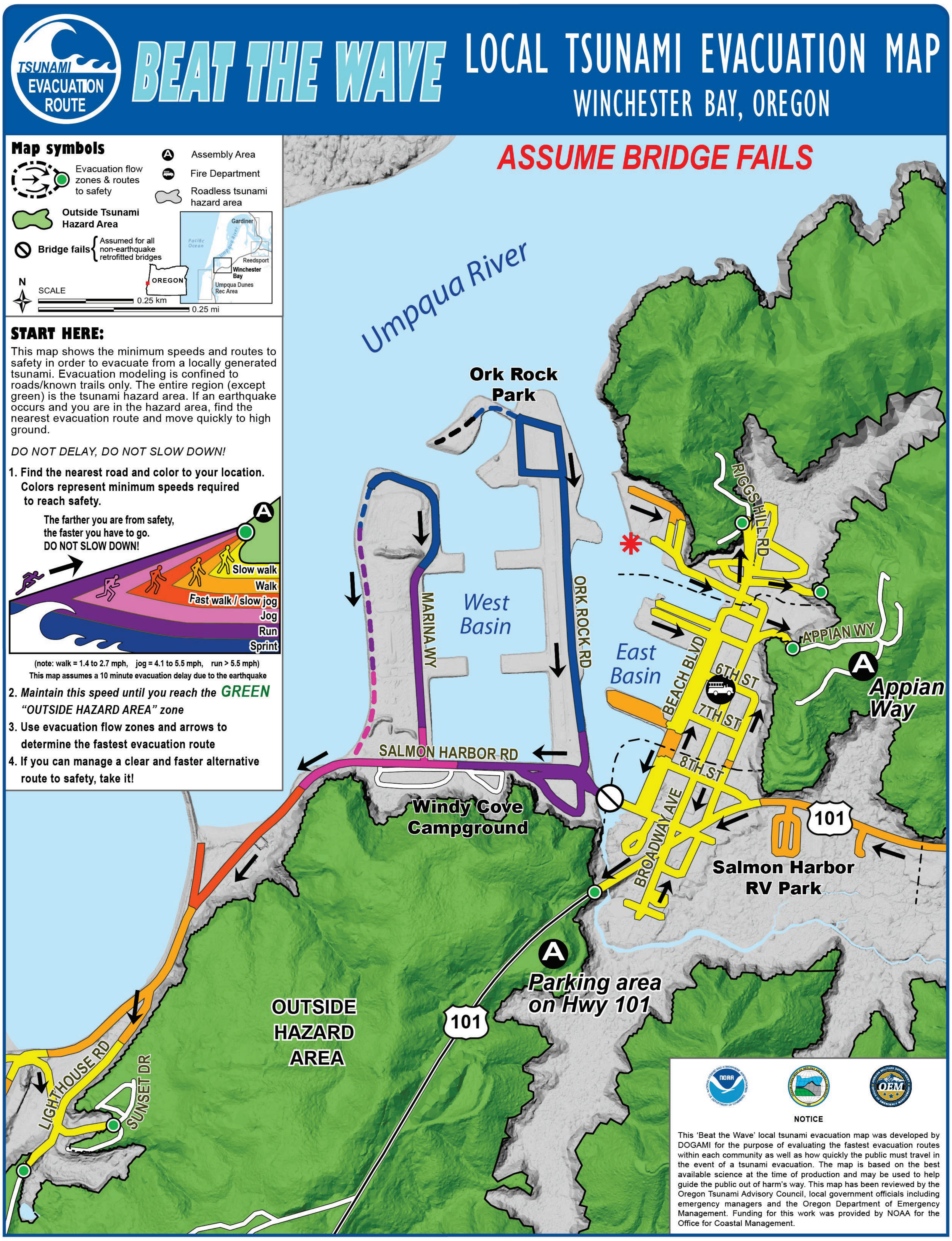
C.3 Winchester Bay – with Salmon Harbor Bridge

Figure C-3. Final Beat the Wave map for Winchester Bay using Scenario 1: Salmon Harbor Bridge remains intact and available for evacuation.



