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TSUNAMI EVACUATION ANALYSIS OF GOLD BEACH AND NEARBY UNINCORPORATED COMMUNITIES, CURRY COUNTY, OREGON

By Laura L. S. Gabel[1], Fletcher O'Brien[2], and Jonathan Allan[1]

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[1]Oregon Department of Geology and Mineral Industries, Coastal Field Office, P.O. Box 1033, Newport, OR 97365
[2]Oregon Department of Geology and Mineral Industries, 800 NE Oregon Street, Suite 965, Portland, OR 97232

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WHAT'S IN THIS REPORT?

This report shows modeled pedestrian evacuation routes to escape a local tsunami generated by an earthquake on the Cascadia Subduction Zone (CSZ) for Gold Beach and nearby unincorporated communities of Hunter Creek, Indian Creek, Rogue Shores, Wedderburn, and Nesika Beach, Curry County, Oregon.

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For additional information:
Administrative Offices
800 NE Oregon Street, Suite 965
Portland, OR 97232
Telephone (971) 673-1555
https://www.oregongeology.org/
https://www.oregon.gov/DOGAMI

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XXL1_BridgesOut feature dataset:

XXL1_BridgesOut_EvacuationFlowZones
XXL1_BridgesOut_EvacuationRoutes
XXL1_BridgesOut_WalkingSpeeds_Roads
XXL1_BridgesOut_WalkingSpeeds_Trails

L1_BridgesOut feature dataset:

L1_BridgesOut_EvacuationFlowZones
L1_BridgesOut_EvacuationRoutes
L1_BridgesOut_WalkingSpeeds_Roads
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Raster_Flow_Depth_XXL1
Raster_Wave_Arrival_XXL1

Metadata in .xml file format:

Each feature class listed above has an associated, standalone .xml file containing metadata in the Federal Geographic Data Committee Content Standard for Digital Geospatial Metadata format.

ABSTRACT

Pedestrian evacuation routes were evaluated for a local tsunami generated by an earthquake on the Cascadia Subduction Zone (CSZ) in the City of Gold Beach and nearby unincorporated communities of Curry County, Oregon. Our analyses focused on a maximum-considered CSZ tsunami event, termed XXL, that could be produced by a locally generated magnitude (Mw) 9.1 earthquake and covers 100 percent of potential variability. We also analyzed evacuation for a slightly smaller local tsunami event covering 95% of potential variability, termed Large (sometimes referred to as L1 in other DOGAMI reports), and generated by a magnitude 8.9 earthquake. Evacuation paths were limited to established roads, trails, and pedestrian pathways designated by local government reviewers as the most likely routes.

To assist in pedestrian tsunami evacuation, we produced maps and digital data that include the following:

- Tsunami wave arrival times for an XXL event,
- Detailed *Beat the Wave* (BTW) results for the XXL and Large scenarios, including evacuation routes and minimum walking speeds, and
- BTW results for multiple hypothetical scenarios.

The BTW maps depict the ***minimum evacuation speed*** required to stay ahead of the tsunami wave for each scenario. For planning purposes, we present a variety of scenarios that increase and decrease evacuation difficulty (due to additional complications and mitigation options, respectively). Model assumptions include:

- Restricting evacuation to pathways rather than permitting cross county travel (i.e., backyard or golf course)
- Applying a 10-minute delay from the start of an earthquake before beginning evacuation to account for:
    - the time in which earthquake shaking takes place (3–5 minutes)
    - disorientation, shock and collecting family members, go-bags, etc.
    - the time required to evacuate a building and reach the nearest road (navigating fallen debris inside building, exiting building, crossing fenced yard, etc.)

In addition to the assumptions listed above, the current conditions scenario also assumes the failure of non-retrofitted bridges. 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 assumptions defined in the Methods section and summarized above, results show that evacuation for most of the region examined is only achievable at relatively fast walking speeds (6 fps, or 4.1 mph) or greater. Those people who find themselves especially far from high ground, such as the beach and the Rogue Shores neighborhood, have the greatest challenge. It will be difficult for evacuees from these locations to reach safety prior to the arrival of the tsunami. Liquefaction and landslides could present additional challenges to evacuation across the region.

In this report, tsunami mitigation refers to actions used to improve the survivability of a local community population. This project is about evaluating ways to help move people out of the tsunami zone in the shortest amount of time possible between the start of earthquake shaking and the arrival of the tsunami. Mitigation options may include adding new evacuation routes, constructing earthquake-hardened roads and trails (that is, built or remodeled to withstand shaking from a major earthquake and liquefaction), enhancing tsunami wayfinding signage along core routes, and/or installing a tsunami refuge, otherwise known as a vertical evacuation structure.

1.0 INTRODUCTION

The objective of this study is to provide local government with a quantitative assessment of challenges affecting tsunami evacuation in the coastal city of Gold Beach and nearby communities (**Figure 1-1**) for the XXL and L scenarios. These results are important for evaluating mitigation options such as evacuation route improvements, better wayfinding, land use planning, and vertical evacuation options.

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 magnitude (Mw) ~9.0 (Priest and others, 2009; Witter and others, 2011), severely damaging bridges and other infrastructure that may be critical to evacuation. The most recent tsunami generated by a large subduction zone earthquake on the Oregon coast occurred on January 26, 1700 (Atwater and others, 2005). Goldfinger and others (2017) estimated the conditional probability of a full margin (coastwide) earthquake on the Cascadia subduction zone (CSZ) at ~16–22% in the next 50 years; a partial rupture of the CSZ impacting the southern Oregon coast including Gold Beach has a conditional probability of ~37–43% (Goldfinger and others, 2017).

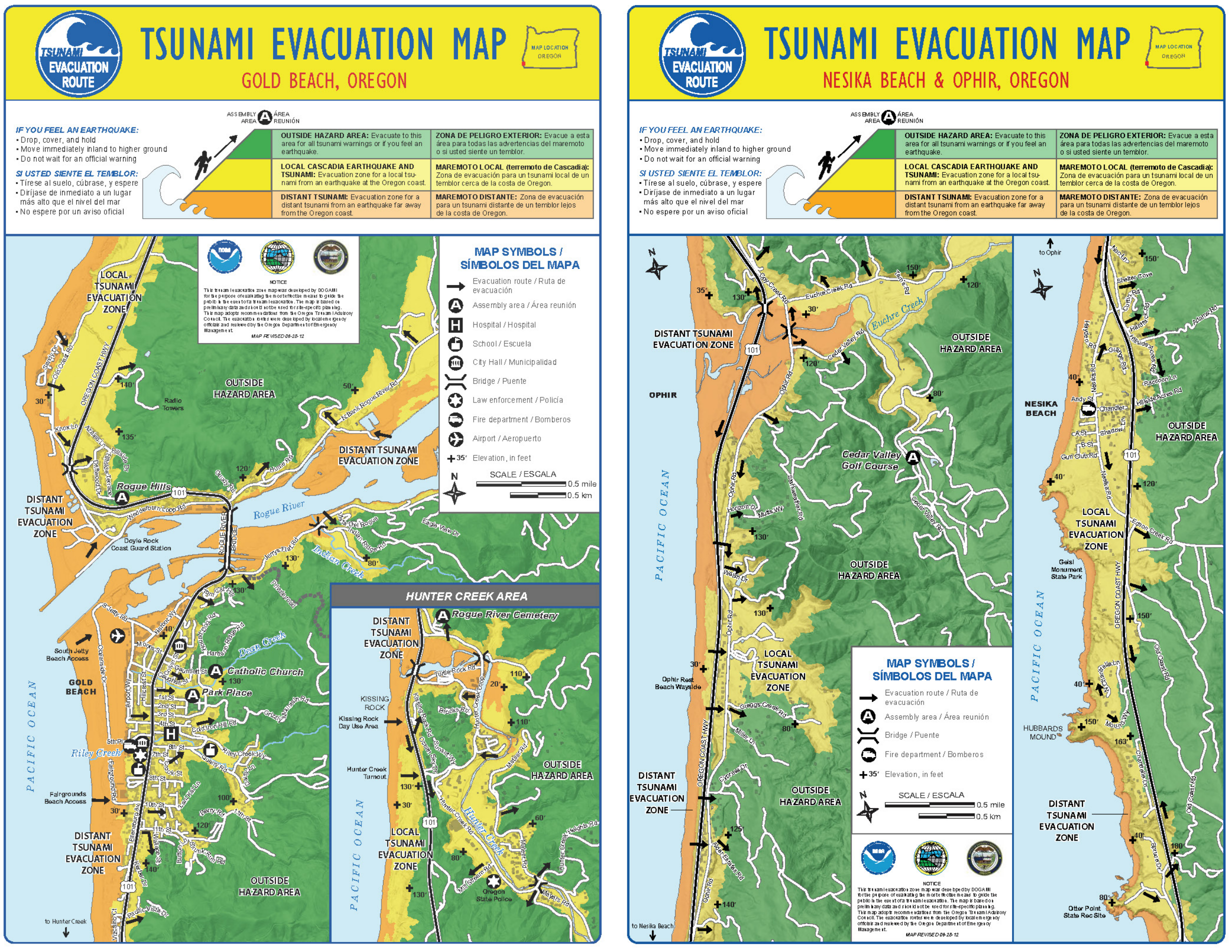
To evaluate CSZ tsunami impact, Witter and others (2011) used a logic tree approach to produce a suite of deterministic scenarios, five of which are mapped statewide. The five scenarios are named with relative sizes of extra-extra-large, extra-large, large, medium, and small. Each scenario has a potential likelihood of being the size of the next Cascadia event. For example, 26% of past tsunamis were no larger than the Small scenario. This suggests that there is a 26% chance that the next CSZ event will also be size Small or smaller. Conversely, 74% of tsunami events in the geologic record have been larger than Small. XXL describes a scenario slightly larger than the largest tsunami in the 10,000-year historical record and therefore 100 percent of past tsunamis were smaller than this scenario. This implies that the XXL scenario encompasses the maximum possible tsunami that will occur next (Priest and others, 2013b):

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

The maximum-considered CSZ tsunami (XXL1, referred to as “XXL” for the remainder of this report) will reach the coast within ~12 minutes and will fully inundate the open coast, including much of Gold Beach, Wedderburn, Rogue Shores, and Nesika Beach, within 20 minutes of the start of earthquake shaking (**Figure 1-1**). The region will continue to experience large tsunami waves for up to 12 hours after the start of earthquake shaking.

A Note about Bridges and Tsunami Evacuation in Gold Beach and Nearby Communities
Bridges can further complicate tsunami evacuation if they prove to be essential to a route and are not built to withstand the shaking from the earthquake. Because of this, DOGAMI tsunami evacuation analyses include both “Bridges In” and “Bridges Out” *Beat the Wave* scenario modeling. For the Gold Beach area, “Bridges In” and “Bridges Out” *Beat the Wave* results are similar so only “Bridges Out” results are included in this report.

Figure 1-1. DOGAMI (2013) tsunami evacuation maps for Gold Beach (left) and Nesika Beach (right). Inundation for a maximum-considered Cascadia subduction zone (CSZ) tsunami scenario (XXL) is shown in yellow, while the maximum-considered distant tsunami scenario 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 versions of these maps are available at https://www.oregongeology.org/tsuclearinghouse/.



We evaluate tsunami evacuation difficulty using an approach termed *Beat the Wave* (BTW), developed by Priest and others (2015, 2016). It uses the least-cost distance (LCD) approach of Wood and Schmidtlein (2012), which provides estimates of evacuation travel times to safety assuming a constant travel speed. We can now account for variable speeds along a route due to differences in route characteristics including terrain (e.g., flat vs. steep; loose sand vs. pavement) and precise wave arrival times. Evacuation routes are restricted to roads and trails to enable more informative maps as well as to remove the complication of crossing private property. 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.

This report provides the following maps and GIS data:

1. XXL wave arrivals: How quickly the wave front of an XXL tsunami advances across the area after the earthquake.
2. BTW results for existing road conditions: Determining whether an evacuee can stay ahead of the tsunami all the way to safety on the routes defined by the LCD analysis. Results include minimum travel speeds, the nearest safety destination, and detailed evacuation routes for every road in the community.
3. Hypothetical BTW scenarios to investigate potential vulnerabilities and mitigation options.

2.0 METHODS

Agent-based and least-cost distance (LCD) modeling are the two most common approaches for simulating pedestrian evacuation. Agent-based modeling focuses on the individual and how travel would most likely be impacted by localized effects in the landscape such as congestion points at bridges (Yeh and others, 2009). LCD modeling is similar but focuses more on evacuation difficulty across the landscape, which may be caused by both slope and land cover type (e.g., navigating a road versus traveling over a wetland or dune). LCD modeling essentially defines the most efficient path to the tsunami inundation limit for every point in the inundation zone, artificially increasing distances as terrain conditions change (e.g., slope increases, a person travels across a wetland versus on pavement) and ultimately defining the best evacuation routes. Time to traverse a route can then be estimated by dividing the least-cost path by a particular pedestrian travel speed (e.g., walk, jog, or run). We used the LCD model of Wood and Schmidtlein (2012) because we wanted to understand the spatial distributions of evacuation times throughout the region 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 maps of ***minimum*** speeds that must be maintained along the entire route in order to reach safety in time. Additional information on the methodology is provided by Priest and others (2015, 2016) and Gabel and Allan (2017).

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 excluded). This removes the complication of crossing private property and reflects the reality that most people will follow established roads to high ground rather than strike out cross county. Restricting evacuation to pathways also enables us to make more informative maps. Geospatial data representing roads, pedestrian paths, and beaches were generated through manual classification of imagery (lidar and aerial photographs), field verified, and then reviewed by local officials. The backshore is defined as areas landward of the beach-dune junction approximated by the 18-foot NAVD88 (North American Vertical Datum of 1988) contour. The beach (below 18 feet) 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 of beach surfaces, modeled BTW speeds on beach “trails” are intended to provide an approximation of the time and speeds required to evacuate those areas. We chose to ignore travel time from buildings or other parts of urban areas to the roads, because there is large uncertainty in conditions contributing to the time it will take an evacuee to reach the nearest road. For example, reaching the nearest road may require crossing a fenced yard. In addition, after the earthquake there will undoubtedly be fallen debris and other impediments. Because of these assumptions and factors, the modeling approach represents ***minimum*** evacuation speeds needed to safely evacuate from the inundation zone.

2.2 Hypothetical scenarios

The evacuation landscape was first evaluated by 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 reflecting hypothetical mitigation options were then considered to address these challenges, including constructing new trails, hardening existing roads or trails, seismically retrofitting bridges, constructing new pedestrian and/or car bridges, and building vertical evacuation structures. In some cases, no options were considered feasible, and no hypothetical scenarios were modeled. Multiple review sessions with community officials ensured local needs and concerns were addressed by the hypothetical scenarios.

Bridge failure was simulated by removing that section of the road network, thus forcing the model to recalculate routes that originally relied on bridge connectivity. Which bridges to remove for the simulations was based on discussion at a public town hall meeting and on information about which bridges had been designed to withstand significant seismic forces. 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 different safety destination. Our standard modeling process begins with a “base” scenario that includes all bridges, for comparison to scenarios without them. This highlights which bridges are important for evacuation and can be important when prioritizing which bridges to retrofit or to construct as part of a long-term resilience plan. For this area, modeling indicates local bridges are not essential for tsunami evacuation.

In coastal towns, landslide-prone slopes and saturated sandy soils are common; therefore slides, liquefaction (**Figure 2-1**, **left**), and lateral spreading (**Figure 2-1**, **right**) are likely to occur during an earthquake (Madin and Wang, 1999; Madin and Burns, 2013). These hazards can damage roads and will 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. In areas with high liquefaction susceptibility, we evaluate evacuation difficulty using data from 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 provided 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, vibrocompaction, and construction of liquefaction-proof paths.

Figure 2-1. Water-saturated sand can turn to quicksand during strong shaking, causing sand boils, ponding, and sunken roads. In these examples, (left) extensive liquefaction occurred along River Road in Christchurch, New Zealand following the February 2011 earthquake, while (right) 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 (SLIDO, version 3.4, https://www.oregongeology.org/slido/index.htm) to evaluate previously identified landslides in the area. We also considered possible landslide activity based on susceptibility mapping by Burns and others (2016). For areas of the coast where landslides have the potential to completely remove an evacuation route, we create hypothetical scenarios to account for that. There are many landslides in the Gold Beach area; however, none have the potential to significantly alter evacuation options. Therefore, we did not model any landslide scenarios for this area. It is also likely that the area will be littered with smaller shallow 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 or structures that can serve dual purposes as parking garages, community facilities, commercial facilities (e.g., hotels), and schools (Applied Technology Council, 2012). In the United States, the first vertical evacuation 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 can congregate during a tsunami evacuation. A second vertical evacuation structure was recently completed at the Hatfield Marine Science Center (HMSC) in south Newport, Oregon. We incorporate vertical evacuation structures into BTW modeling by editing the tsunami hazard zone to include a small polygon of safety at the location of a hypothetical structure.

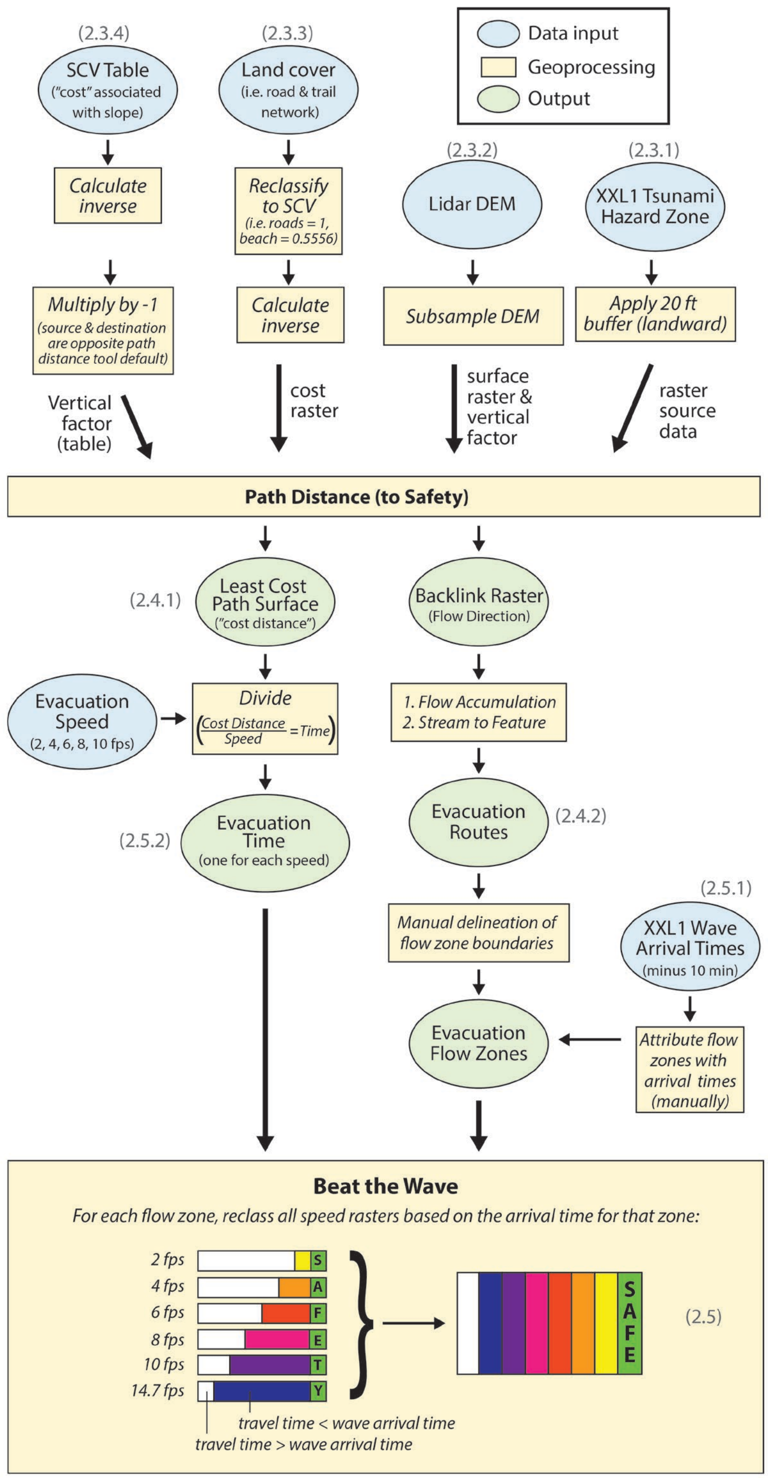
Regardless of infrastructure improvements considered for an area, wayfinding and outreach will always be an essential part of local tsunami evacuation planning.

2.3 LCD model inputs

Least-cost distance (LCD) modeling is based on four inputs: the tsunami inundation limit (XXL or L), 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 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, is 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 lateral feet (6 meters) outside 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 *Beat the Wave* tsunami evacuation methodology using the 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 (2015, 2016). 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

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 DOGAMI evacuation brochures (https://www.oregongeology.org/tsuclearinghouse/pubs-evacbro.htm) and online (http://nvs.nanoos.org/TsunamiEvac) for the entire Oregon coast. Evacuation modeling also examines the effects of the Large (L) scenario, which covers 95% of the potential CSZ inundation. Another way to consider this is that there is a ~5% chance that the next CSZ tsunami could exceed the Large tsunami zone.

For the purposes of this study, safety is reached when an evacuee has walked ~20 feet beyond the limit of tsunami inundation. Safety is also referred to as "high ground" throughout the remainder of this report. Safety *destinations* represent locations on the road and trail network that are ~20 feet beyond the limit of inundation (primarily XXL). These locations were created by applying a buffer of 20 feet (6 meters) 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-foot-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, 2015, 2016). 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 3-foot-cell lidar DEM. Priest and others (2015, 2016) performed trials at 25, 50, and 100 feet and found that the 50-foot interval achieved the best compromise between accuracy and smoothness. The final sampling interval was ~50 feet on straight paths and somewhat less for curved paths in order to accurately depict the curvatures. We then interpolated those points using an Esri ArcGIS Natural Neighbor function to produce a smoothed DEM (6-foot cell size) 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 by using terrain-energy coefficients as 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 to reflect the difficulty in walking that section of road or trail. The SCV values used are shown in **Table 2-1**, and an example land cover raster is shown in **Figure 2-3**.

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

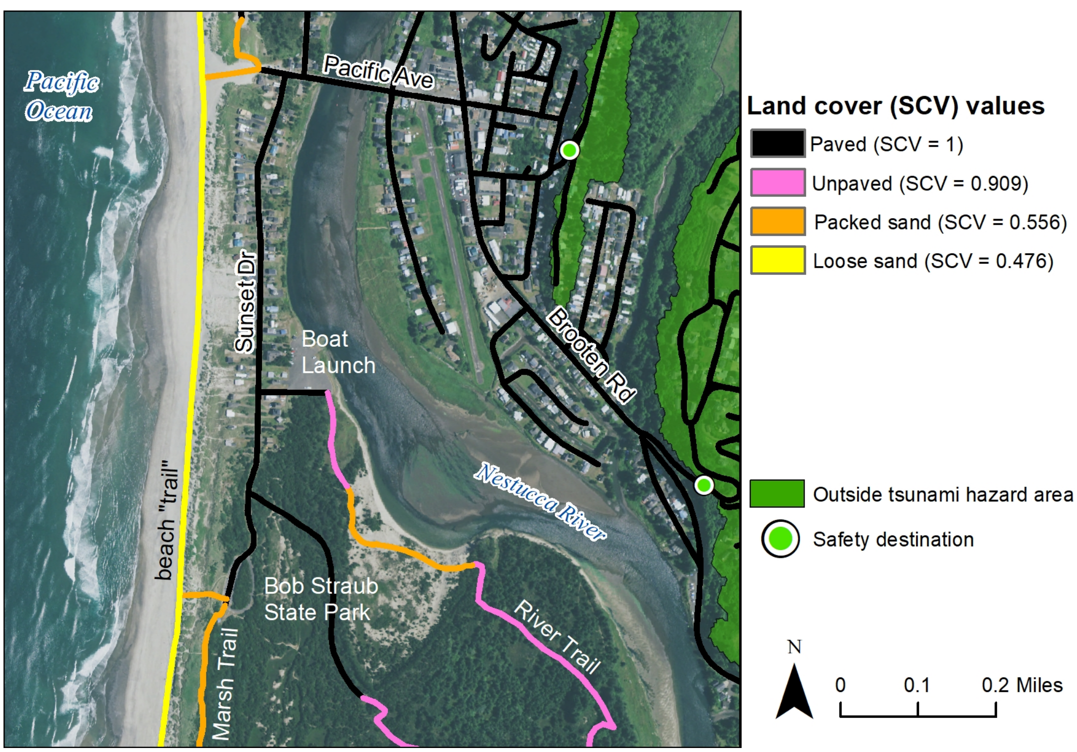
Feature Type	Speed Conservation Value*
Roads (paved surface)	1
Unpaved trails	0.9091
Dune trails (packed sand)	0.5556**
Muddy bog	0.5556
Beaches (loose sand)	0.476
Everywhere else	0

*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 (40 feet wide) 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-foot cell size) for input into the LCD model.

Figure 2-3. Example of a land cover raster in Pacific City, Tillamook County, Oregon. The land cover raster serves the dual purpose of defining the road and trail network and classifying it with land cover values. Base map is 2016 National Agriculture Imagery Program (NAIP) imagery; the XXL inundation zone (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 (1993) 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.

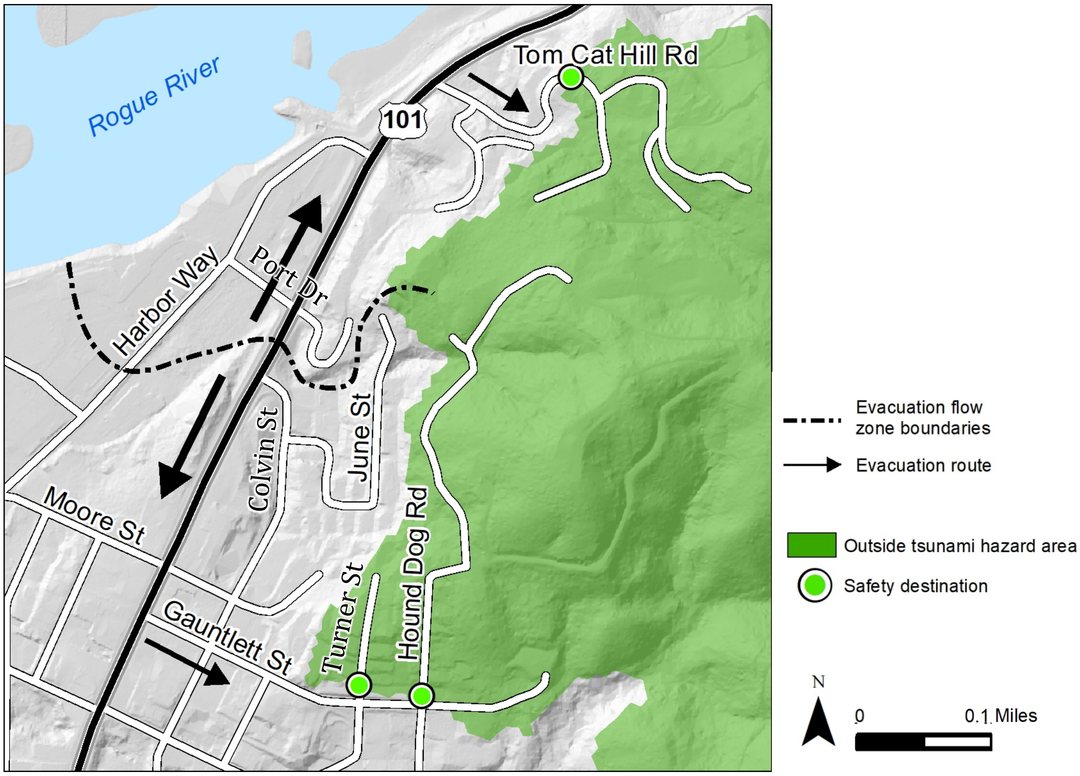
2.4 LCD model outputs

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 evacuation route, flow zone, 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 intersection of Harbor Way and Port Dr (**Figure 2-4**), the actual distance to safety up Tom Cat Hill Rd is 1,800 feet, while the least-cost path distance is 2,900 feet (path distances not shown on map). This difference is due to the model accounting for variations in slope and landcover along the entire route (although in this case the entire route is paved, meaning the cost is entirely due to the significant slope on Tom Cat Hill Rd).

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 in Gold Beach, Curry County, Oregon. Base map on this and subsequent figures is shaded relief from 2009 lidar data (Oregon Lidar Consortium North Coast Project, https://www.oregongeology.org/lidar/index.htm).



2.4.2 Evacuation routes and flow zones

The LCD backlink raster shows, for each cell, the direction to 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 on trails and roads. 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. **Figure 2-4** shows what we call "generalized evacuation routes," meaning the arrows illustrate the overall direction of travel toward a safety destination and are not turn-by-turn directions. Detailed evacuation routes are found in the digital data.

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 Port Dr is Tom Cat Hill Rd, while the nearest safety destination for people on Colvin St is Turner St (off Gauntlett St). The black dot-dashed line delineates the evacuation flow zone boundary.

We manually drew the flow zone polygons using the evacuation routes as a guide. Flow zone rasters can also be generated by using the Esri Watershed tool in the Hydrology toolset; however, we found this method useful as a guide only, not as a source of functional data.

The importance of flow zone boundaries varies depending on the specific locale. In some areas, so many roads head toward high ground that the decision to take one road versus another is minor. In other locations, flow zone boundaries inform the decision to travel in potentially opposite directions (for example, see **Figure 2-4**).

2.5 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 more evacuation difficulty in order to direct future mitigation efforts and educate the public on where to go and how fast to travel.

2.5.1 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 arrived using flow depth as a proxy. We determined the time at which water levels rose to more than half a foot at each computational grid point and interpolated those arrival data to create a continuous map showing wave arrival time. When tsunami waters rise above 6 inches, the rushing water will sweep people off their feet and can entrain debris.

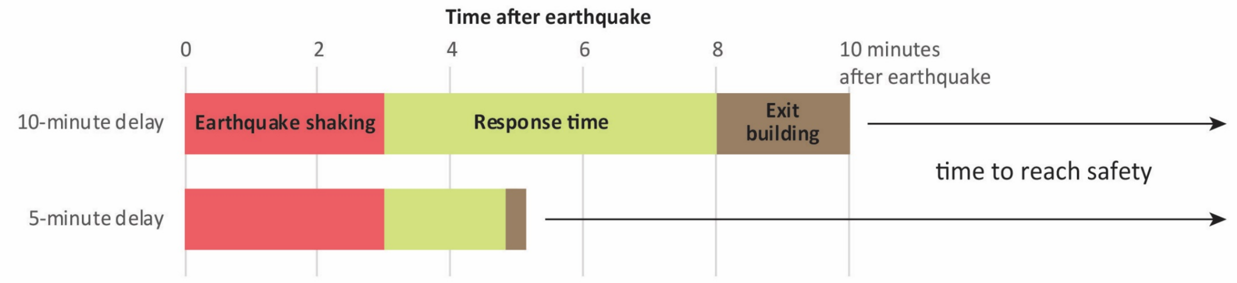
Wave arrival times were then assigned to each evacuation flow zone based on the time when the first wave reaches the *point of safety* for each zone. Depending on the safety destination, this time can be less than 15 minutes to more than 30 minutes after the tsunami first reaches land. We then subtracted 10 minutes from the simulated tsunami arrival times to account for:

- the time in which earthquake shaking takes place,
- disorientation, shock and collecting family members, go-bags, et cetera, and
- the time required to evacuate buildings.

Using the March 11, 2011, Tohoku earthquake (U.S. Geological Survey, 2012) as an analogue to an XXL or L scenario, the minimum delay is probably ~3–5 minutes due to strong shaking for an ~Mw 9.0 event. There are few 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 has experienced several local earthquakes and tsunamis over the last ~400 years, the last being in 1974. **Figure 2-5** graphically describes how the three components of evacuation delay are related in this study. It is important to appreciate that the values adopted are not explicitly known because there are uncertainties associated with the length of the earthquake shaking, the human response dimension (i.e., how quickly people respond and how organized they are [e.g., packing a bag, time spent searching for family members and pets]) and, lastly, how difficult it may be to leave a building (e.g., digging out of rubble) and get underway.

For areas with large campgrounds and few to no permanent residents, we reduced the delay from 10 minutes to 5 minutes to reflect the likelihood of people being outdoors (or inside an RV or tent) when the earthquake begins. We anticipate a shorter delay between earthquake shaking and evacuating for someone in a tent or RV compared with someone in a building. Results from the 5-minute evacuation delay also emphasize that the sooner one can begin evacuating, the more time one has to reach safety ahead of the tsunami.

Figure 2-5. Evacuation delays incorporated into BTW analyses undertaken in Oregon account for the earthquake shaking, human response, and building egress. The schematic shows that the less time spent in the response and exit phases, the sooner the evacuation phase can begin, thus giving an evacuee more time to reach safety.



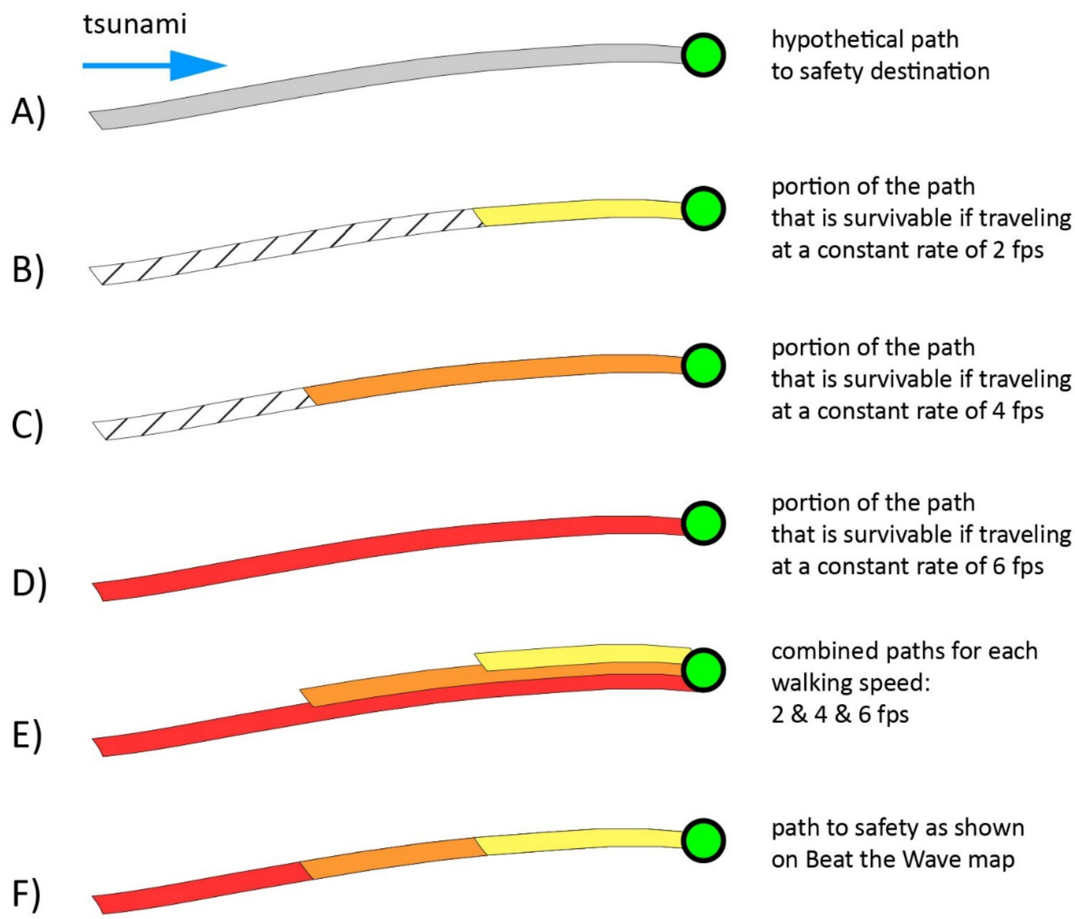
2.5.2 Evacuation time maps

We converted the path distance surfaces to walking times to compare tsunami arrival times to pedestrian arrival at various critical junctures. We did this by dividing the path distance surface raster by a constant speed (distance ÷ speed = time). We started by assuming a pedestrian walking speed of 4 feet per second (fps) (22 minutes/mile; 1.22 meters/second), a pace 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).

To explore an array of evacuation speeds appropriate for specific populations (e.g., the elderly or small children versus able-bodied adults), 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"[1] 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 **Figure 2-6** and in the final step of **Figure 2-2**. By integrating evacuation time maps with tsunami wave arrival data, we can produce *Beat the Wave* (BTW) maps that estimate the ***minimum speed*** needed to reach safety ahead of the wave.

[1] "Clip" is a GIS software program command that "extracts features from one feature class that reside entirely within a boundary defined by features in another feature class" (https://support.esri.com/en/other-resources/gis-dictionary).

Figure 2-6. Illustration of *Beat the Wave* (BTW) tsunami evacuation map construction. (A) shows a hypothetical evacuation route. (B), (C), and (D) show the path with constant walking speeds of 2 fps, 4 fps, and 6 fps, respectively. The farther away from safety (green dot) evacuees begin the route, the faster they must walk the route to survive (hashed areas denote unsurvivable sections of the path at given walking speed); however, at faster walking speeds, evacuees can cover more distance and reach safety if they maintain the initial walking speed. (E) displays how the different constant walking speeds are combined to create the (F) final BTW map. The BTW map shows minimum constant speeds necessary to reach safety ahead of the tsunami.



Evacuation speeds were initially grouped into 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, 2015) 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 ≤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, Oregon, to evaluate the validity of the ***walk***, ***fast walk***, and ***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). Symbol 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

2.5.3 Reading a BTW map

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).

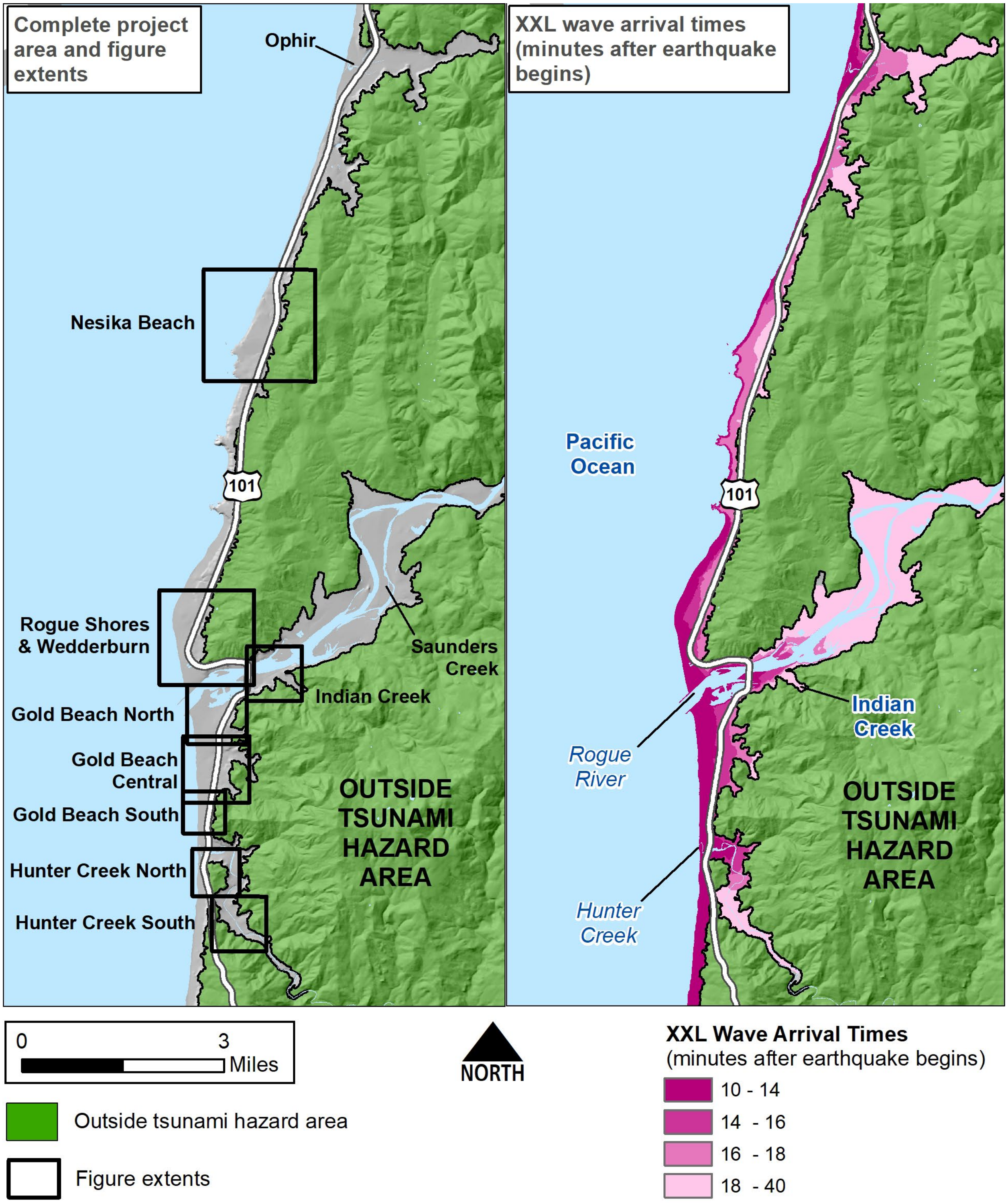
BTW map colors represent the speed that must be **maintained** from a starting location all the way to safety. If an evacuee slows down for some portion of the route, the evacuee must account for the time deficit by traveling faster than the required speed for the remainder of the route. We stress this 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.

3.0 RESULTS AND DISCUSSION

This report covers the Curry County coastline from Ophir in the north to Hunter Creek in the south, focusing on the City of Gold Beach, Rogue Shores, and Nesika Beach (**Figure 3-1**, **left**). Digital data are also provided for the community of Saunders Creek, located several miles inland, along the Rogue River. However, due to its distance upriver and proximity to high ground, our evacuation modeling indicates that survivability is very high, such that no further discussion of Saunders Creek included in this report.

Figure 3-1, **right** shows the arrival times for an XXL tsunami in the Gold Beach project area. The earliest wave arrivals are along the open coast; the tsunami reaches the beach ~10-12 minutes after the start of the earthquake shaking. By ~18-20 minutes, most of the region has been fully inundated. The tsunami continues up the Rogue River ~10 river miles, reaching its farthest upriver extent ~2 hours after the earthquake just shy of the Lobster Creek Campground (not shown in figure). Additional waves will continue to strike the coast and enter the estuaries, causing water levels to fluctuate for up to 12 hours after the earthquake. Tsunami wave arrival time data are found in the accompanying Gold_Beach_Tsunami_Evacuation_Modeling geodatabase.

Figure 3-1. (left) Gold Beach, Oregon, project area map. Results will be discussed separately for each panel. (right) Illustration of tsunami wave arrivals after XXL Cascadia subduction zone earthquake.



We evaluated a suite of scenarios starting with current conditions, followed by several hypothetical scenarios to look at what might improve evacuation and what could make evacuation more difficult. Hypothetical scenarios are only presented for impacted communities. We did not evaluate the potential impact from landslides; section 3.8 presents mapped landslide data to encourage further discussion of associated risk and mitigation options. Each section of this chapter focuses on a different scenario, as described below:

Section 3.1 A maximum-considered XXL scenario that uses the existing road and trail network (referred to as "current conditions scenario). This scenario and all others unless otherwise stated assume "non-retrofitted bridges fail" due to earthquake ground motion and that people evacuate within 10 minutes from the start of earthquake shaking. GIS data for this scenario are found in the Gold_Beach_Tsunami_Evacuation_Modeling geodatabase.

Section 3.2 Three separate XXL scenarios that include hypothetical vertical evacuation structures to demonstrate the potential evacuation improvements provided to nearby people (North Gold Beach, Central Gold Beach, and Rogue Shores).

Section 3.3 XXL scenarios that assume a hypothetical trail is constructed to shorten distances to safety (South Gold Beach, North Hunter Creek, Rogue Shores, Wedderburn, and Nesika Beach).

Section 3.4 An XXL scenario that examines the importance of bridges over Indian Creek by showing *Beat the Wave* results with bridges included, effectively assuming they have been seismically retrofitted to withstand earthquake shaking.

Section 3.5 An XXL scenario that assumes people evacuate within 5 minutes (i.e., 3 minutes of shaking, 2 minutes of delay) from the start of earthquake shaking (all communities except for Indian Creek and South Hunter Creek).

Section 3.6 A Large tsunami scenario that reduces the distance people must travel to evacuate due to a smaller inundation zone (all communities except for South Hunter Creek). GIS data for this scenario are found in the Gold_Beach_Tsunami_Evacuation_Modeling geodatabase.

Section 3.7 An XXL scenario that assumes liquefaction makes roads and trails significantly more difficult to walk on.

Unless otherwise noted, all scenarios include a 10-minute delay before starting evacuation to account for the expected disoriented state of people following severe earthquake shaking and the time required to exit buildings. While results are shown for the beach itself, we will not discuss those results as our method was not built with the assumption of sustained walking on soft sand. We include it only to provide some guidance on minimum travel speeds required to reach high ground from the beach. **Table 3-1** represents a summary of the range of speeds and their conversions that will be used throughout the remainder of this report.

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).

For most of the region, we find that the evacuation speeds necessary to escape an XXL (maximum-considered) CSZ tsunami range from a ***fast walk*** (6 fps, or 4.1 mph) to ***run*** (10 fps, or 6.8 mph), with some areas requiring a ***sprint*** (15 fps, or 10 mph). Only those who are very close to high ground can travel at speeds slower than ***walk*** (4 fps, or 2.7 mph). Early wave arrivals in this region result in evacuation speeds that are much faster than communities examined on the central and northern Oregon coast with comparable distances to safety. While it is reassuring that there are almost no bridges or other key infrastructure that could compromise pedestrian evacuation, clear and visible signage as well as community outreach are needed to ensure that residents and visitors understand they must evacuate immediately following the earthquake and move as quickly as possible because it will be the difference between life and death.