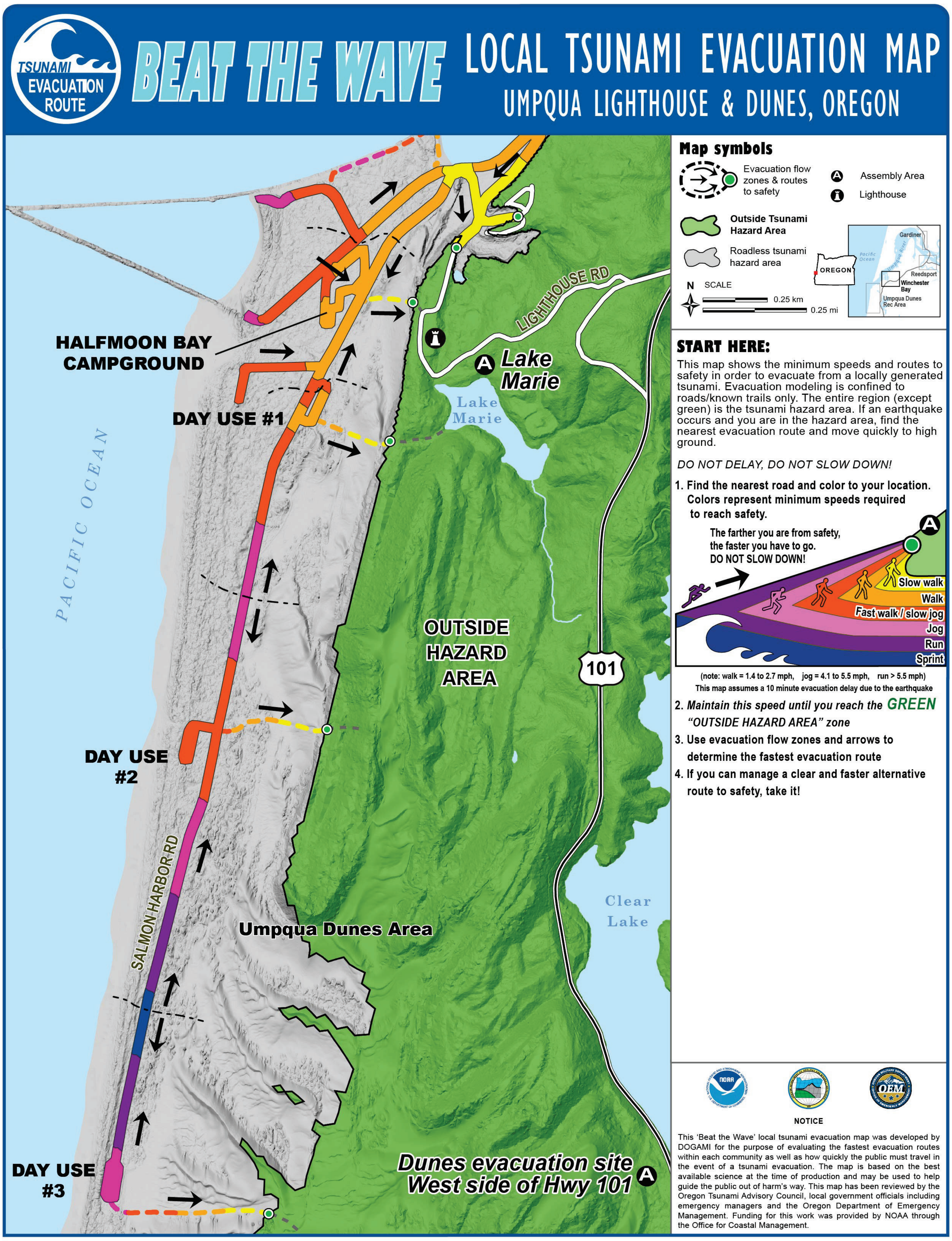
C.4 Winchester Bay – without Salmon Harbor Bridge

Figure C-4. Final Beat the Wave map for Winchester Bay using Scenario 2: Assuming Salmon Harbor Bridge fails during earthquake shaking.