Finally, it is inevitable that following the earthquake other factors may also impede travel and increase evacuation time. This modeling does not account for these ancillary effects, which could include obstacles such as downed power lines or buildings. As a result, ***the public should evacuate immediately after the earthquake and move rapidly toward high ground to ensure they reach safety.***

3.1 XXL current conditions scenario and wave arrival

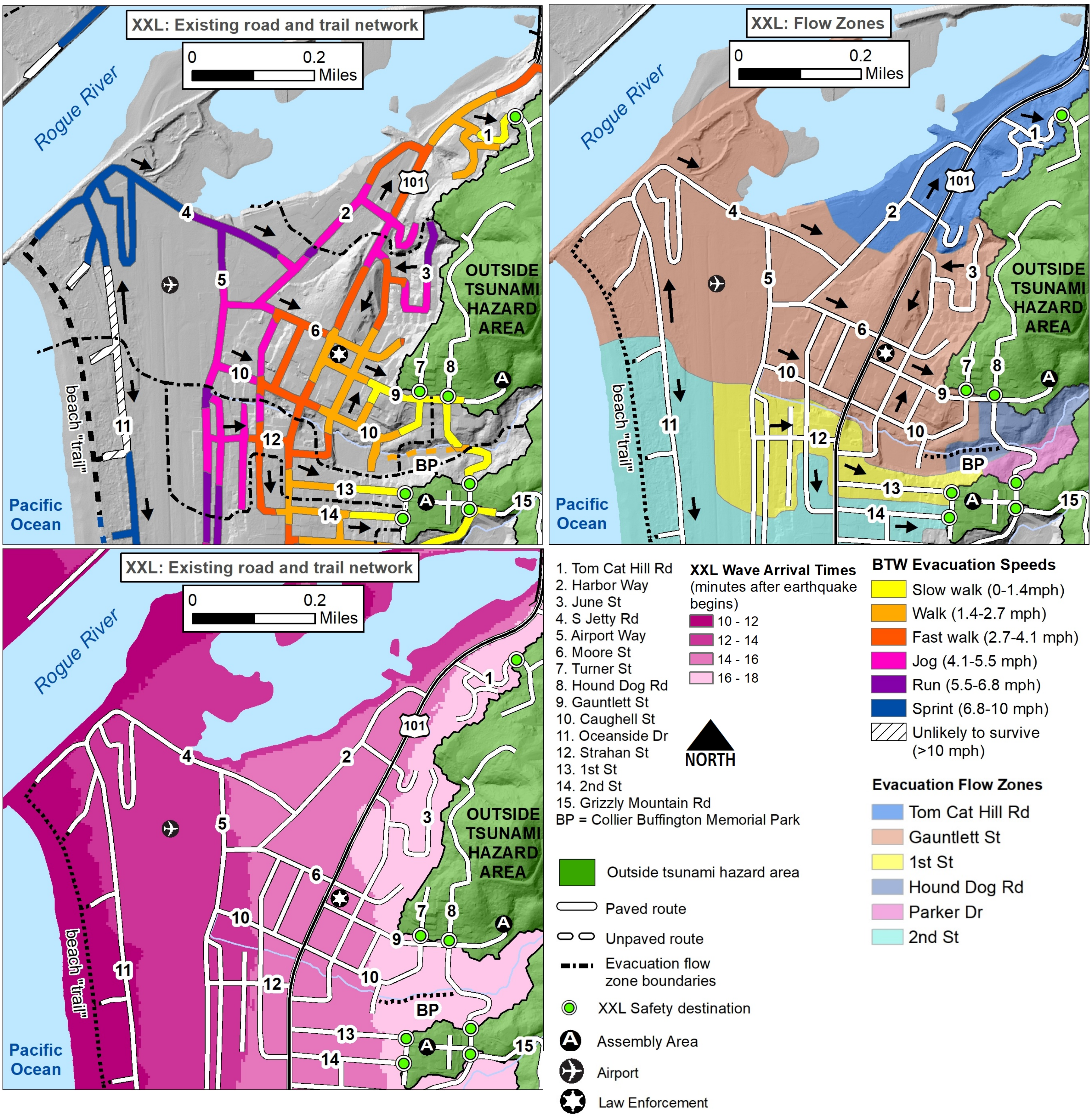
We first present an XXL scenario showing the minimum travel speeds required to reach safety using the existing road and trail network. This scenario assumes all bridges in the region fail during earthquake shaking and are not available for evacuation. These results represent the "current conditions" were evacuation to occur today. We will compare hypothetical *Beat the Wave* scenarios representing various improvements and added difficulties in sections 3.2 through 3.7 against this scenario.

3.1.1 North Gold Beach

The City of Gold Beach sits on the open coast and along the southern edge of the Rogue River where it meets the Pacific Ocean. Much of the community, including police and fire stations, the county courthouse and jail, hospital, and the high school and elementary school, is inside the XXL and Large tsunami zones. In addition to its full-time residents, Gold Beach is a popular tourist destination and second-home community. The Gold Beach population can increase significantly on a summer weekend; most temporary visitors sleep in hotels and vacation homes, which tend to be closer to the ocean and farthest from high ground. The visitor population is especially vulnerable given their probable lack of knowledge about geological hazards and local geography. Wave arrivals and current conditions BTW results are presented separately for North, Central and South Gold Beach to allow for more detail. In addition to the existing conditions, scenarios considered for North Gold Beach include a vertical evacuation structure, reduced evacuation delay, evacuating in the Large tsunami scenario, and liquefaction.

Detailed XXL tsunami wave arrivals are presented in **Figure 3-2, bottom.** The tsunami simultaneously reaches the beach and enters the Rogue River, resulting in very rapid inundation of the port area (within ~14 minutes after the start of earthquake shaking). Water reaches Highway 101 in another ~1-2 minutes and by ~18 minutes the XXL tsunami zone has been fully inundated. **Figure 3-2, top** presents minimum travel speeds required to reach safety assuming the existing road network remains intact. Those evacuees on and east of Highway 101 can travel at a minimum speed of ***walk*** (4 fps, or 2.7 mph) or ***fast walk*** (6 fps, or 4.1 mph) and reach high ground ahead of the tsunami (**Figure 3-2, top left)**. Between Highway 101 and Airport Way, walking speeds increase to ***jog*** (8 fps, or 5.5 mph) and ***run*** (10 fps, or 6.8 mph). Evacuees in the airport, jetty, and beach areas west of Airport Way must ***sprint*** (>15 fps, or >10 mph). Evacuation flow zones for the current conditions scenario are presented in **Figure 3-2**, **top right**. The evacuation flow zones make clear which safety destination evacuees should choose and which direction to travel based on their location. The very northern region, including Jerry's Jets, should evacuate to Tom Cat Hill Rd (blue polygon). The majority of evacuees in North Gold Beach head east to Gauntlett St (brown polygon), while those on the southern edge of this area, including in the trailer park on Strahan St, should seek high ground on 1st St (yellow polygon). Although not included in this report, we evaluated a hypothetical trail that could be established at the end of June St. However, this approach yielded negligible improvement to the surrounding evacuation speeds.

Figure 3-2. ***Beat the Wave*** **modeling and wave arrival in North Gold Beach for the XXL current conditions scenario depicting the existing road and trail network. (top left) BTW evacuation speeds and flow zones. Colors on top of roads reflect minimum travel speeds that must be maintained along the route. Black dot-dashed lines delineate evacuation flow zone boundaries. (top right) Evacuation flow zones displayed as colored polygons for the current conditions scenario. (bottom) Illustration of tsunami wave arrivals after XXL Cascadia subduction zone earthquake.**



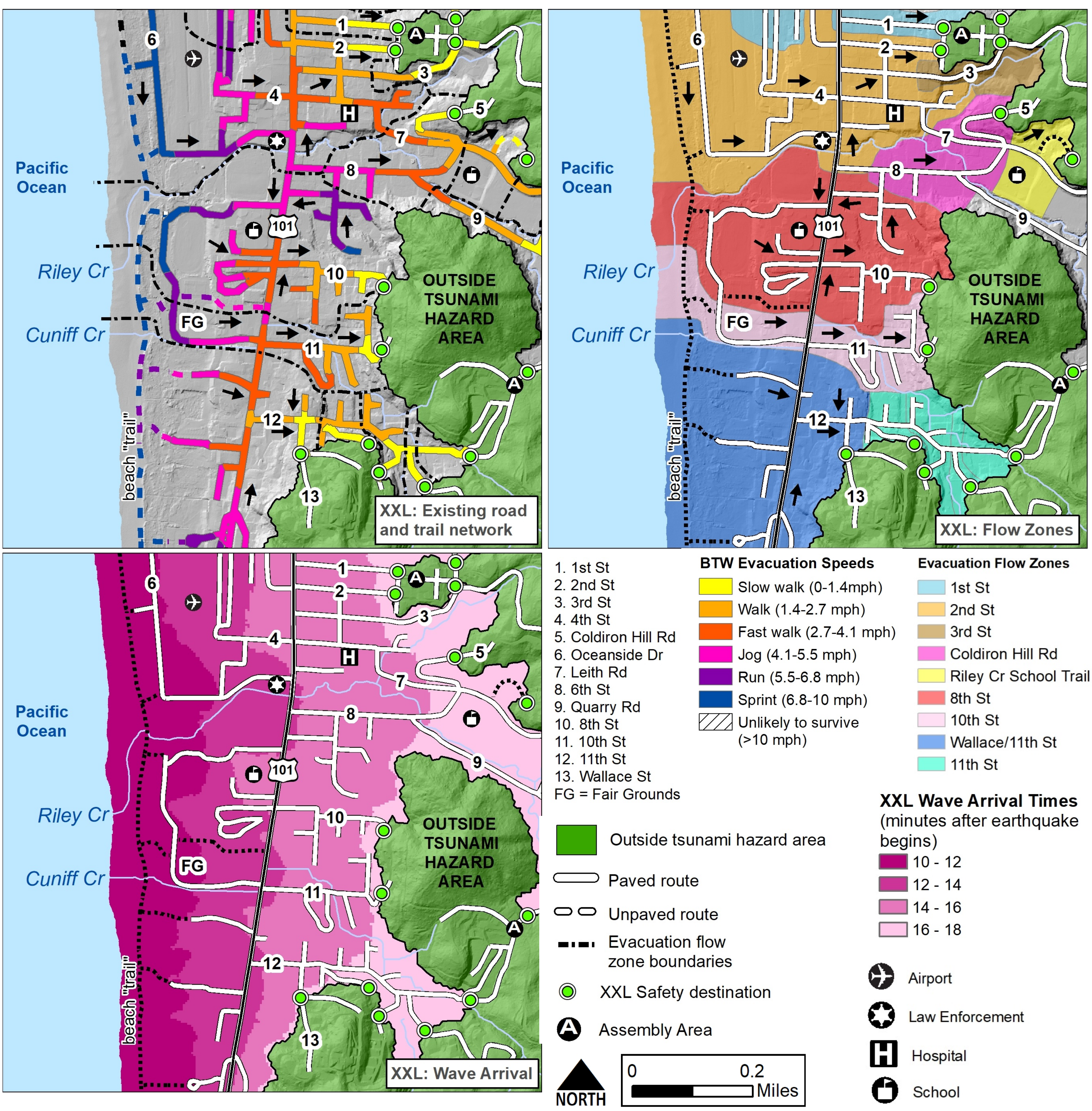
3.1.2 Central Gold Beach

Detailed XXL tsunami wave arrivals are presented in **Figure 3-3, bottom.** The tsunami reaches the beach ~10 minutes after the start of earthquake shaking. Water reaches Highway 101 by ~14 minutes and the majority of the area is inundated within ~16 minutes. It takes another ~2 minutes for the tsunami to inundate the Riley Creek area (Quarry Rd). **Figure 3-3, top left** presents minimum travel speeds required to reach safety assuming the existing road network remains intact. The majority of people on or east of Highway 101 can travel at a minimum speed of a ***walk*** (4 fps, or 2.7 mph) or ***fast walk*** (6 fps, or 4.1 mph) and reach high ground ahead of the tsunami (**Figure 3-3, top left)**. However, a section of 6th St by the police station requires a speed of ***jog*** (8 fps, or 5.5 mph). Between Highway 101 and Airport Way, required evacuation walking speeds increase to ***jog*** (8 fps, or 5.5 mph) and ***run*** (10 fps, or 6.8 mph). Evacuees in the area of the airport, jetty, and beach areas west of Airport Way must ***sprint*** (>15 fps, or >10 mph). Evacuation flow zones for the current conditions scenario are presented in **Figure 3-3, top right**. The evacuation flow zones make clear which safety destination evacuees should choose and which direction to travel based on their location. 6th St area evacuees head to Cold Iron Hill Rd (pink polygon), while Riley Creek Elementary uses the evacuation trail behind the school (yellow polygon). The high school and a portion of the Curry County Fairgrounds uses 8th St (red polygon), and the southern half of the Fairgrounds uses 10th St (lilac polygon). For those located south of the Fairgrounds (including several hotels along Highway 101), the nearest safety destination is up 11th St (blue polygon).

Input from the county indicates there is a belief that 3rd St is a key evacuation route for the northern part of this region, including the police station and hospital. However, our analyses demonstrate that 2nd St is a better route to take because high ground is reached sooner (orange polygon). The evacuation flow zone for 3rd St is shown in brown and only services a small portion of 3rd St. This stretch of 3rd St is also an area affected by an historic landslide deposit (**Figure 3-41, right**). There is a possibility that this slide could block passage on 3rd St; however, results show that alternative routes to high ground on 1st St and 2nd St can get everyone to high ground just as effectively. Connectivity on 3rd St will undoubtedly be important in the aftermath of the CSZ earthquake and tsunami, and mitigation options could be considered for this purpose.

In addition to current conditions, scenarios considered for Central Gold Beach include a vertical evacuation structure, reduced evacuation delay, evacuation in the Large tsunami scenario, and liquefaction.

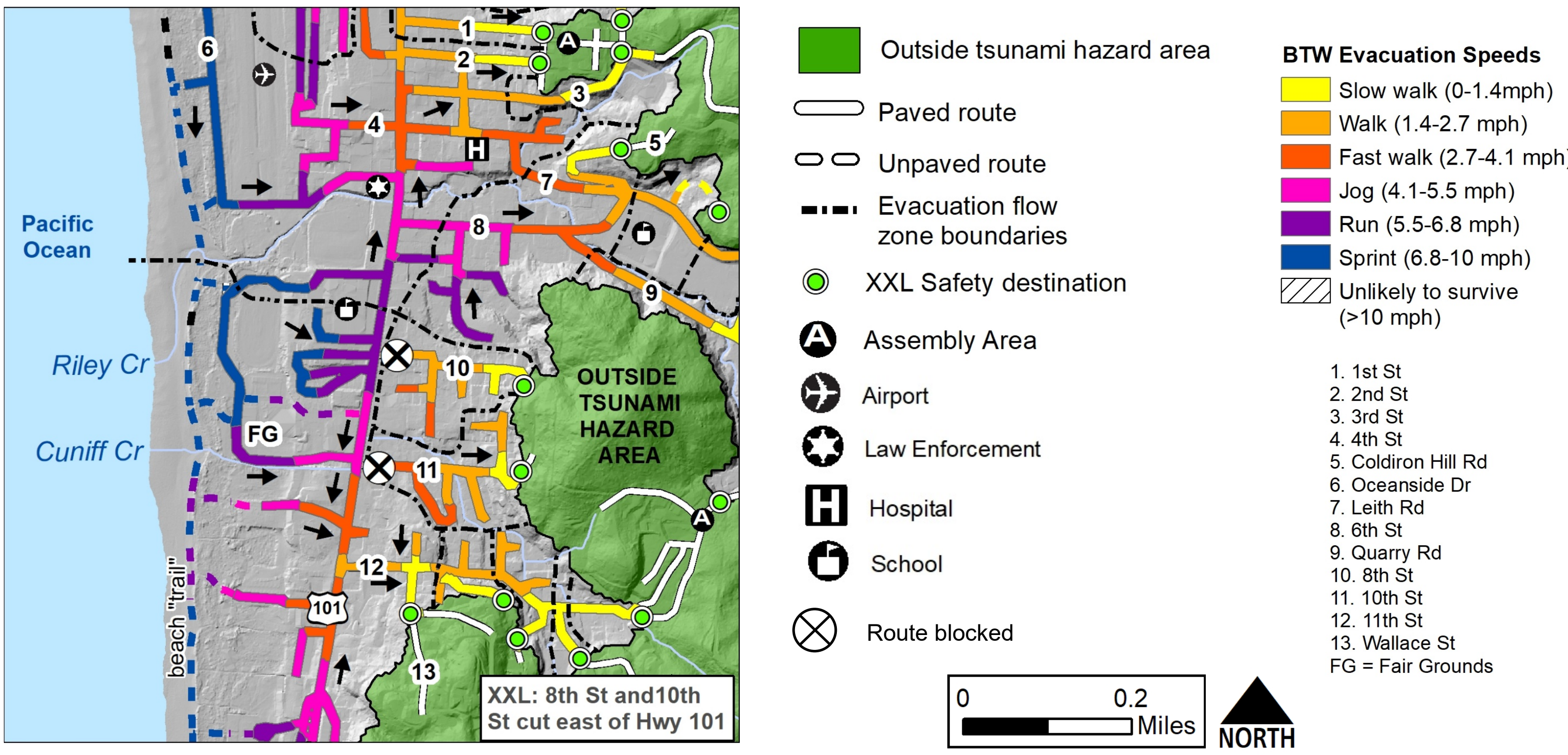
Figure 3-3. *Beat the Wave* modeling and wave arrival in Central Gold Beach for the XXL current conditions scenario depicting the existing road and trail network. (top left) BTW evacuation speeds and flow zones. Colors on top of roads reflect minimum travel speeds that must be maintained along the route. Black dot-dashed lines delineate evacuation flow zone boundaries. (top right) Evacuation flow zones displayed as colored polygons for the current conditions scenario. (bottom) Illustration of tsunami wave arrivals after XXL Cascadia subduction zone earthquake.



3.1.2.1 8th St and 10th St are key evacuation routes

One topic of additional concern for this region is a potential lack of accommodation space on 8th St and 10th St outside the XXL tsunami zone (this includes Lanikai Lane east of 10th St, not labeled in figure). The total number of people potentially needing to seek safety at the end of these two narrow and steep residential streets could be quite high considering this evacuation flow zone includes both the high school and fairgrounds as well as those living on 8th St and 10th St. We modeled an evacuation scenario that blocks 8th St and 10th St, thus channeling people at the fairgrounds and high school to evacuate up 11th St (Figure 3-4). Our analyses indicate that such a move would cause a significant increase in required evacuation speeds, suggesting that many people could be killed were they to take that alternative route. Accordingly, our modeling results confirm the importance of 8th St or 10th St and recommend the community carefully evaluate accommodation space.

Figure 3-4. *Beat the Wave* modeling in Central Gold Beach for an XXL scenarios where 8th and 10th Streets are unavailable.

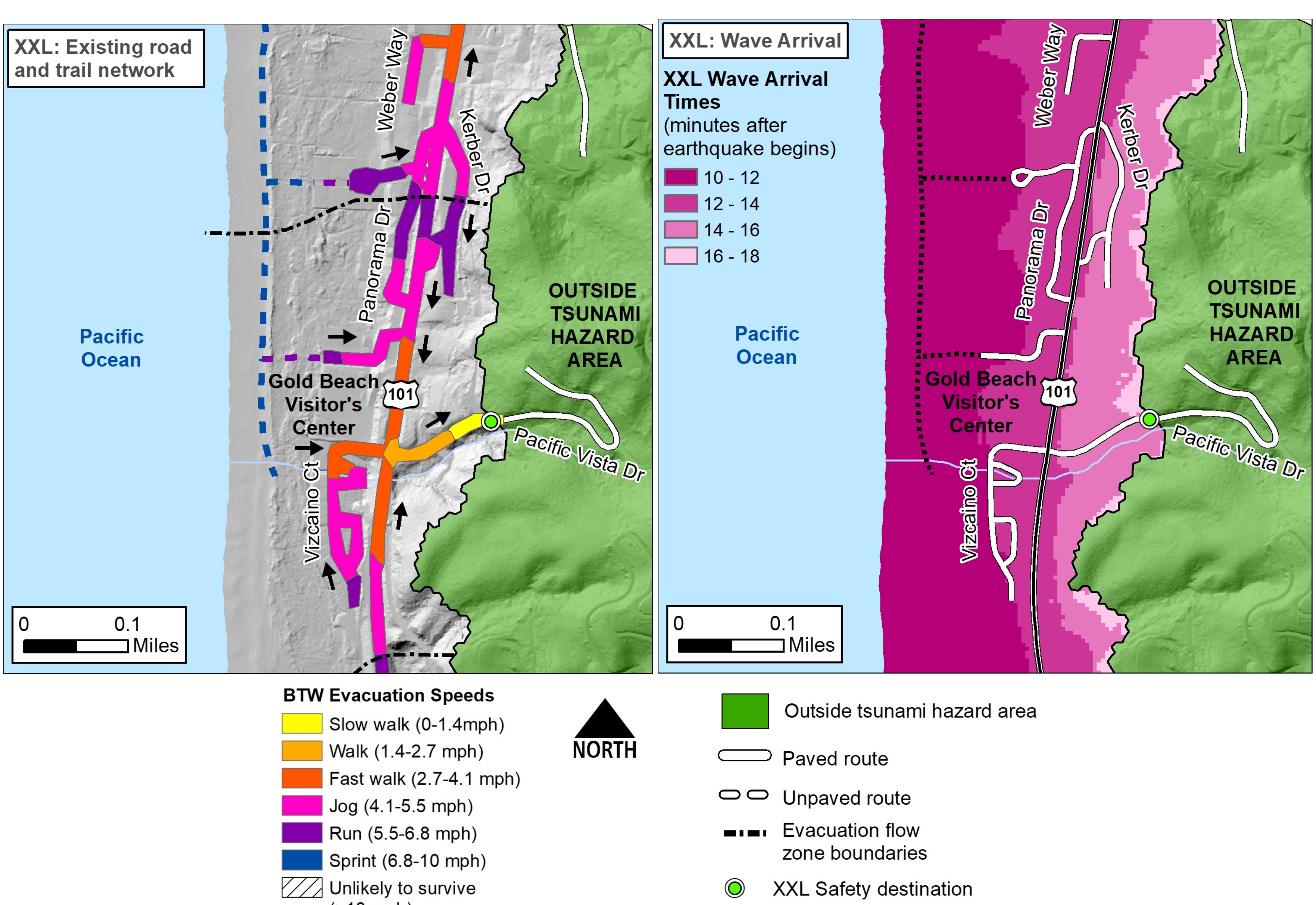


3.1.3 South Gold Beach

Detailed XXL tsunami wave arrivals are presented in **Figure 3-5, right.** The tsunami reaches the beach ~10 minutes after the start of earthquake shaking. Water reaches Highway 101 by ~14 minutes, and the remainder of the area is inundated within ~18 minutes. **Figure 3-5, left** presents minimum travel speeds required to reach safety assuming the existing road network remains intact. Despite high ground being much closer to Highway 101 here than farther north in Gold Beach, there are fewer roads that reach high ground; minimum BTW evacuation speeds reflect this. South Gold Beach is characterized by minimum travel speeds that range from ***jog*** (8 fps, or 5.5 mph) to ***run*** (10 fps, or 6.8 mph). Evacuation flow zones for the current conditions scenario are presented as black dot-dashed lines in **Figure 3-5, left.** The evacuation flow zones make clear which safety destination evacuees should choose and which direction to travel based on their location. Evacuees near Vizcaino Ct (Sebastian Shores community), the Visitor's Center, and the southern half of Panorama Dr must travel up Pacific Vista Dr. Those farther north including near Weber Way must head north back to 11th St.

In addition to current conditions, scenarios considered for South Gold Beach include an evacuation trail, reduced evacuation delay, evacuation in the Large tsunami scenario, and liquefaction.

Figure 3-5. *Beat the Wave* modeling and wave arrival in South Gold Beach for the XXL current conditions scenario depicting the existing road and trail network. (left) BTW evacuation speeds and flow zones. Colors on top of roads reflect minimum travel speeds that must be maintained along the route. Black dot-dashed lines delineate evacuation flow zone boundaries. (right) Illustration of tsunami wave arrivals after XXL Cascadia subduction zone earthquake.



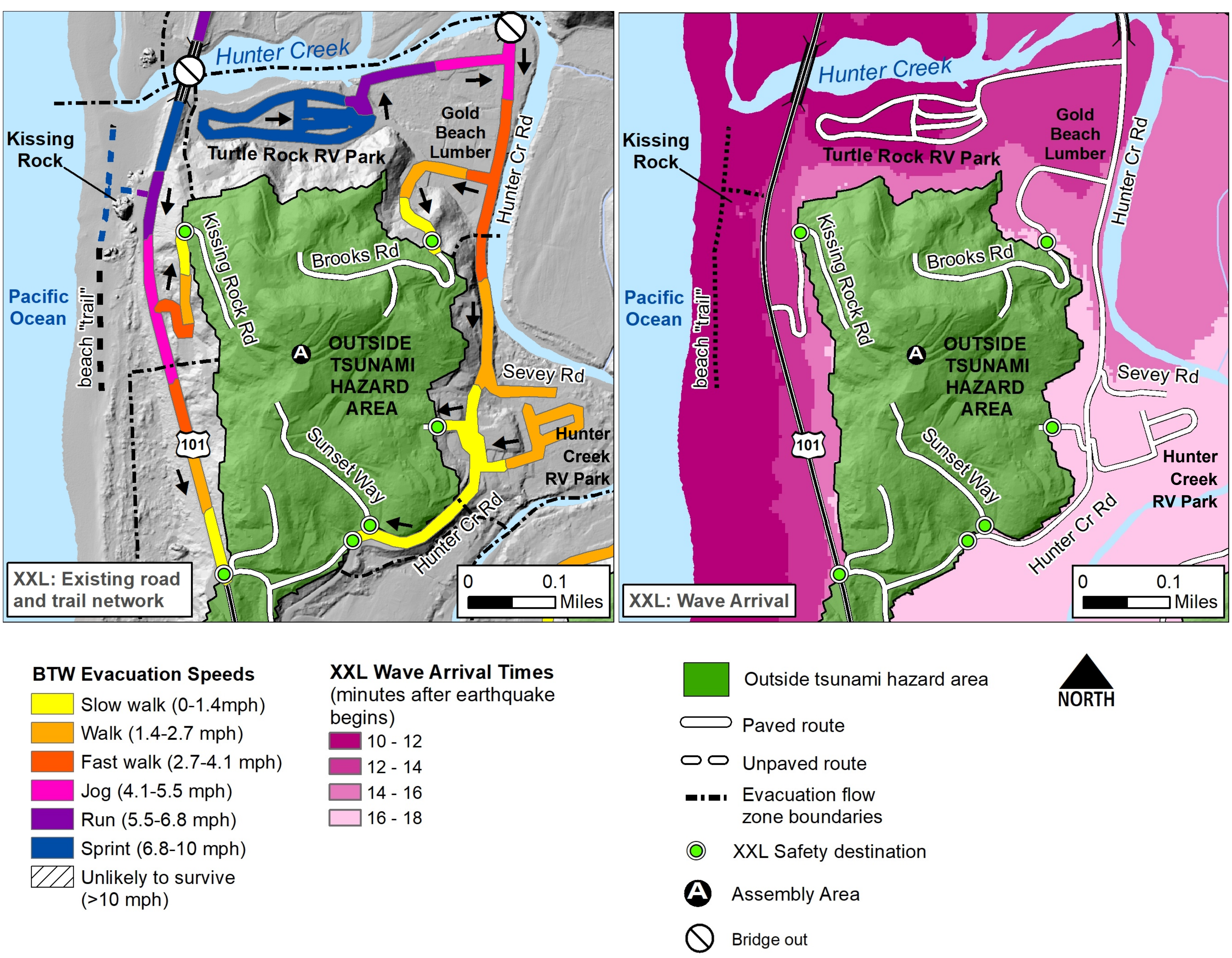
3.1.4 North Hunter Creek

Hunter Creek meets the Pacific Ocean south of Sebastian Shores. The area contains several RV parks and businesses within the XXL tsunami zone including Turtle Rock and Hunter Creek RV Parks and Gold Beach Lumber. Much of the area lies within the XXL tsunami zone; however, high ground is generally nearby. One exception to this is Turtle Rock RV Park, where high ground is currently accessible only via Brooks Rd. There are few residential buildings, with most permanent residents residing farther up the estuary (discussed in section 3.1.5). North Hunter Creek also contains Kissing Rock, a popular beach access on the open coast just south of Hunter Creek. There are two bridges in this area, both of which are excluded from BTW modeling based on the likelihood they could fail during earthquake shaking: a ~350-ft-long bridge spans the mouth of Hunter Creek on Highway 101 and a 150-ft-long bridge on Hunter Creek Rd crosses the creek just inside the mouth. In addition to current conditions, scenarios considered for North Hunter Creek include an evacuation trail, reduced evacuation delay, evacuation in the Large tsunami scenario, and liquefaction.

Hunter Creek Rd is likely susceptible to lateral spreading in places where the downhill/creek-side of the road is essentially unsupported. Lateral spreading can result in major failures to road infrastructure as the road slumps toward the creek. We did not consider a scenario that blocked sections of Hunter Creek Rd because we do not know precisely where this phenomenon might occur. The modeling does not account for all possibilities that come with this hazard (e.g., the complete removal of a section of Hunter Creek Rd).

Detailed XXL tsunami wave arrivals are presented in **Figure 3-6, right.** The tsunami simultaneously reaches Highway 101 and enters Hunter Creek as far as Turtle Rock RV Park ~10 minutes after the start of earthquake shaking. Within ~6 minutes the tsunami has passed Hunter Creek RV Park on its way upstream. **Figure 3-6, left** presents minimum travel speeds required to reach safety assuming the existing road network remains intact and bridges fail. Evacuation flow zones, which make clear which safety destination evacuees should choose and which direction to travel based on their location, are presented as black dot-dashed lines. Those on the open coast, including near Kissing Rock beach access, must ***jog*** (8 fps, or 5.5 mph) or ***run*** (10 fps, or 6.8 mph) to reach high ground on Kissing Rock Rd. Within the estuary, minimum travel speeds are predominantly ***slow walk*** and ***walk*** with the notable exception of Turtle Rock RV Park, where evacuees must ***sprint*** (15 fps, or 10 mph). This is due to the long distance required to reach high ground on Brooks Rd.

Figure 3-6. ***Beat the Wave*** **modeling and wave arrival in North Hunter Creek for the XXL current conditions scenario depicting the existing road and trail network. (left) BTW evacuation speeds and flow zones. Colors on top of roads reflect minimum travel speeds that must be maintained along the route. Black dot-dashed lines delineate evacuation flow zone boundaries. (right) Illustration of tsunami wave arrivals after XXL Cascadia subduction zone earthquake.**

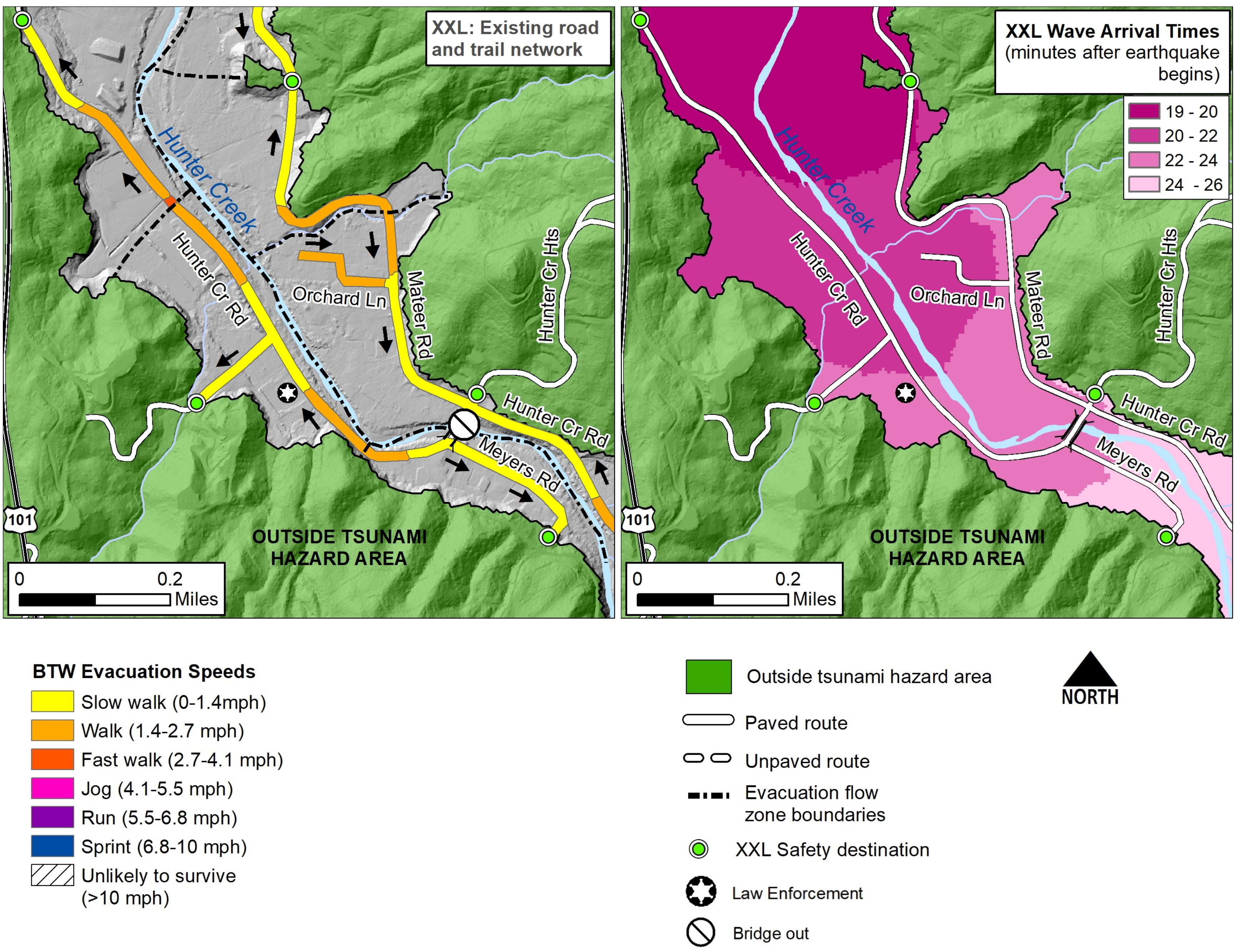


3.1.5 South Hunter Creek

Roads and developed land within the XXL tsunami zone dwindle as the tsunami travels up Hunter Creek. However, as discussed in section 3.1.4, lateral spreading will continue to be an issue on low-lying roads (e.g., Hunter Creek Rd, Mateer Rd, and Meyers Rd). Detailed XXL tsunami wave arrivals are presented in **Figure 3-7, right.** The tsunami passes under one bridge where Hunter Creek Rd crosses back over the creek, ~24 minutes after the start of earthquake shaking. This bridge is not expected to survive earthquake shaking and was excluded from BTW modeling. The tsunami reaches its terminus approximately 1.4 miles upstream from Hunter Creek Heights (not shown in figure), ~30 minutes after the start of earthquake shaking.

Figure 3-7, left presents minimum travel speeds required to reach safety assuming the existing road network remains intact and bridges fail. Evacuation flow zones, which make clear which safety destination evacuees should choose and which direction to travel based on their location, are presented as black dot-dashed lines. Safety can be reached on several roads off Hunter Creek Rd as well as Hunter Creek Rd itself. Relatively longer wave arrivals and shorter distances to safety result in low minimum travel speeds necessary to reach high ground in this area (***slow walk/walk***). Because results from the current conditions scenario cannot be effectively improved upon, the only additional scenario presented is liquefaction.

Figure 3-7. ***Beat the Wave*** **modeling and wave arrival in South Hunter Creek for the XXL current conditions scenario depicting the existing road and trail network. (left) BTW evacuation speeds and flow zones. Colors on top of roads reflect minimum travel speeds that must be maintained along the route. Black dot-dashed lines delineate evacuation flow zone boundaries. (right) Illustration of tsunami wave arrivals after XXL Cascadia subduction zone earthquake.**



3.1.6 Indian Creek

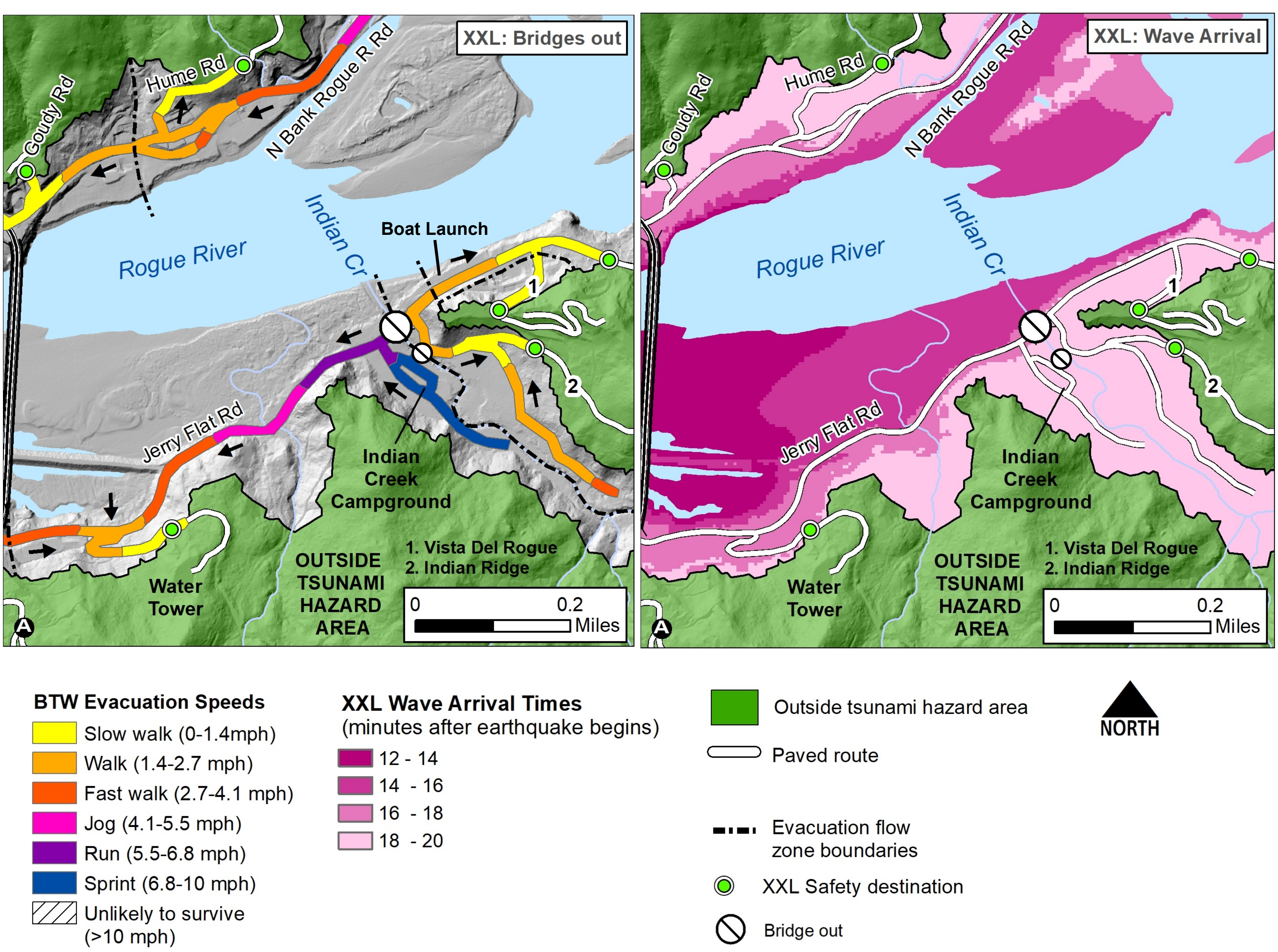
The eastern limit of the City of Gold Beach lies along Jerrys Flat Rd where Indian Creek empties into the Rogue River. There are several small population centers within the XXL tsunami zone in this area including Indian Creek Campground, Indian Creek Café, Rogue Landing Resort, and a popular Rogue River boat launch. **Figure 3-8, right** shows the arrival times for an XXL tsunami in this area. The tsunami reaches the Highway 101 bridge over the Rogue River ~13 minutes after the start of earthquake shaking, starts to overtop Jerrys Flat Rd around 16 minutes, and floods Indian Creek Campground by ~20 minutes. In addition to current conditions, scenarios considered for Indian Creek include seismic retrofit of bridges, reduced evacuation delay, evacuation in the Large tsunami scenario, and liquefaction.

While there is nearby high ground on both sides of Indian Creek, it is not currently accessible on the west side where the campground and café are located. Two bridges cross the creek: a standard concrete bridge on Jerrys Flat Rd and a wooden footbridge within the campground. Although it is not a certainty that these bridges will fail completely during earthquake shaking, there is a distinct possibility that a combination of bridge damage and high water levels (were the event to occur in winter) could make crossing extremely difficult, especially for anyone with ambulatory difficulties. Following the current road network, the nearest high ground on the west side of the creek is ~0.6 miles west toward the water tower. The east side of the creek has two primary routes to high ground: Indian Ridge and Vista Del Rogue. Both routes are steep but short.

Jerrys Flat Rd is likely susceptible to lateral spreading in places where the river-side of the road is essentially unsupported. Lateral spreading can result in major failures to road infrastructure as the road slumps toward the creek. We did not consider a scenario that blocked sections of Jerrys Flat Rd because we do not know precisely where this phenomenon might occur and results will look similar to the "bridges out" scenario (i.e., the current conditions scenario). The modeling does not account for all possibilities that come with this hazard (e.g., the complete removal of a section of Jerrys Flat Rd). We recommend looking into mitigation options including ways to reinforce Jerrys Flat Rd against lateral spreading to stabilize key routes.

Figure 3-8, left presents minimum travel speeds required to reach safety assuming the existing road network remains intact and Indian Creek cannot be crossed. Evacuation flow zones, which make clear which safety destination evacuees should choose and which direction to travel based on their location, are presented as black dot-dashed lines. Evacuees at the campground must travel at a minimum speed of ***sprint*** (15 fps, or 10 mph) to reach high ground at the water tower. This route is non-ideal for several reasons: it is a long distance to travel; in the direction of the incoming tsunami; and a long stretch of the road will likely be compromised due to lateral spreading and liquefaction. As will be discussed in section 3.4, the alternative route across Indian Creek removes these issues and dramatically reduces evacuation speeds. **Figure 3-8, left** demonstrates that those on the east/upstream side of Indian Creek can reach high ground at a ***slow walk*** or ***walk*** (4 fps, or 2.7 mph) via Vista Del Rogue or Indian Ridge.

Figure 3-8. *Beat the Wave* modeling and wave arrival in Indian Creek for the XXL current conditions scenario depicting the existing road and trail network and assuming bridges fail. (left) BTW evacuation speeds and flow zones. Colors on top of roads reflect minimum travel speeds that must be maintained along the route. Black dot-dashed lines delineate evacuation flow zone boundaries. (right) Illustration of tsunami wave arrivals after XXL Cascadia subduction zone earthquake.

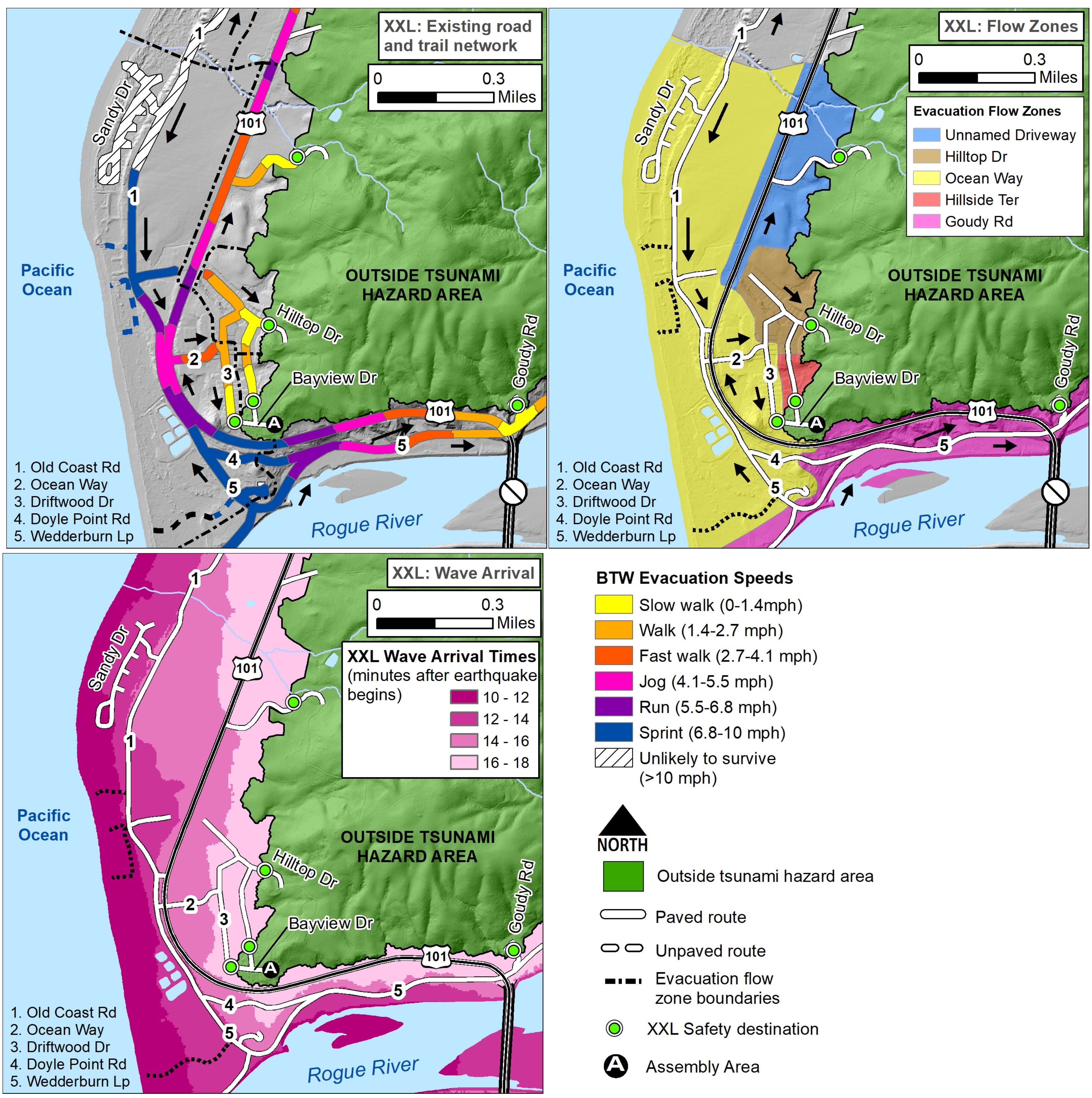


3.1.7 Rogue Shores

The unincorporated community of Rogue Shores (Sandy Dr and Old Coast Rd) sits on the open coast just north of the mouth of the Rogue River. This area is extremely vulnerable to the tsunami hazard because it is far from high ground (~2,000 ft due east) and evacuation to Rogue Hills (Ocean Way to Hilltop Dr) requires an even longer, circuitous route (~7,000 ft) because it must circumvent a large pasture. Rogue Hills sits farther back from the water, nestled against the hillside and immediately adjacent to the XXL inundation limit. This region has a relatively small full-time population; however, it contains many second homes and vacation rentals. The visitor population is especially vulnerable given their probable lack of knowledge about geological hazards and local geography. Detailed XXL tsunami wave arrivals are presented in **Figure 3-9, bottom.** The tsunami reaches the beach ~10 minutes after the start of earthquake shaking. The tsunami reaches Sandy Dr in ~13 minutes and Old Coast Rd in ~14 minutes; the remainder of the inundation zone is flooded within ~18 minutes. In addition to current conditions, scenarios considered for Rogue Shores include a vertical evacuation structure, an evacuation trail, reduced evacuation delay, evacuation in the Large tsunami scenario, and liquefaction.

Figure 3-9, top presents minimum travel speeds required to reach safety assuming the existing road network remains intact. Evacuees from the Rogue Hills neighborhood can travel at a minimum speed of ***walk*** (4 fps, or 2.7 mph) or ***fast walk*** (6 fps, or 4.1 mph) and reach high ground ahead of the tsunami. Rogue Shores, however, is characterized by speeds of ***sprint*** (15 fps, or 10 mph) and ***unlikely to survive*** (>15 fps, or >10 mph) (**Figure 3-9, top left**). Evacuation flow zones for the current conditions scenario are presented in **Figure 3-9, top right**. The evacuation flow zones make clear which safety destination evacuees should choose and which direction to travel based on their location. The nearest safety destination for Rogue Shores is at the south end of the Rogue Hills neighborhood (yellow polygon).

Figure 3-9. ***Beat the Wave*** **modeling and wave arrival in Rogue Shores and Wedderburn for the XXL current conditions scenario depicting the existing road and trail network. (top left) BTW evacuation speeds and flow zones. Colors on top of roads reflect minimum travel speeds that must be maintained along the route. Black dot-dashed lines delineate evacuation flow zone boundaries. (top right) Evacuation flow zones displayed as colored polygons for the current conditions scenario. (bottom) Illustration of tsunami wave arrivals after XXL Cascadia subduction zone earthquake.**



3.1.8 Wedderburn

The low-lying Wedderburn area sits on the north shore of the Rogue River where it reaches the Pacific Ocean. This region has a relatively small full-time population; however, it contains several second homes, vacation rentals, and hotels. The visitor population is especially vulnerable given their probable lack of knowledge about geological hazards and local geography. Detailed XXL tsunami wave arrivals are presented in **Figure 3-9, bottom.** The tsunami reaches the beach and the north shore of the river ~10 minutes after the start of earthquake shaking. Water reaches all of Wedderburn Loop simultaneously after ~14 minutes and Highway 101 by ~17 minutes; the remainder of the XXL tsunami zone is flooded within

~18 minutes. In addition to current conditions, scenarios considered for Wedderburn include evacuation trails, reduced evacuation delay, evacuation in the Large tsunami scenario, and liquefaction.