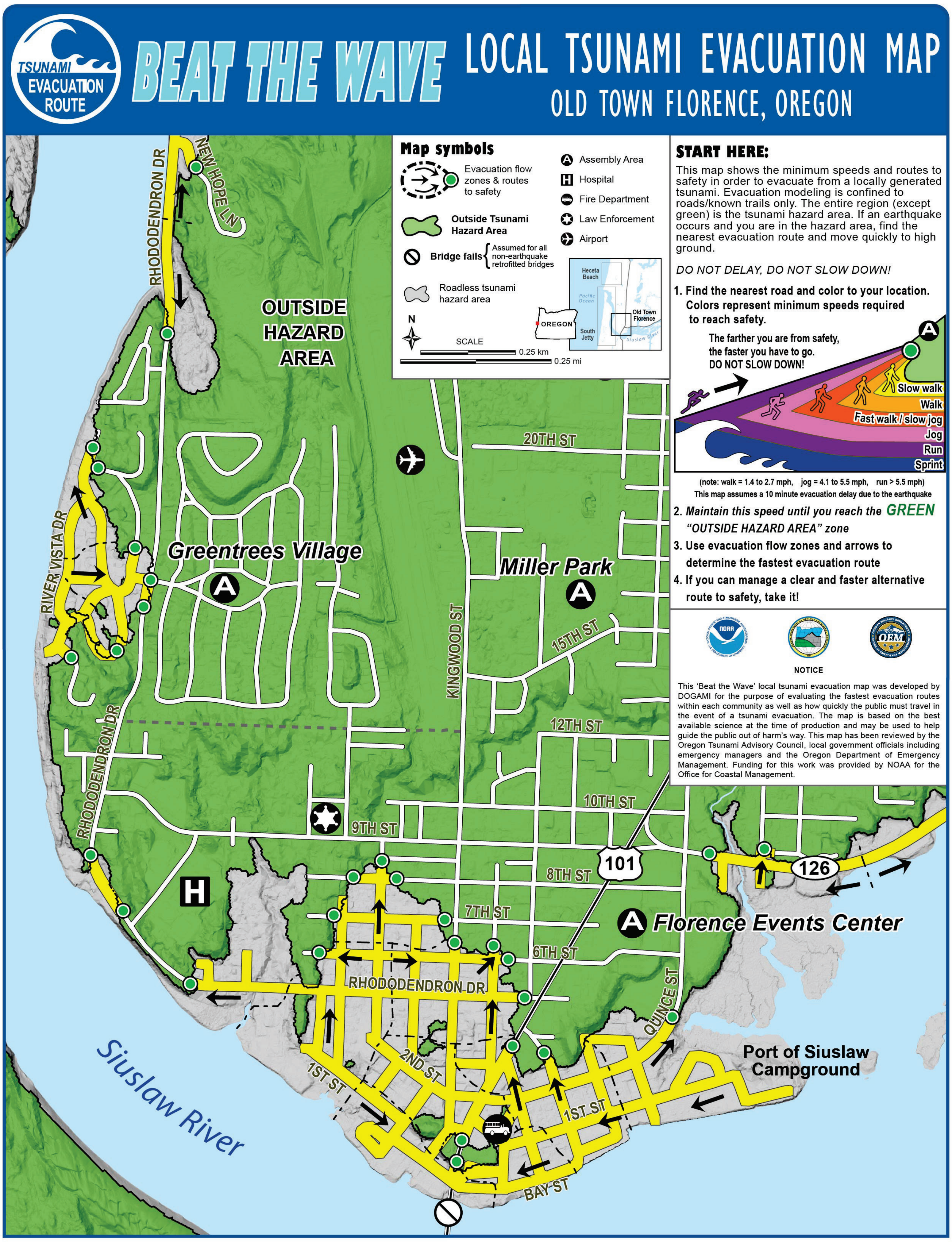
C.5 Umpqua Lighthouse and Dunes Rec Area

Figure C-5. Final Beat the Wave map for the Umpqua Dunes Recreation Area.