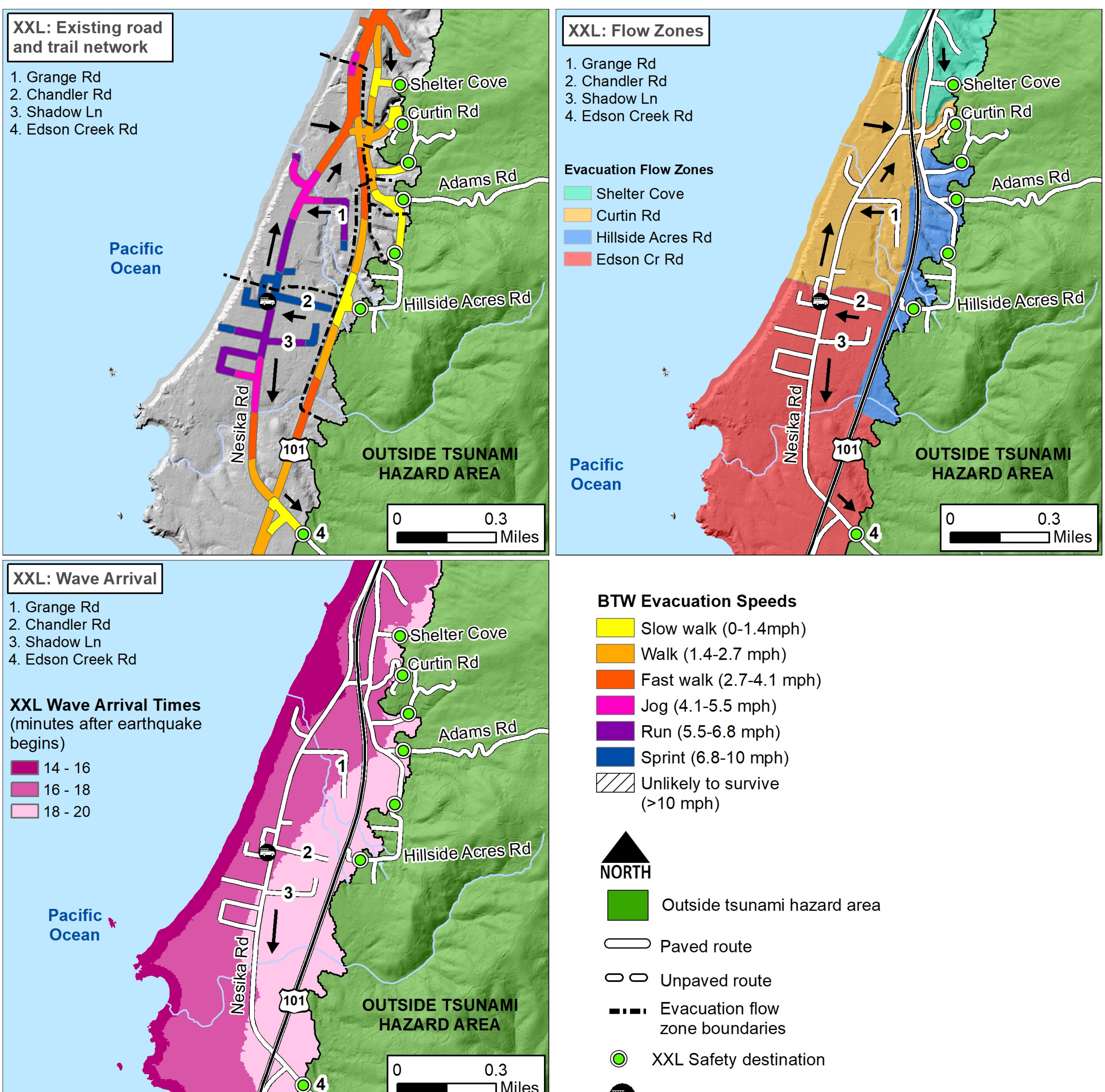
The western half of Wedderburn Loop is known as Doyle Point. Safety from the XXL tsunami is immediately to the north across Highway 101; however, if the road network is followed, evacuees from the area must initially travel west along Wedderburn Loop before turning north to Ocean Way and ultimately into the Rogue Hills neighborhood (**Figure 3-9**, **top right**, yellow polygon). This route is characterized by speeds of ***sprint*** (**Figure 3-9**, **top left**). The eastern half of this area, referred to as Wedderburn Loop, runs east from Doyle Point along the north shore of the Rogue River all the way to the Highway 101 bridge over the Rogue River. If the road network is followed, this community must head east to Goudy Rd, by the north end of the Highway 101 bridge (**Figure 3-9**, **top right**, purple polygon). This area is characterized by speeds of ***jog*** (8 fps, or 5.5 mph) and ***run*** (10 fps, or 6.8 mph) (**Figure 3-9**, **top left**).

3.1.9 Nesika Beach

The unincorporated community of Nesika Beach sits on a bluff along the open coast ~6 miles north of Gold Beach. The entire community is inundated by an XXL tsunami, with high ground east side of Highway 101. The challenge for Nesika Beach is that Highway 101 is accessible only at the very north and south ends of the community. In addition to current conditions, scenarios considered for Nesika Beach include an evacuation trail, reduced evacuation delay, evacuation in the Large tsunami scenario, and liquefaction.

Detailed XXL tsunami wave arrivals are presented in **Figure 3-10, bottom.** The tsunami reaches the beach ~14 minutes after the start of earthquake shaking. The tsunami reaches the top of the bluff in ~16 minutes and Highway 101 in ~18 minutes. **Figure 3-10**, **top left** presents minimum travel speeds required to reach safety assuming the existing road network remains intact. Minimum travel speeds range from ***jog*** (8 fps, or 5.5 mph) in the south, ***sprint*** (>15 fps, or >10 mph) in the center, and ***fast walk*** (6 fps, or 4.1 mph) in the north. Evacuation flow zones for the current conditions scenario are presented in **Figure 3-10**, **top right**. The evacuation flow zones make clear which safety destination evacuees should choose and which direction to travel based on their location. The southern half of Nesika Beach evacuates south to Edson Creek Rd (red polygon) and the northern half evacuates to Curtin Rd or Shelter Cove (orange polygon).

Figure 3-10. ***Beat the Wave*** **modeling and wave arrival in Nesika Beach for the XXL current conditions scenario depicting the existing road and trail network. (top left) BTW evacuation speeds and flow zones. Colors on top of roads reflect minimum travel speeds that must be maintained along the route. Black dot-dashed lines delineate evacuation flow zone boundaries. (top right) Evacuation flow zones displayed as colored polygons for the current conditions scenario. (bottom) Illustration of tsunami wave arrivals after XXL Cascadia subduction zone earthquake.**



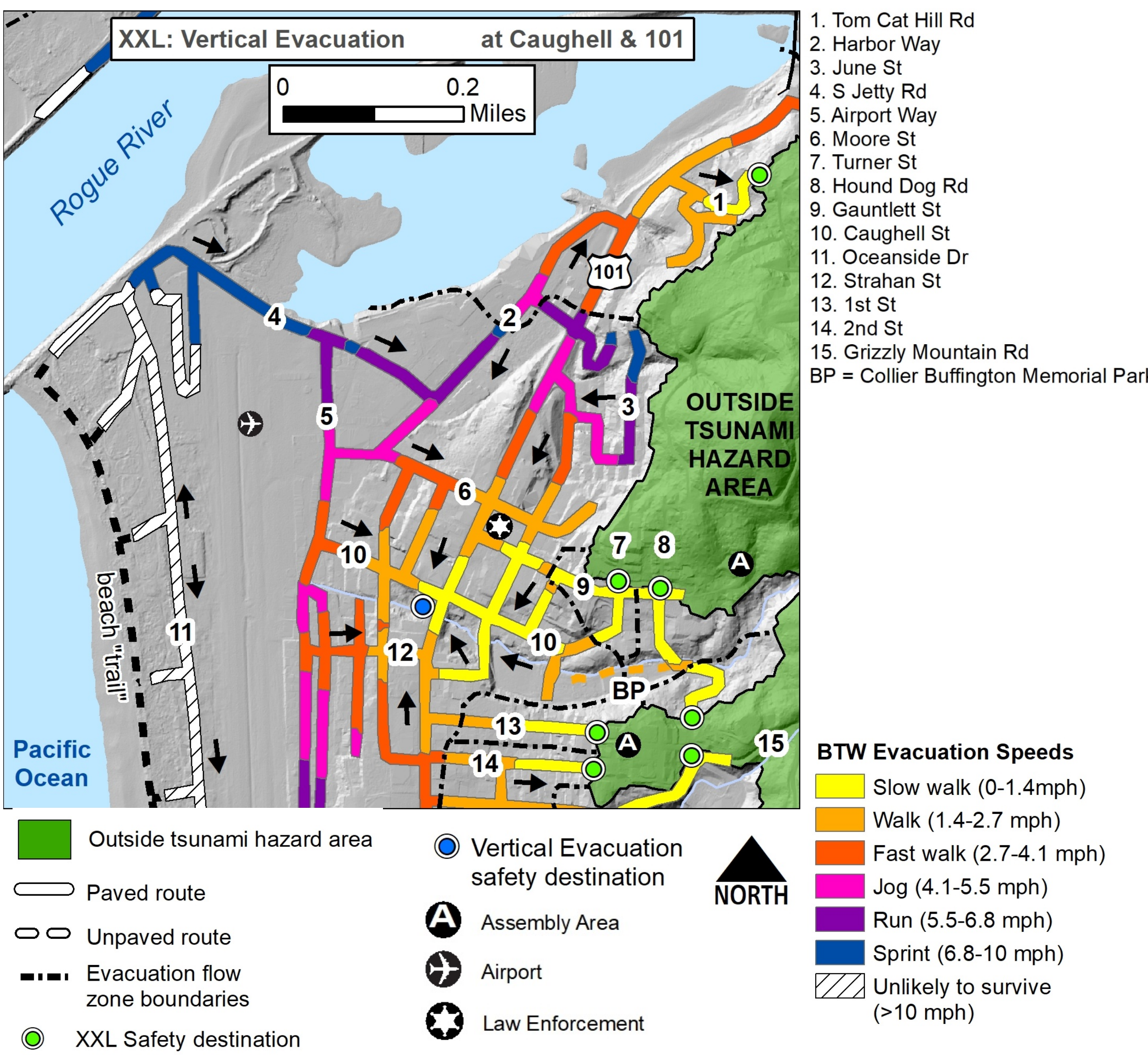
3.2 Vertical evacuation structures

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 or roads. Given these circumstances, communities may want to explore the construction of a vertical evacuation structure (VES). A VES is a refuge designed to remain intact and accessible after the earthquake shaking while also resisting tsunami forces and scour. Such structures include soil berms or structures that can serve dual purposes such as parking garages, community facilities, commercial facilities (e.g., hotels), and schools (Applied Technology Council, 2012). We incorporate vertical evacuation structures into BTW modeling by editing the tsunami hazard zone to include a small polygon of safety at the location of a hypothetical structure. Such a structure would need to be carefully designed to accommodate the number of people in the relevant evacuation flow zone and built to a sufficient height. Tsunami inundation flow depths modeled for this area are very high, suggesting a tall structure requiring a large footprint would be needed. Such a structure would likely be very costly. We recommend further evaluation to assess the costs and benefits of such options. Regardless of infrastructure improvements considered for an area, wayfinding and outreach will always be an essential part of local tsunami evacuation planning. VES scenarios were considered in North and Central Gold Beach due to the presence of large vulnerable populations (primarily visitors and high school students). A third VES is proposed for Rogue Shores due to the long distance to high ground.

3.2.1 North Gold Beach

A VES at the intersection of Highway 101 and Caughell Street improves evacuation by bringing high ground closer to the center of town. However, these improvements are only realized for a small region extending ~700 feet radially outward from the hypothetical structure (**Figure 3-11**). We chose this location hoping to improve evacuation for the trailer park off Strahan St to the south as well as port and tourist facilities to the north. Ultimately neither was achieved, suggesting that if a vertical evacuation structure is to be considered in this location, it will serve only a narrowly focused area. As a result, multiple structures are probably needed to fully meet the needs of this section of Gold Beach. Maximum tsunami flow depths at the intersection of Highway 101 and Caughell St are ~90 ft for XXL and ~40 ft for Large. Finally, as can be seen from **Figure 3-11**, a hypothetical VES constructed at Highway 101 and Caughell St would also serve people located just east of Highway 101. However, given the proximity of these residents to high ground in the east, we recommend that people in this area continue eastward to natural high ground rather than walk back seaward toward a vertical evacuation structure.

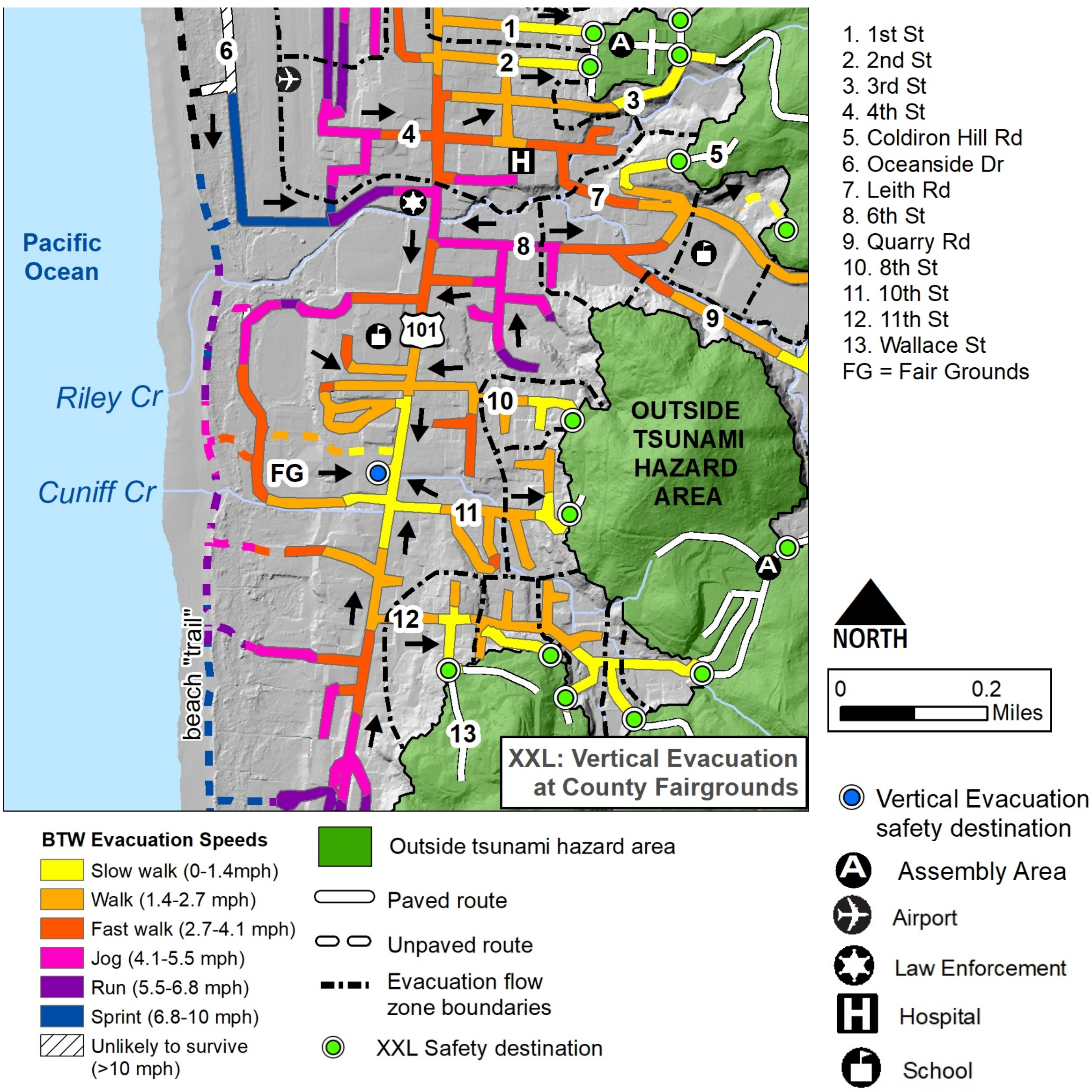
Figure 3-11. ***Beat the Wave*** **modeling in North Gold Beach for a hypothetical vertical evacuation structure.**



3.2.2 Central Gold Beach

A VES at the Curry County Fairgrounds (along Highway 101) improves evacuation by bringing high ground directly to the fairgrounds and high school. As with north Gold Beach, these improvements are only realized for a small region extending ~1,000 feet radially outward from the structure (**Figure 3-12**). We chose this location after discussion with Curry County staff and learning of the fairgrounds' goal to build a new conference center in this vicinity. Such a facility could be designed to potentially serve a dual purpose: an event center and a vertical evacuation structure, where people could congregate in the event of a tsunami. Maximum tsunami flow depths at this site are ~80 ft for XXL and ~30 ft for Large. Finally, as can be seen from **Figure 3-12**, a hypothetical VES constructed at the fairgrounds would also serve people located just east of Highway 101. However, given the proximity of these residents to high ground in the east, we recommend that people in this area continue eastward to the natural high ground rather than walk back seaward toward a vertical evacuation structure.

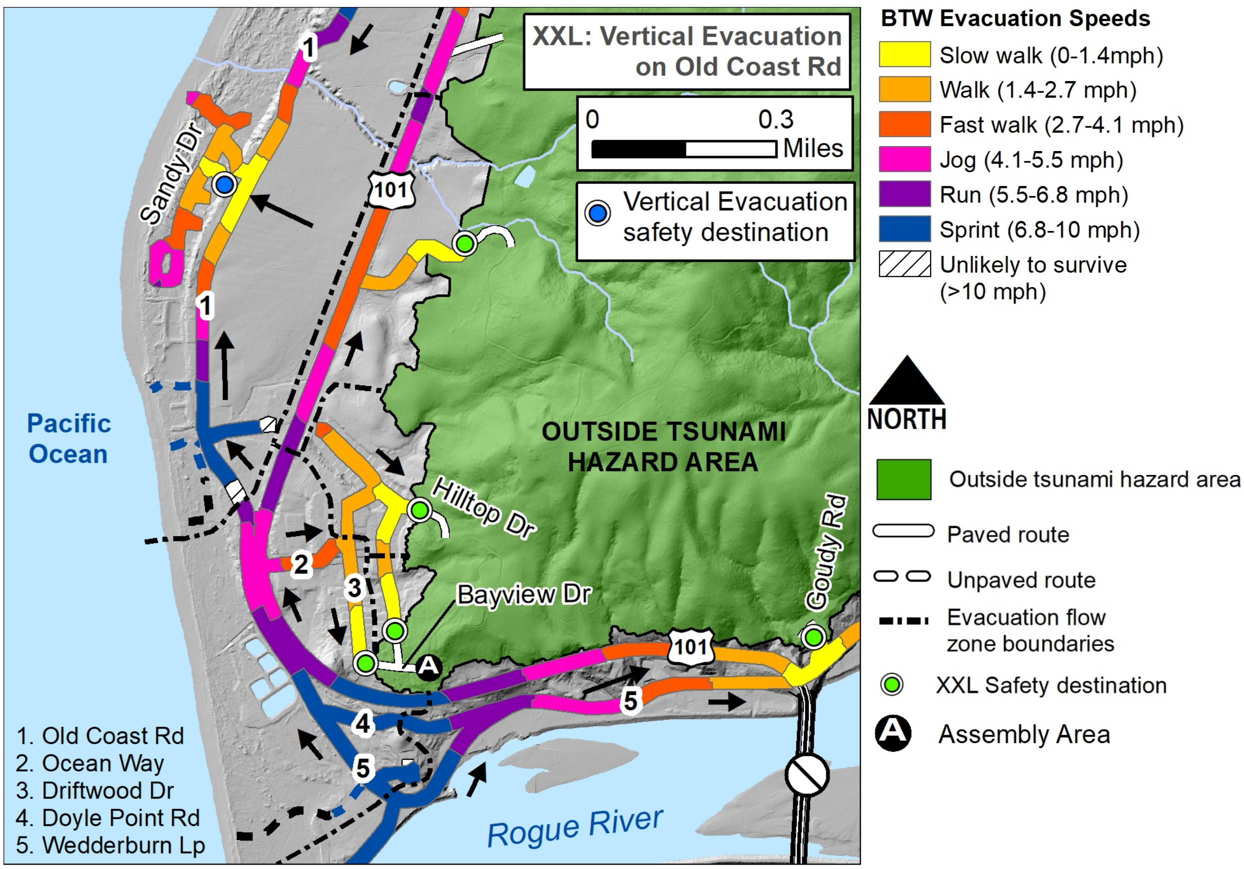
Figure 3-12. ***Beat the Wave*** **modeling in Central Gold Beach for a hypothetical vertical evacuation structure.**



3.2.3 Rogue Shores

A VES is by far the most effective solution for an area like Rogue Shores due to the extreme distance to high ground. **Figure 3-13** demonstrates the improved evacuation speeds were such a structure to exist near the intersection of Sandy Dr and Old Coast Rd. As can be seen from the figure, evacuation speed at Sandy Dr drops from ***unlikely to survive*** for the XXL current conditions scenario to ***jog*** or less. Old Coast Rd reduces from ***sprint*** to ***jog*** or less. This scenario presupposes that the structure has 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. Maximum tsunami flow depths at the proposed site are ~65 ft for XXL and ~26 ft for Large. The significant height of the structure, potentially large footprint, and large cost are likely to be a deterrent. Nevertheless, we recommend further evaluation to assess the costs and benefits of this option.

Figure 3-13. ***Beat the Wave*** **modeling in Rogue Shores for a hypothetical vertical evacuation structure.**



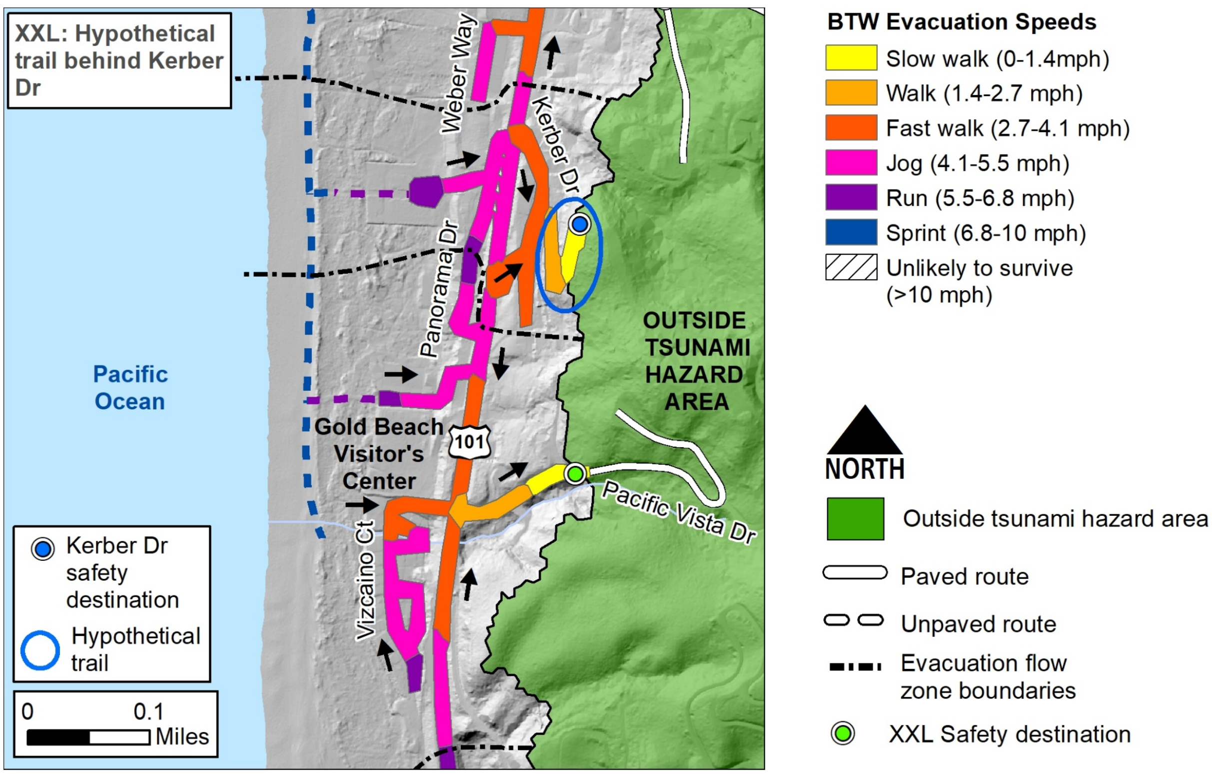
3.3 Evacuation trails

Evacuation can also be improved by shortening distances to safety by constructing a trail to nearby high ground (preferably designed to withstand earthquake shaking). This category of mitigation also includes identifying off-road routes that are already accessible but not officially recognized or included in wayfinding signage or other forms of outreach. We present BTW scenarios for all communities where a shortcut is feasible; some result in significant improvements and some do not. As a reminder, people can and should take whatever route is available to them to reach high ground as quickly as possible.

3.3.1 South Gold Beach

The addition of a trail connecting Kerber Dr to high ground directly uphill (~200 ft to the east) improves evacuation for a small section of Panorama Dr, Highway 101, and Kerber Dr. Safety from XXL can be reached ~200 ft east of Kerber Dr, and an unimproved road east of Kerber Dr reduces the length of new trail that would need to be built to ~40 ft. Without this option, those on Panorama Dr, including evacuees from several hotels adjacent to Highway 101, must travel north to 11th St (see **Figure 3-3**) or south to Pacific Vista Dr at minimum evacuation speeds of ***jog*** and ***run*** (**Figure 3-5**, **left**). **Figure 3-14** demonstrates the slight slower required evacuation speeds that come with a new safety destination east of Kerber Dr along with the creation of a new evacuation flow zone. While this scenario yields only slight decreases in evacuation speeds, it does provide a shorter and more direct route to safety which could minimize confusion and be easier to message. The fact that Kerber Dr itself is outside of the Large tsunami zone (discussed in section 3.6.1) further reinforces our recommendation to direct people here instead of 11th St or Pacific Vista Dr.

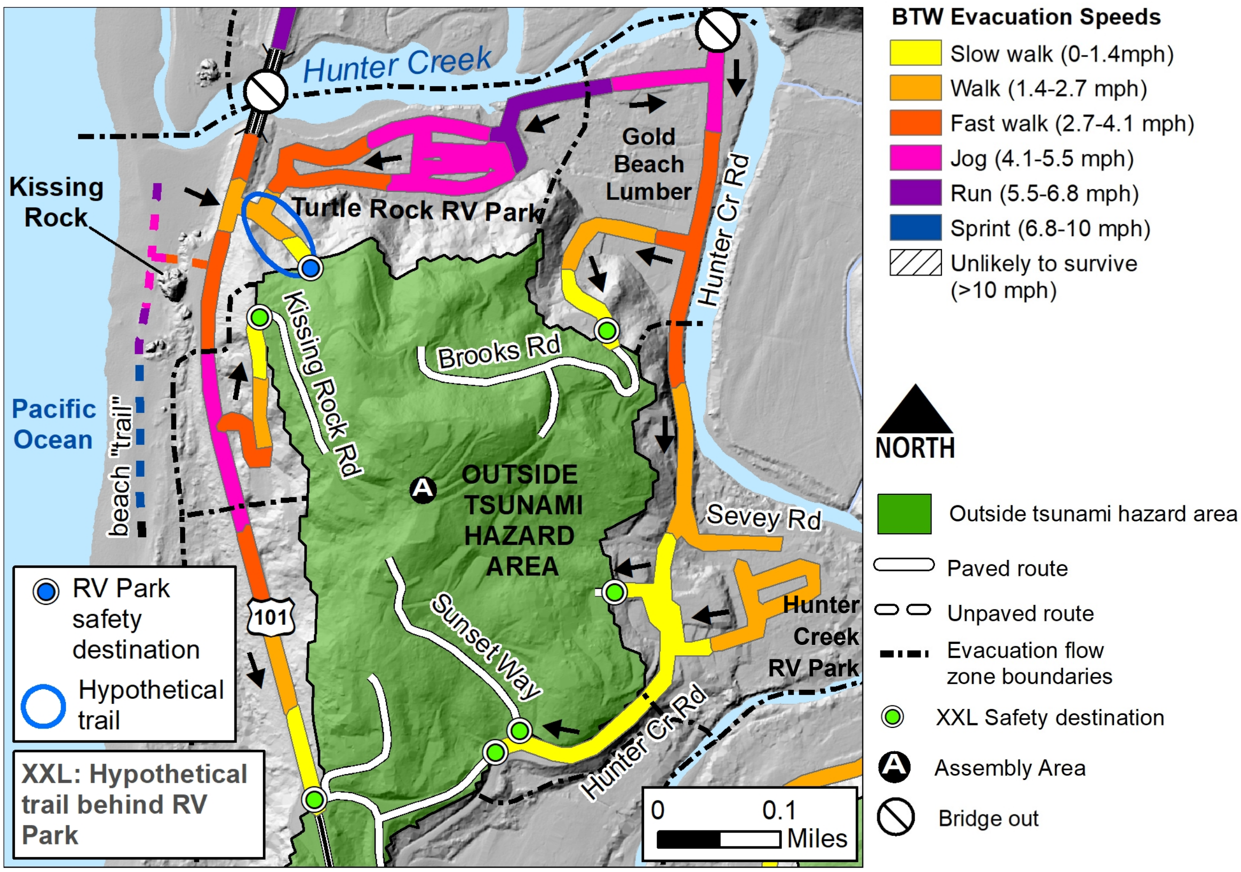
Figure 3-14. *Beat the Wave* modeling in South Gold Beach for a hypothetical trail east of Kerber Drive.



3.3.2 North Hunter Creek

Due to the needed BTW speeds for the current conditions scenario at Turtle Rock RV Park (**Figure 3-6, left**) and reliance on roads that may experience significant liquefaction or lateral spreading, we strongly believe that construction of a new trail providing access to nearby high ground should be evaluated. The terrain is very steep; ultimately, through discussion with Curry County staff, we chose a location in the southwest corner of the campground that has a slightly lower slope and where there may already be a rough trail. However, this area may experience surficial debris runoff of upslope soil, rocks, and vegetation that shakes loose during the earthquake. Although trail construction in this area would be challenging, **Figure 3-15** demonstrates the tangible improvements such a trail can provide for the campground, with minimum evacuation speeds falling from ***sprint*** for current conditions to ***fast walk*** and ***jog***.

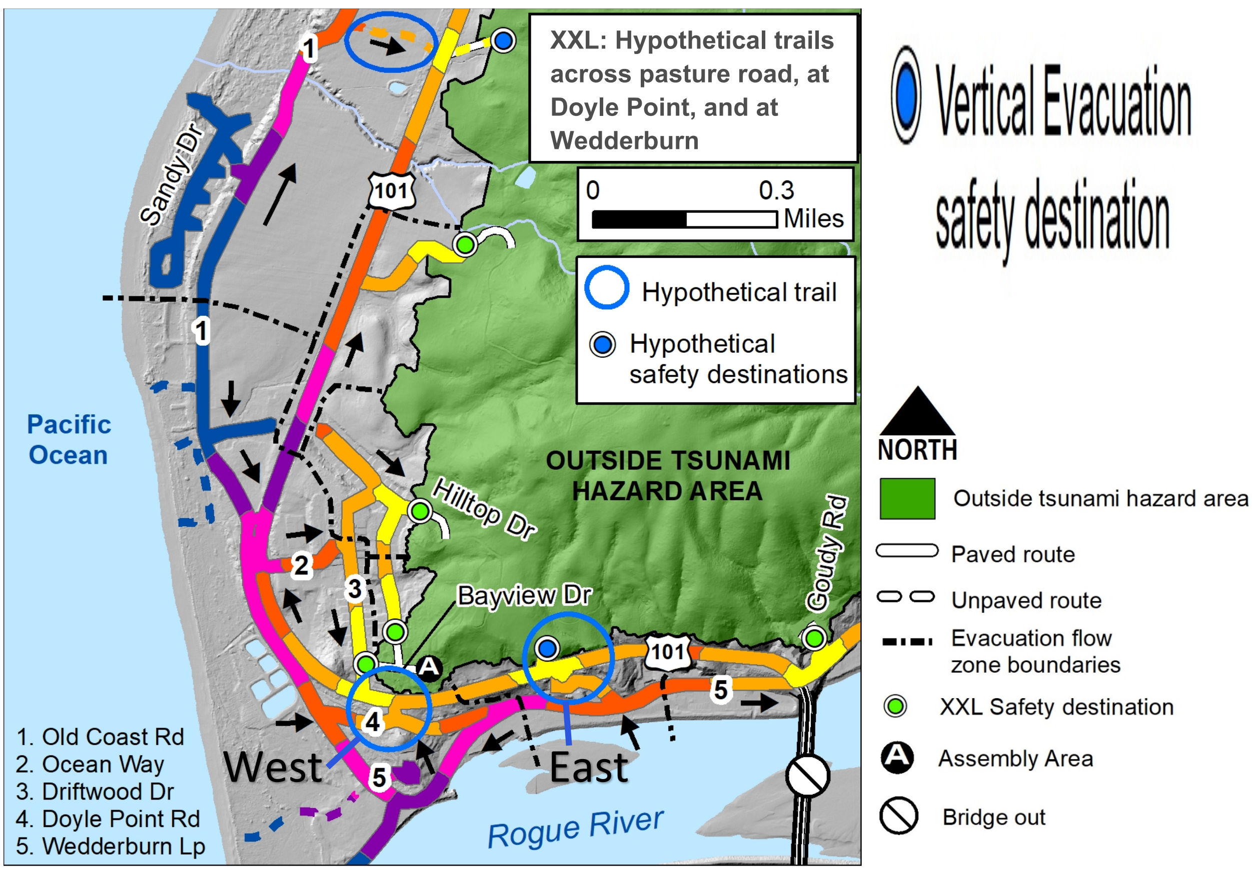
Figure 3-15. ***Beat the Wave*** **modeling in North Hunter Creek for a hypothetical trail at Turtle Rock RV Park.**



3.3.3 Rogue Shores

The ability to evacuate due east from Rogue Shores to Highway 101 via a hypothetical trail across a pasture appears reasonable because it would reduce the total distance required to reach high ground. We chose the location of this path to coincide with a farm road that already crosses the pasture and has simple cow gates at either end, providing a break in the barbed wire that characterizes the rest of the pasture margin. The path also coincides with a driveway on the east side of Highway 101 that leads directly to high ground (~400 ft east of Highway 101). We recognize that this scenario is unlikely to be realized due to private property issues. We chose to include it because in a tsunami evacuation situation as serious as that of Rogue Shores, every option must be examined. However, our evacuation modeling demonstrates that although the accompanying travel speed is reduced relative to the original XXL current conditions scenario (**Figure 3-9**, top left), the overall speed required to reach safety (***sprint,*** **Figure 3-16**) remains high. This suggests that this option is probably not viable and that other options should be evaluated.

Figure 3-16. ***Beat the Wave*** **modeling in Rogue Shores and Wedderburn for hypothetical evacuation trails. Also see Figure 3-17 for more detail in the areas of the hypothetical West and East shortcut routes.**



3.3.4 Wedderburn

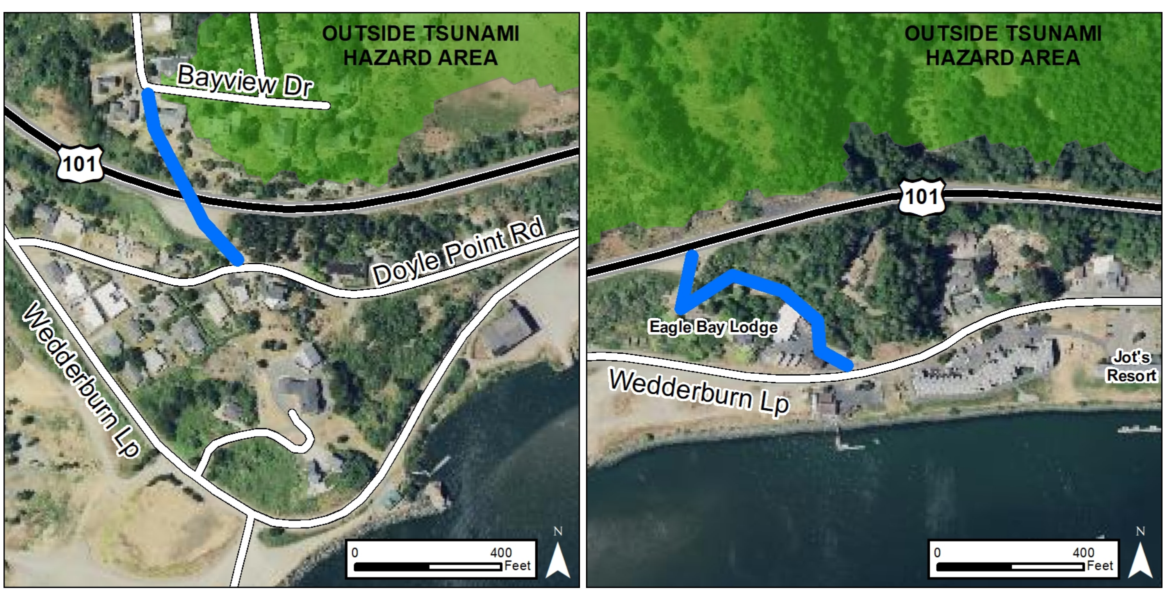
An obvious approach that could be taken in the Wedderburn area is to travel cross-country (as opposed to staying on roads) in order to reach adjacent high ground. As can be seen from **Figure 3-16**, high ground in many places is located adjacent to the roads. If an evacuee can take shortcuts between roads and scramble up the hillside on Highway 101, evacuation routes can be reduced in length by as much as 75%. Author Gabel and Jeremy Dumire (Curry County Emergency Manager) explored this area in depth to confirm the ability for people to take a more direct route to high ground via the following two sets of shortcuts:

WEST:
1. Doyle Point Rd to Highway 101 (where the two roads are only separated by ~200 feet)
2. Highway 101 by Doyle Point Rd to Bayview Dr (scramble up the hillside)

EAST:
1. Wedderburn Loop to Highway 101 through the Eagle Bay Lodge property
2. Highway 101 by the Eagle Bay Lodge property to safety just off the road (scramble up the hillside)

As demonstrated in **Figure 3-16** and shown in more detail in **Figure 3-17**, these shortcuts dramatically reduce minimum travel speeds necessary to survive the tsunami. Doyle Point Rd speed drops from ***sprint*** to ***walk***, and speed at the west end of Wedderburn Loop drops to ***run***. East of Doyle Point, Wedderburn Loop uniformly drops one speed classification: areas of ***run*** drop to ***jog*** and areas of ***jog*** reduce to ***walk*** and ***fast walk***.

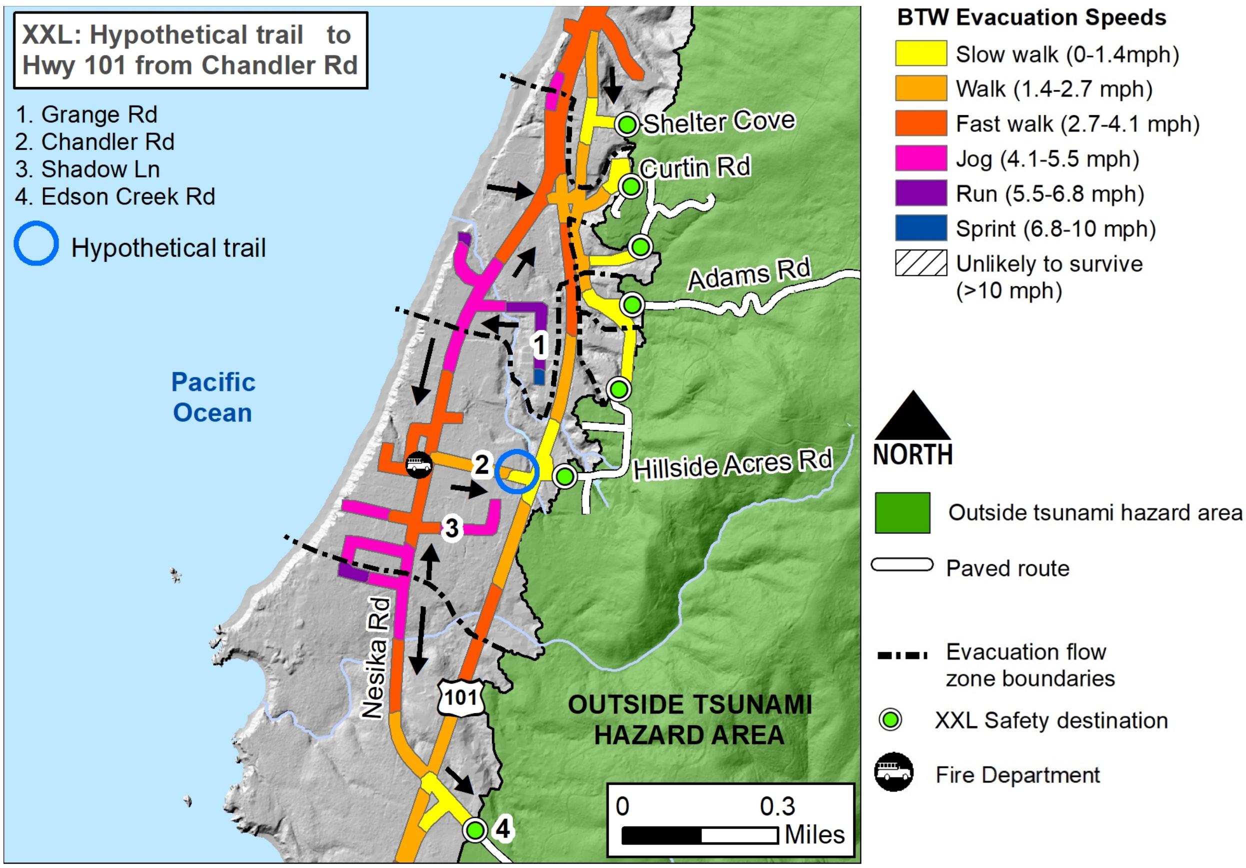
Figure 3-17. Aerial imagery showing (left) WEST shortcut and (right) EAST shortcut in more detail. Blue line traces approximate shortcut routes. Aerial imagery source: ArcGIS Image Service, OSIP_2018/OSIP_2018_WM, via Oregon Explorer website.



3.3.5 Nesika Beach

A trail connecting Chandler Rd with Highway 101 improves evacuation for everyone in south and central Nesika Beach by removing the need to travel all the way to the north or south end of the community to cross Highway 101 and reach safety on the other side. Evacuation distances are reduced by as much as 75% with this shortcut, and minimum evacuation speeds for much of the community are reduced to ***jog*** or slower (**Figure 3-18**).

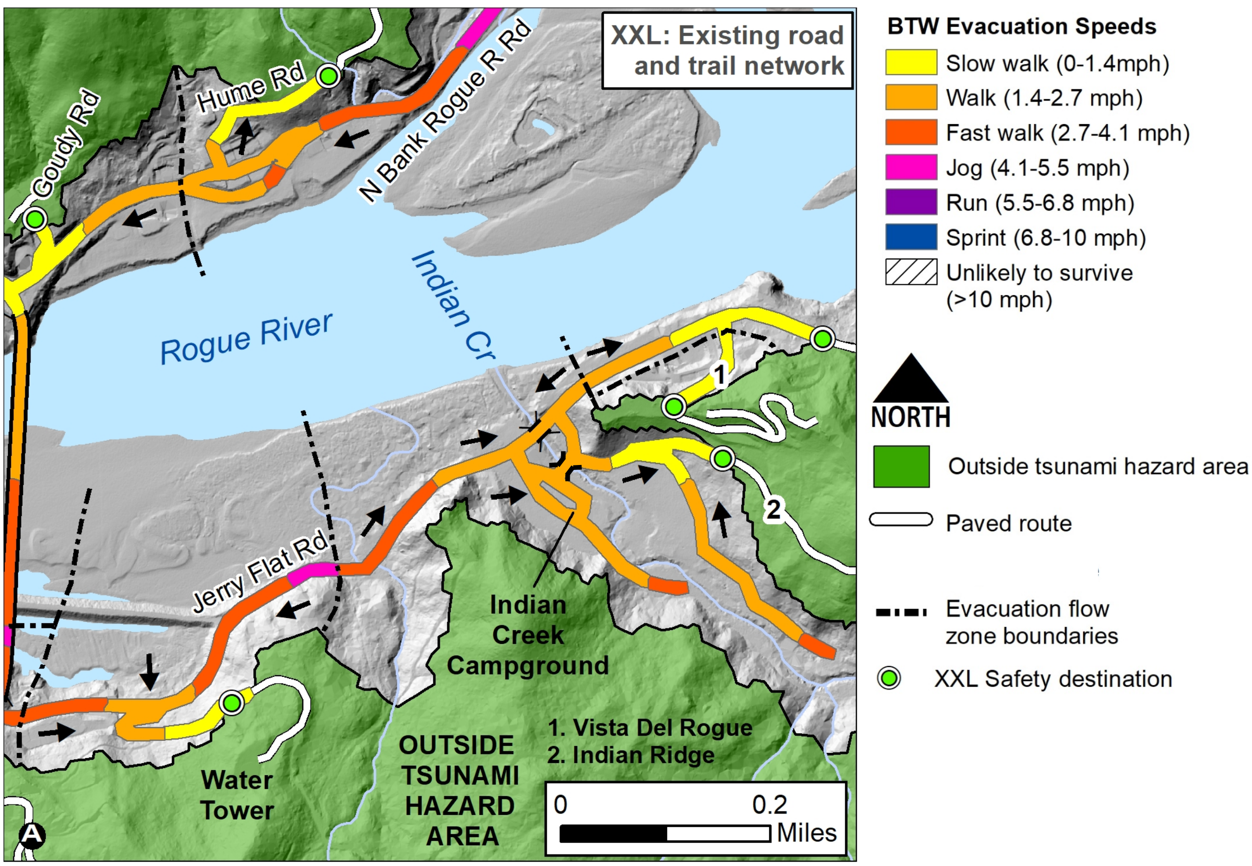
Figure 3-18. ***Beat the Wave*** **modeling in Nesika Beach for a hypothetical trail between Chandler Rd and Hwy 101.**



3.4 Bridge retrofit at Indian Creek

As discussed in section 3.1.6, evacuees at the Indian Creek Campground and Café should not attempt to seek high ground at the water tower because it is a long distance to travel, it is in the direction of the incoming tsunami, and the road will likely be compromised due to lateral spreading and liquefaction. The only other option is to ensure that evacuees on the west side of Indian Creek can cross the creek, either by the bridge on Jerrys Flat Rd, by the footbridge within the campground, or by a structure not yet built. **Figure 3-19** demonstrates the significant potential reduction in evacuation speeds if the bridges are accessible. The campground and café require minimum travel speeds of a ***walk*** (4 fps, or 2.7 mph). This alternative route is modeled for the Large tsunami scenario in section 3.6.2; both sets of results emphasize how important it is for at least one path across the creek to remain available for those at the campground and café.