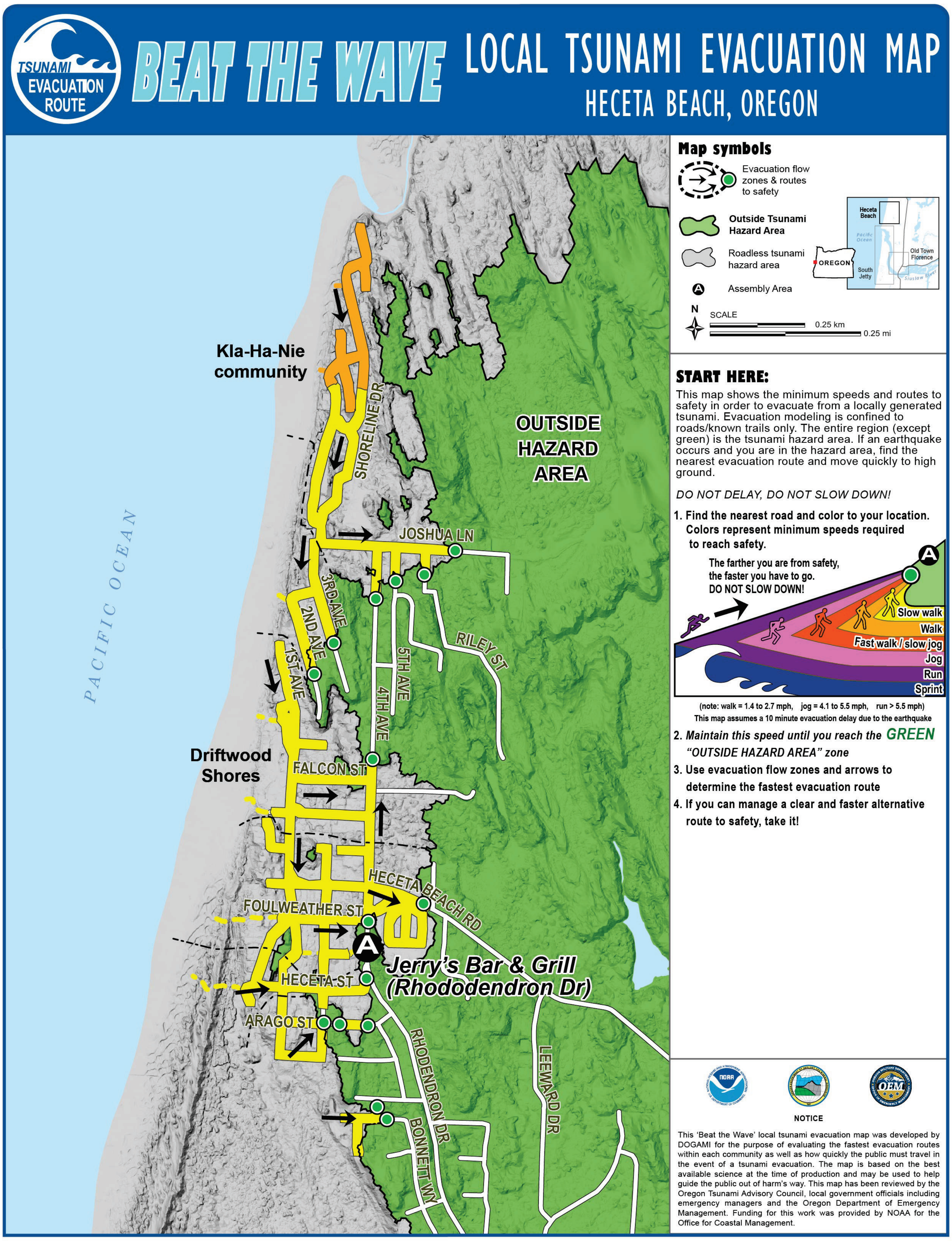
C.6 Old Town Florence

Figure C-6. Final Beat the Wave map for Florence.



C.7 Heceta Beach

Figure C-7. Final Beat the Wave map for Heceta Beach.



C.8 South Jetty Rec Area

Figure C-8. Final Beat the Wave map for the South Jetty Recreation Area.