Figure 3-19. ***Beat the Wave*** **modeling in Indian Creek for hypothetical seismic retrofits of Jerrys Flat Rd bridge and campground footbridge, both over Indian Creek.**



3.5 Evacuation delay

When exploring ways to reduce the potential for tsunami fatalities, any effort directed at reducing people's milling time (evacuation delay) will save lives. Here we re-evaluate the XXL current conditions scenario with a 5-minute evacuation delay compared with the original 10-minute delay. The reduction in response time produces a significant decrease in the required evacuation speed for the entire region. Most locations see a reduction of approximately one speed category (i.e., minimum travel speed of ***jog*** reduced to ***fast walk***), while South Gold Beach and Nesika Beach are reduced by two speed categories. Results for North, Central, and South Gold Beach, North Hunter Creek, Rogue Shores, Wedderburn, and Nesika Beach are presented in **Figure 3-20** through **Figure 3-25**. Results are not presented for South Hunter Creek or Indian Creek because minimum travel speeds for the current conditions scenario are already sufficiently low (assuming Indian Creek can be crossed). The 5-minute-delay scenario demonstrates the importance of leaving as soon as possible as delay costs lives.

Figure 3-20. ***Beat the Wave*** **modeling in North Gold Beach for the XXL scenario with a reduced evacuation delay (5 minutes instead of the standard 10 minutes).**

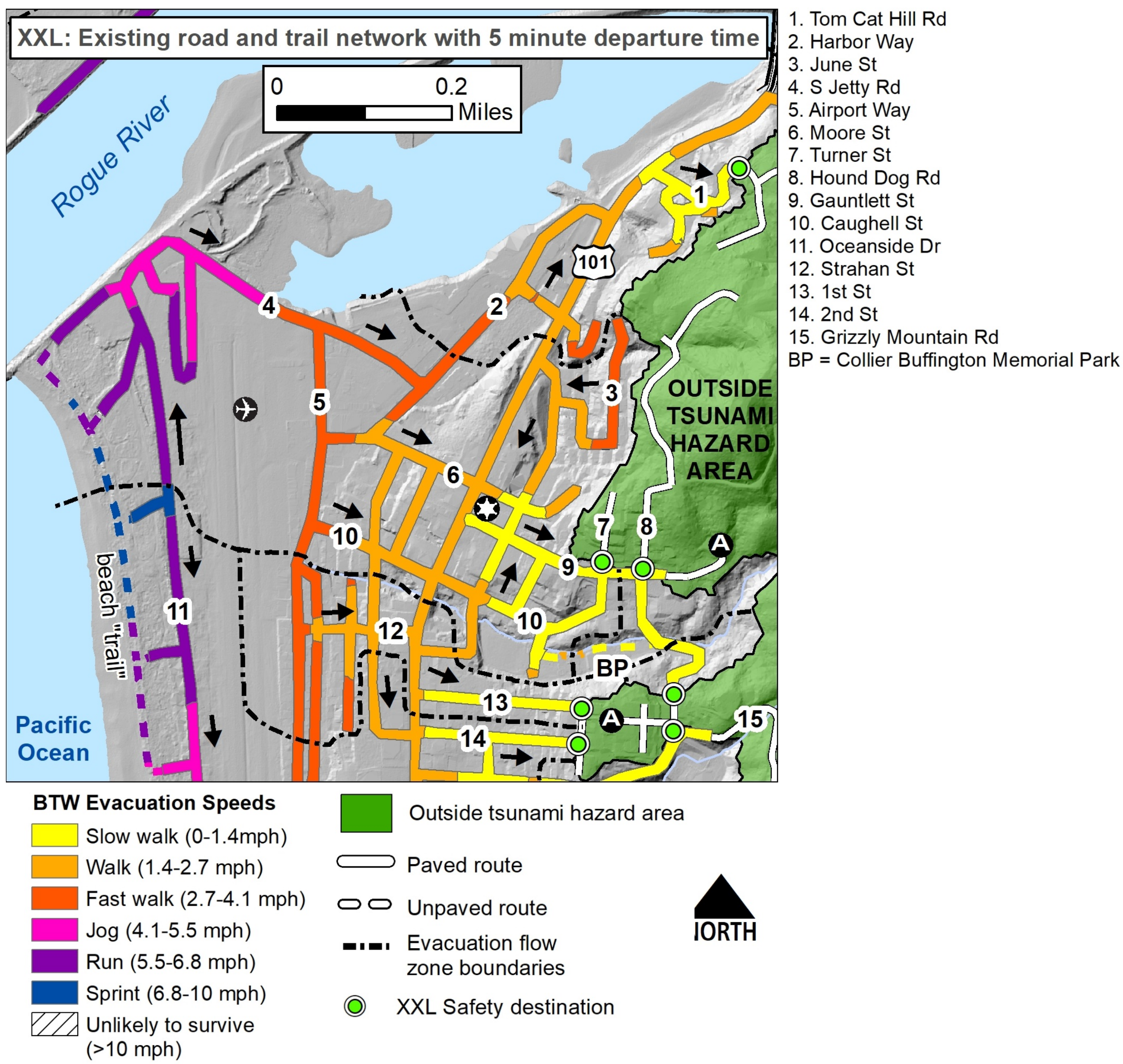


Figure 3-21. ***Beat the Wave*** **modeling in Central Gold Beach for the XXL scenario with a reduced evacuation delay (5 minutes instead of the standard 10 minutes).**

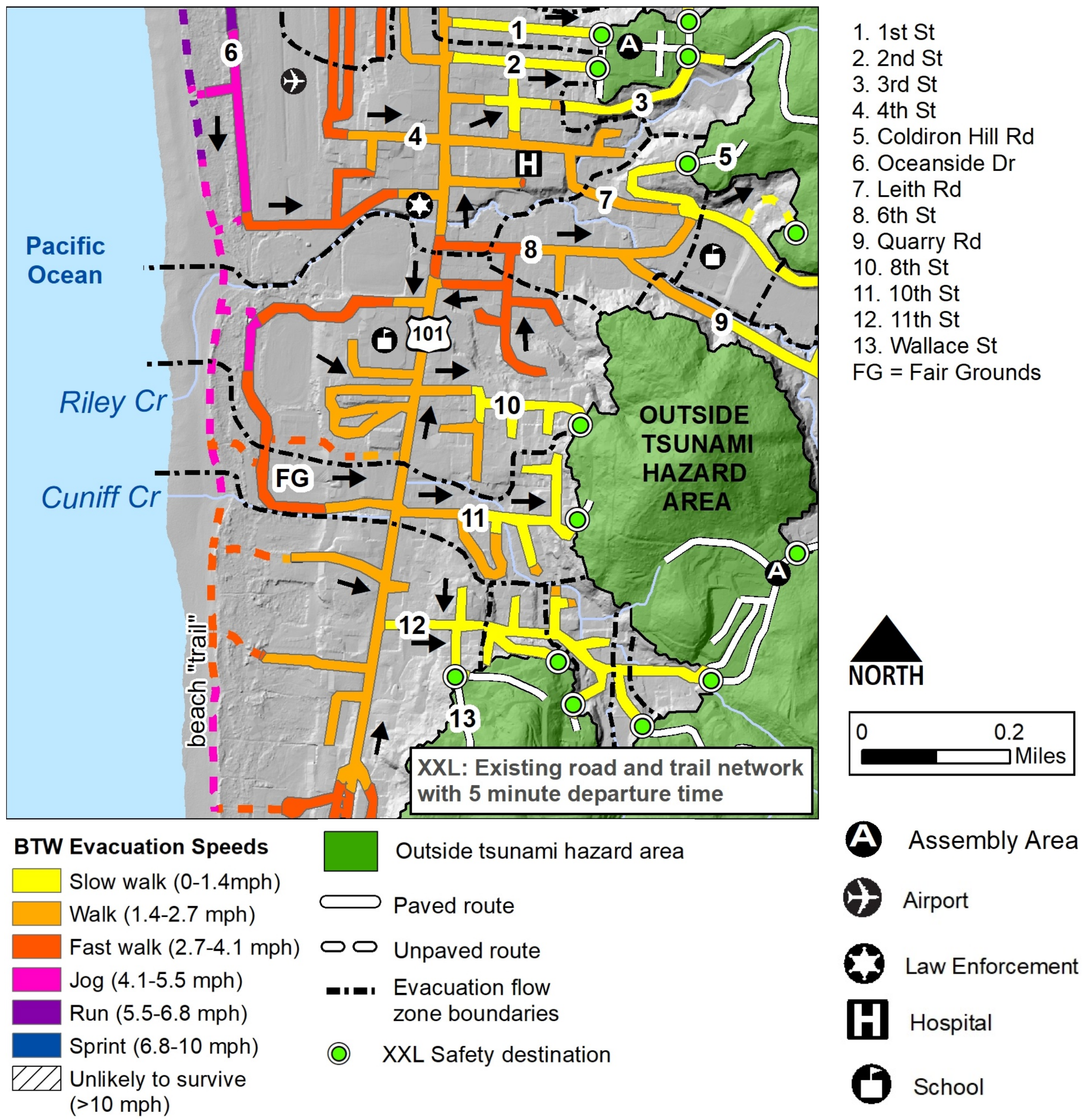


Figure 3-22. ***Beat the Wave*** **modeling in South Gold Beach for the XXL scenario with a reduced evacuation delay (5 minutes instead of the standard 10 minutes).**

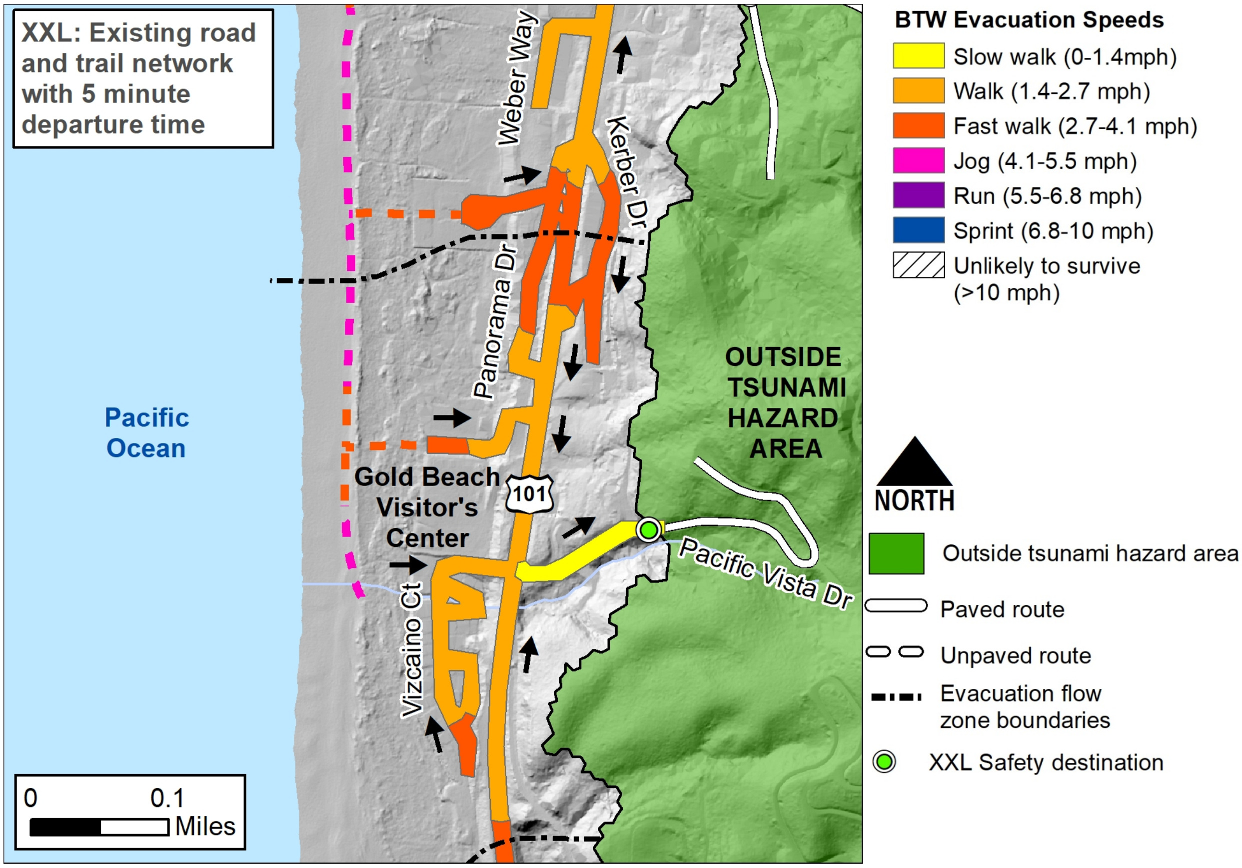


Figure 3-23. ***Beat the Wave*** **modeling in North Hunter Creek for the XXL scenario with a reduced evacuation delay (5 minutes instead of the standard 10 minutes).**

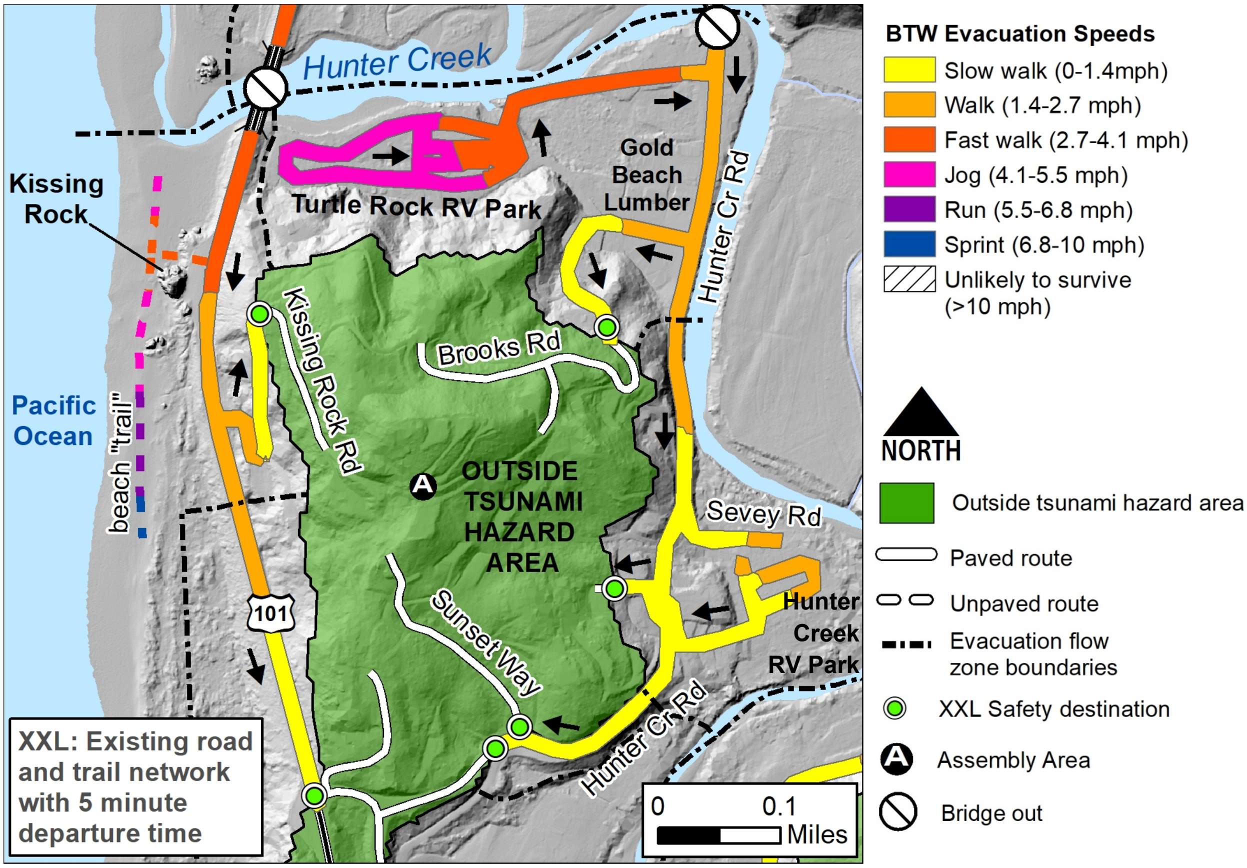


Figure 3-24. ***Beat the Wave*** **modeling in Rogue Shores and Wedderburn for the XXL scenario with a reduced evacuation delay (5 minutes instead of the standard 10 minutes).**

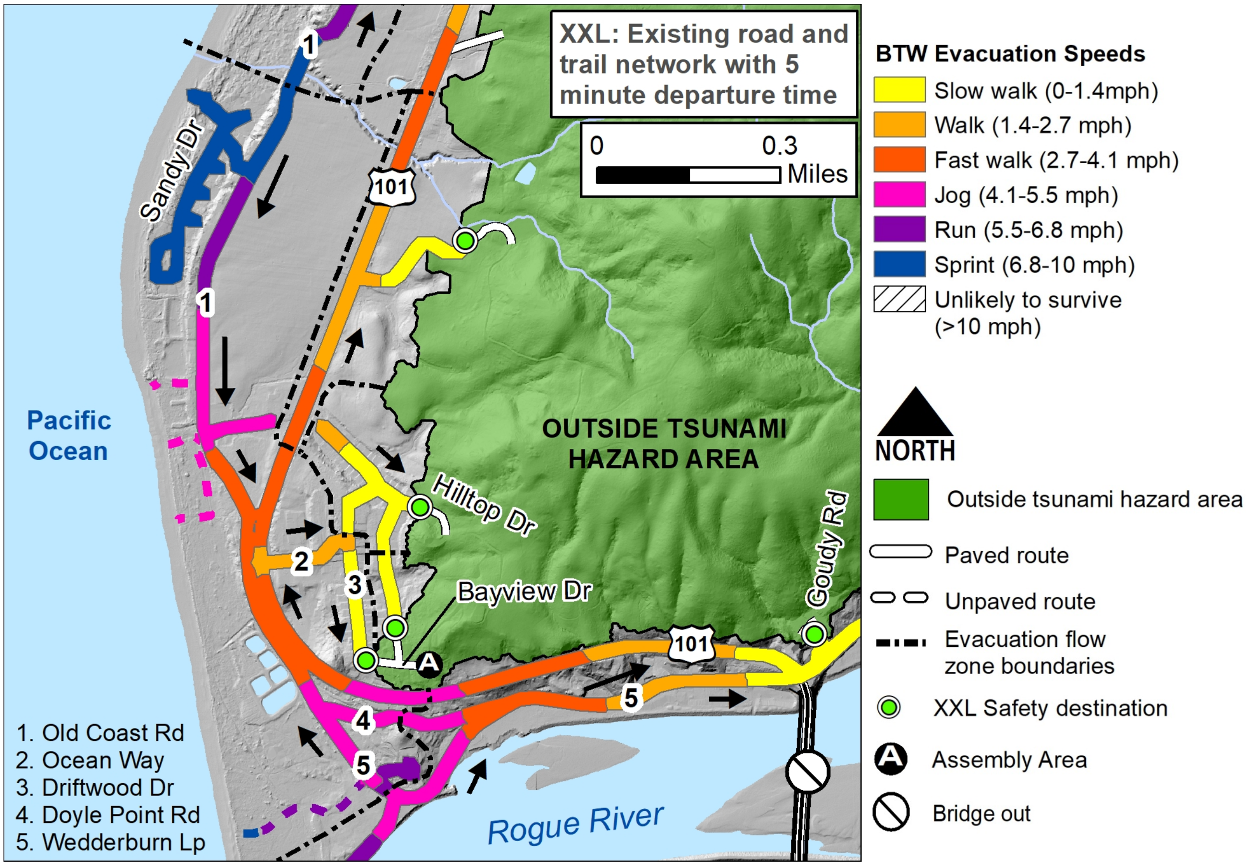
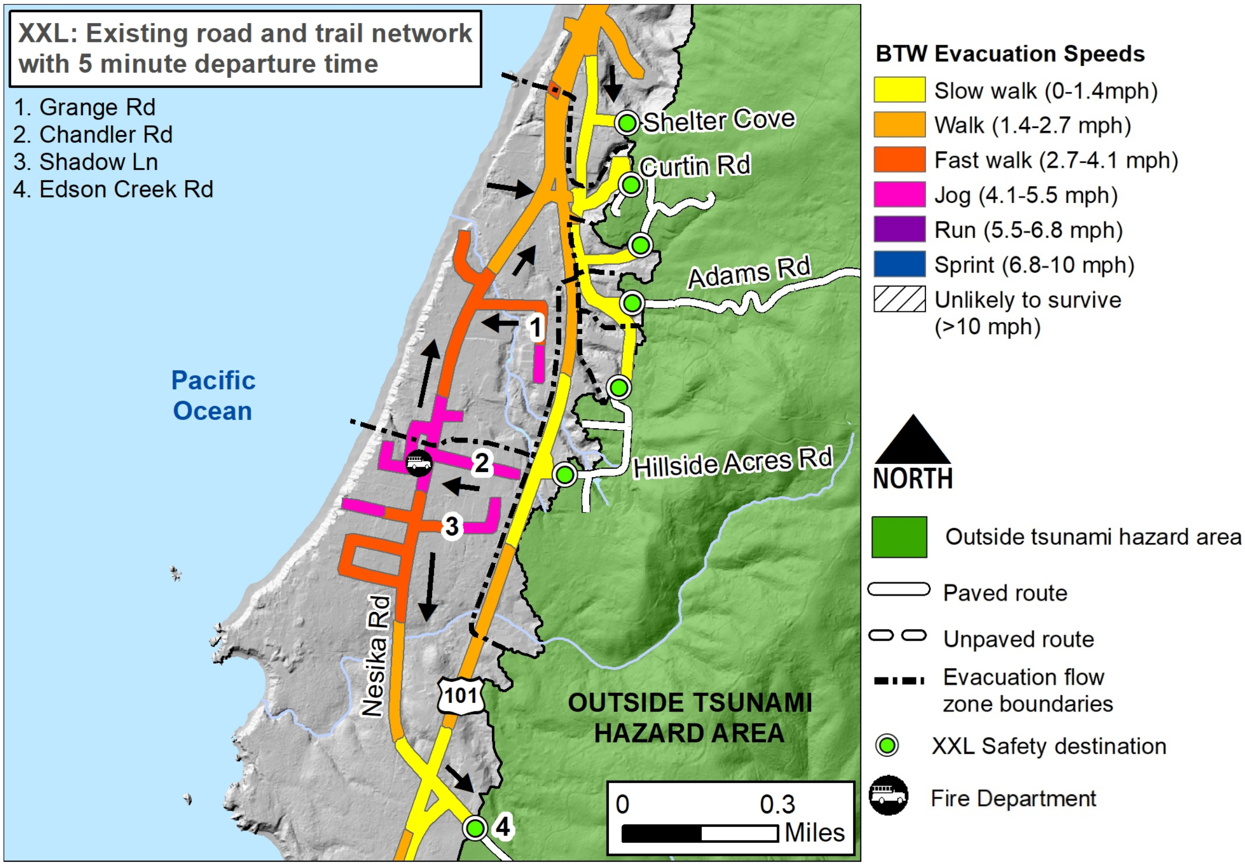


Figure 3-25. ***Beat the Wave*** **modeling in Nesika Beach for the XXL scenario with a reduced evacuation delay (5 minutes instead of the standard 10 minutes).**



3.6 Large tsunami zone

The Large tsunami scenario, which reflects ~95% of the modeled tsunami inundation, produces a slightly smaller inundation zone when compared with XXL. Another way to consider this is that there is a ~5% chance that the next CSZ tsunami could extend beyond the Large tsunami zone. With the Large scenario, safety is effectively shifted westward and/or downhill on all roads, reducing required travel distances to safety. This shift may reduce the physical and sometimes mental barrier some people may have about evacuating from the tsunami zone. The goal for any person evacuating a tsunami zone in the greater Gold Beach area is to at minimum aim for safety outside of the Large tsunami inundation zone and, if at all possible, continue beyond that until they reach the XXL tsunami limit; evacuation is in the same direction for both. Messaging and signage should therefore remain focused on reaching the XXL tsunami limit, acknowledging that every step toward the east beyond the Large tsunami inundation zone further increases a person's chance of surviving the tsunami. It is important that people understand they are choosing to accept a slightly higher risk level with the goal of evacuating outside of the Large zone rather than outside the XXL zone.

3.6.1 Gold Beach, Hunter Creek, and Nesika Beach

Figure 3-26 through **Figure 3-30** present minimum evacuation speeds required to reach safety from the Large tsunami zone for North, Central, and South Gold Beach, Hunter Creek, and Nesika Beach. The reduction in distances to safety produces a significant decrease in the required evacuation speed for the entire region when compared with the XXL current conditions scenario. Most locations see a reduction of approximately two speed categories (i.e., minimum travel speed of ***sprint*** reduced to ***jog***). The top panel presents minimum evacuation speeds and evacuation flow zones, while the bottom panel presents the inundation zones for XXL and Large, highlighting the differences in the tsunami zones.

Figure 3-26. (top) *Beat the Wave* modeling in North Gold Beach for the Large tsunami scenario. (bottom) XXL and Large tsunami inundation zones. Note that the XXL zone extends under the Large zone.

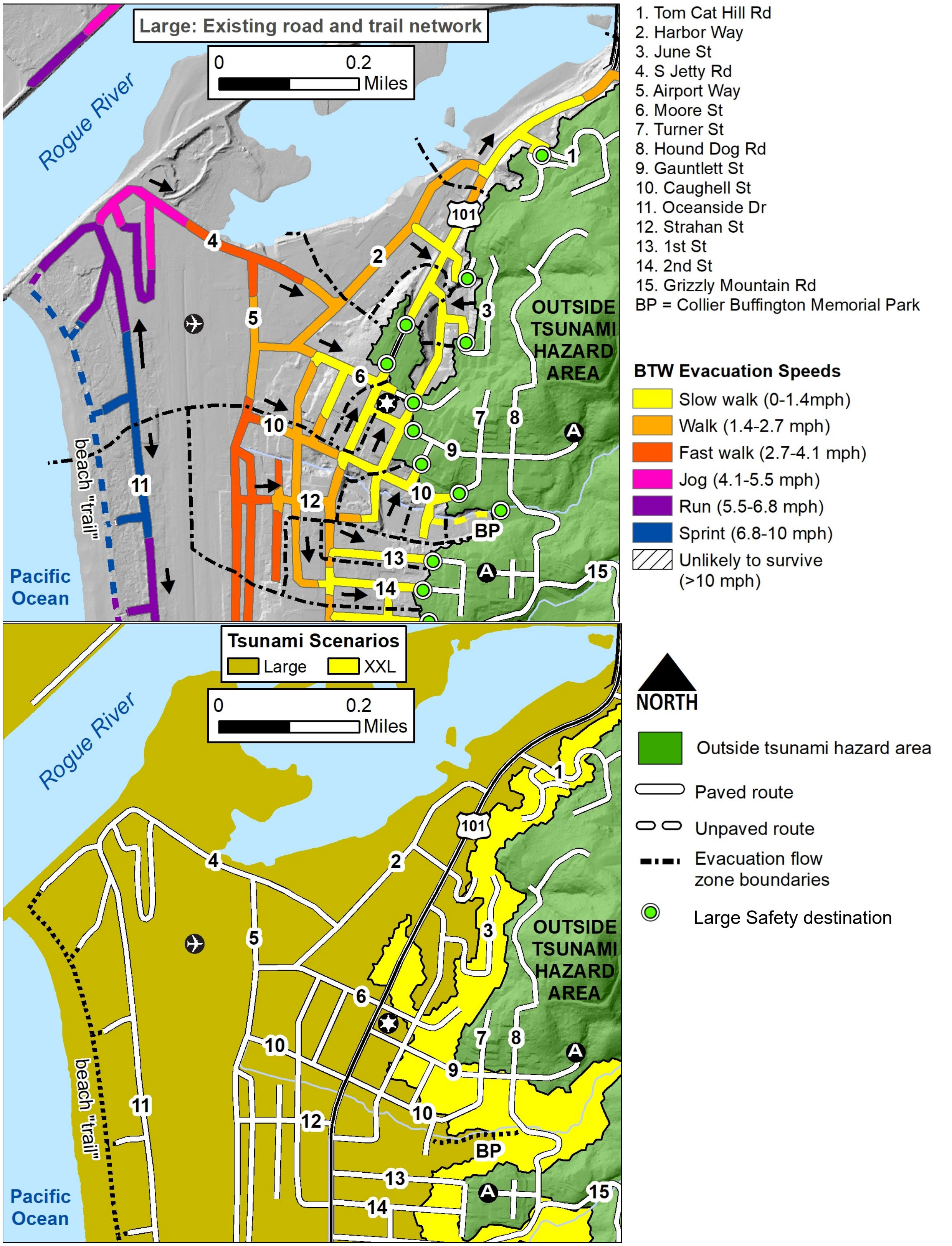


Figure 3-27. (top) *Beat the Wave* modeling in Central Gold Beach for the Large tsunami scenario. (bottom) XXL and Large tsunami inundation zones. Note that the XXL zone extends under the Large zone.

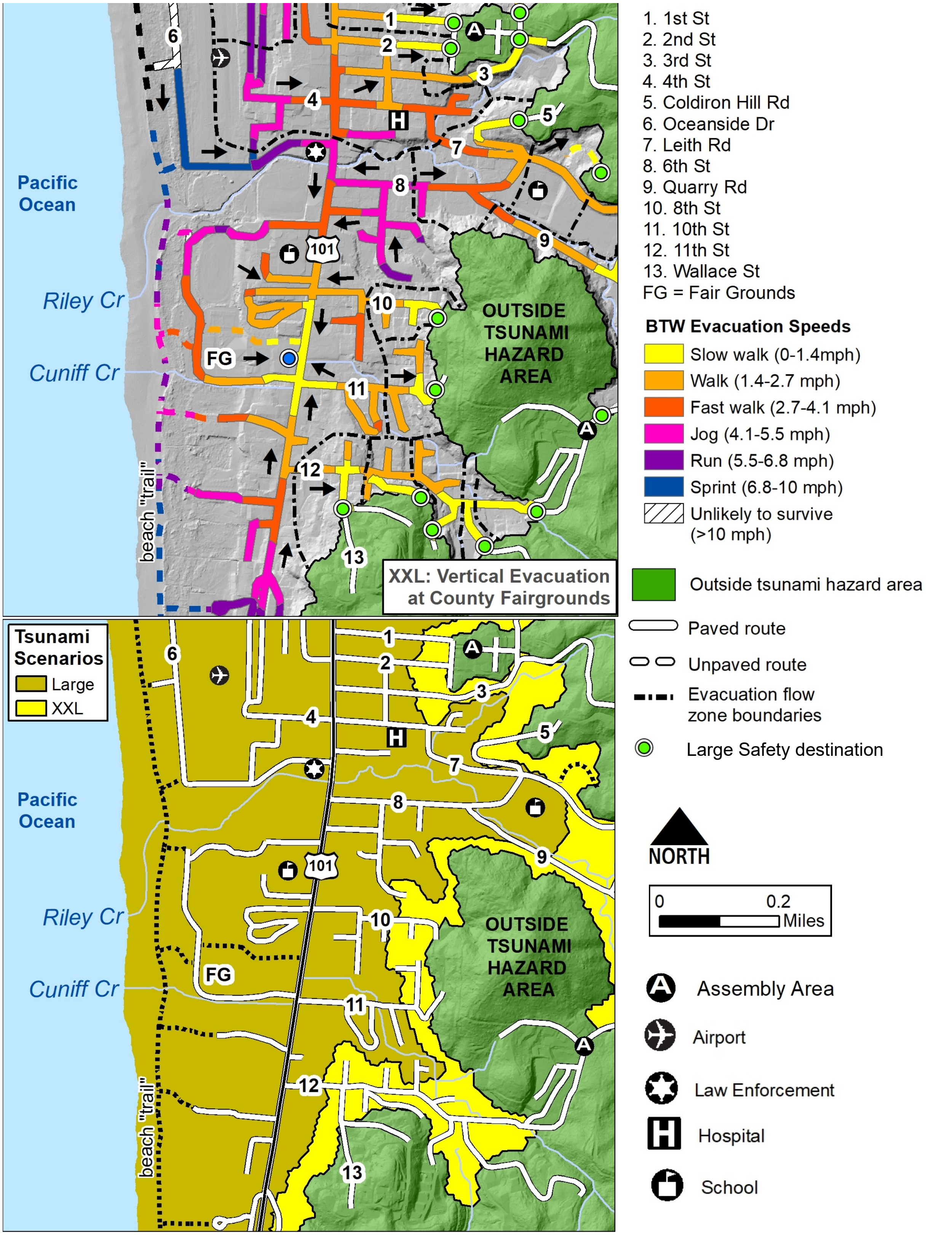


Figure 3-28. (top) *Beat the Wave* modeling in South Gold Beach for the Large tsunami scenario. (bottom) XXL and Large tsunami inundation zones. Note that the XXL zone extends under the Large zone.

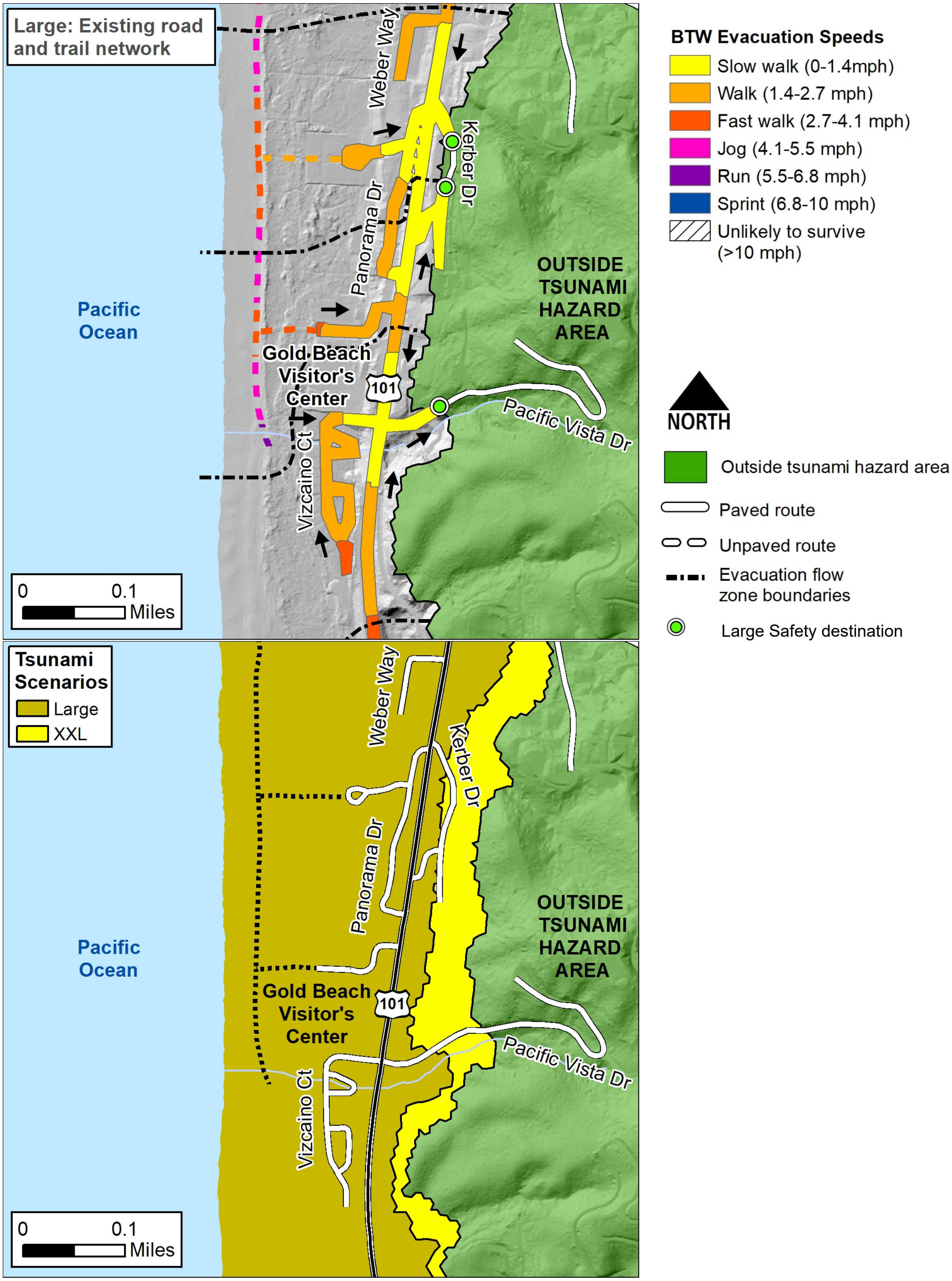


Figure 3-29. (top) *Beat the Wave* modeling in North Hunter Creek for the Large tsunami scenario. (bottom) XXL and Large tsunami inundation zones. Note that the XXL zone extends under the Large zone.

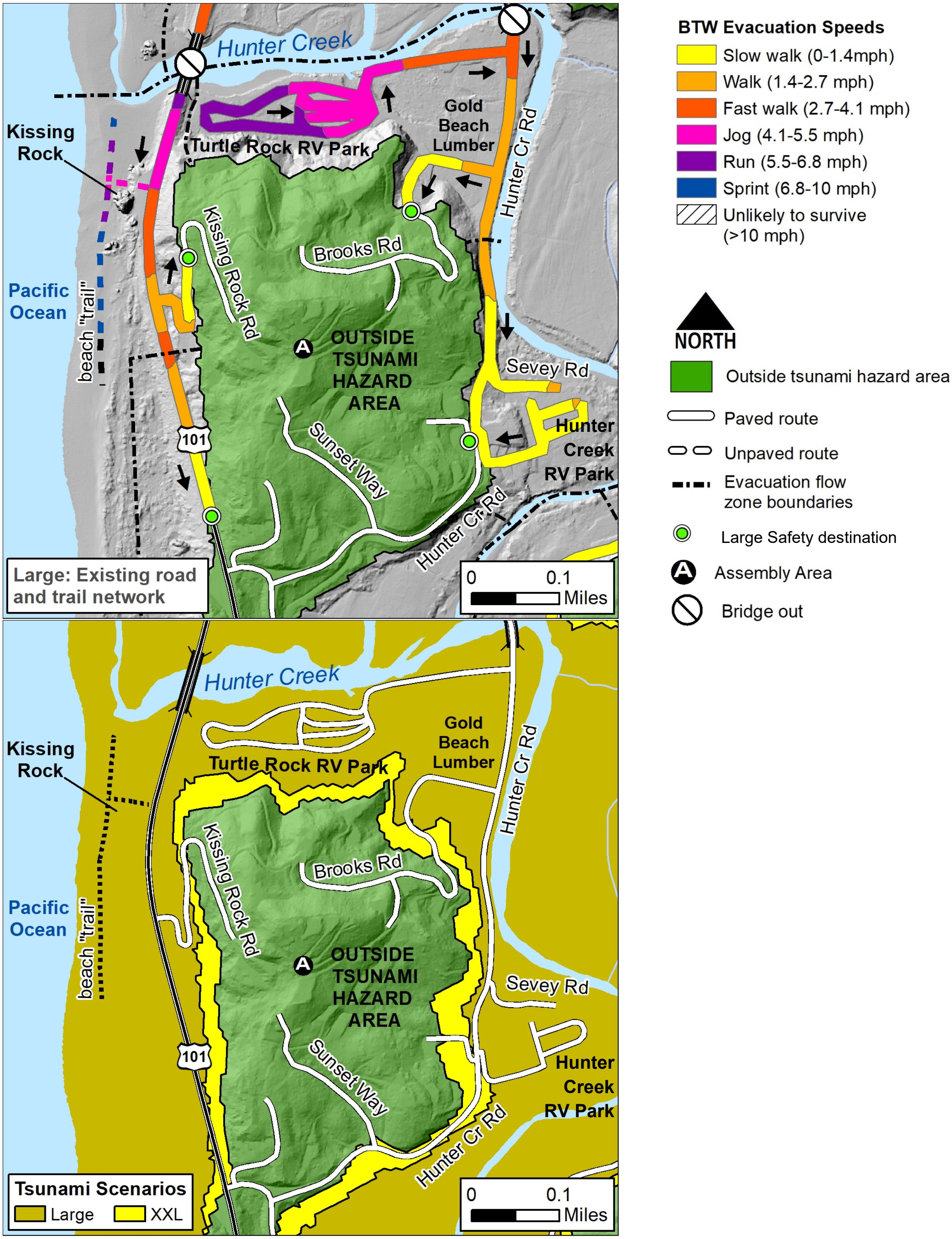
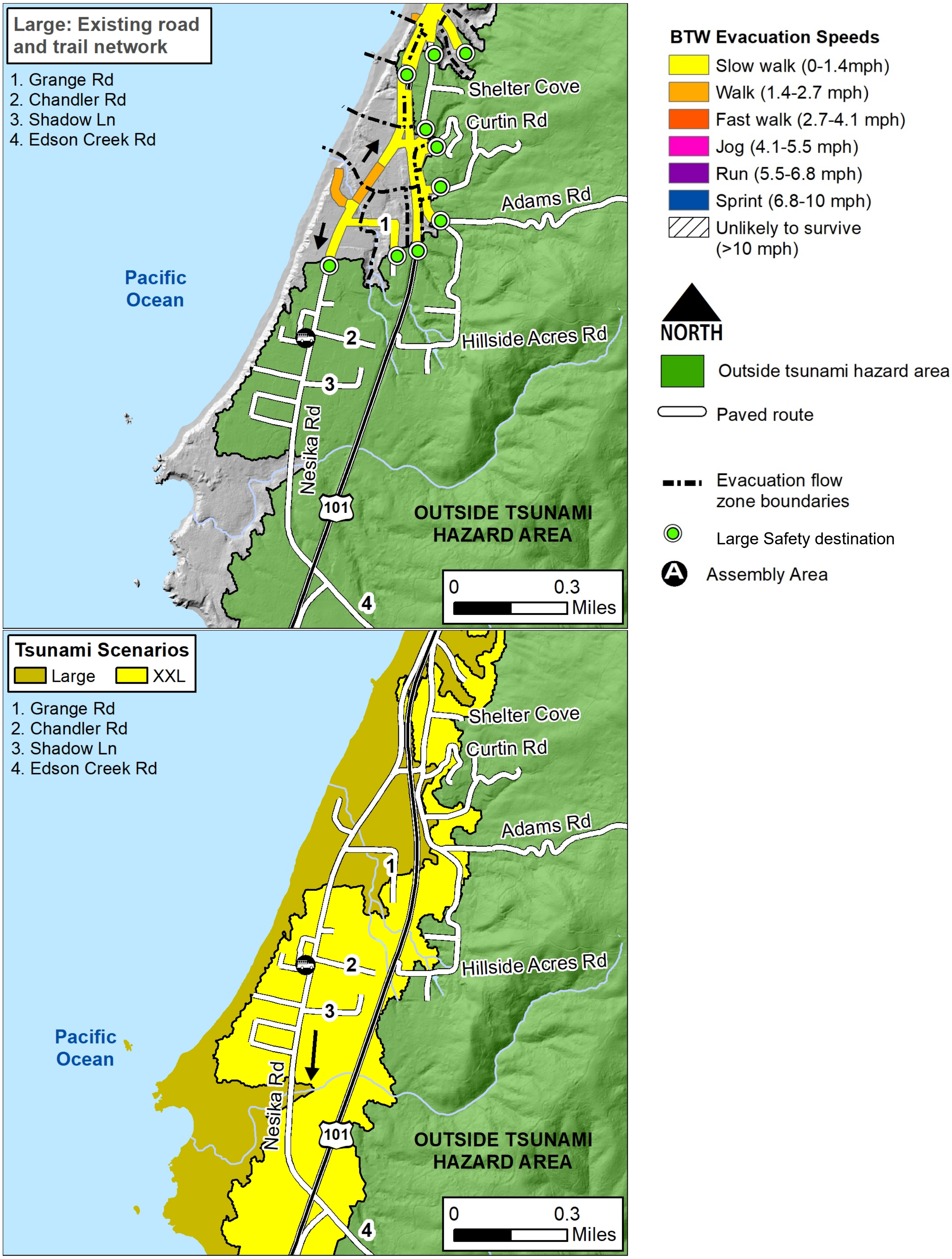


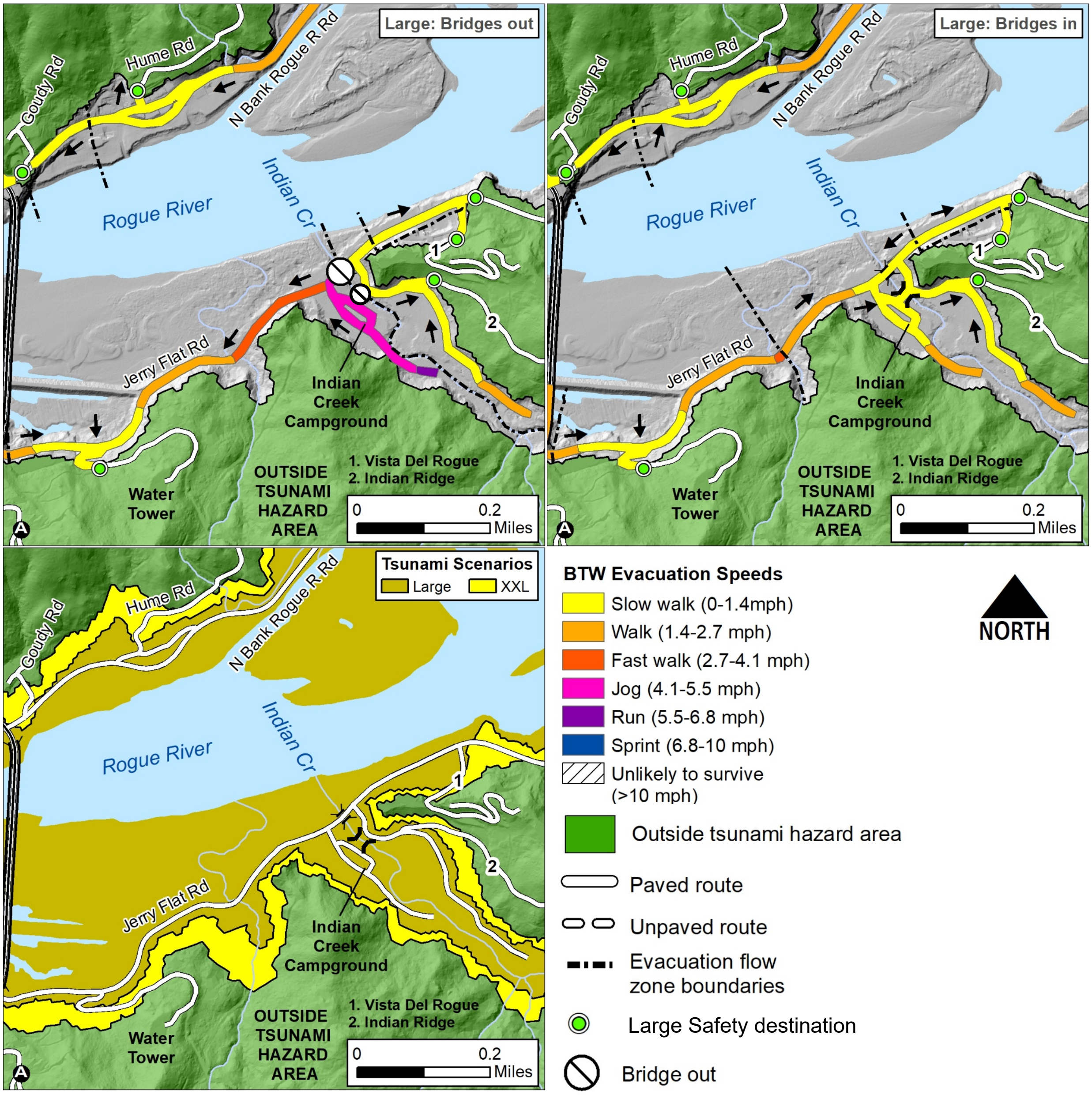
Figure 3-30. (top) *Beat the Wave* modeling in Nesika Beach for the Large tsunami scenario. (bottom) XXL and Large tsunami inundation zones. Note that the XXL zone extends under the Large zone.



3.6.2 Indian Creek

As discussed in section 3.4, passable bridges are very important for Indian Creek Campground and Café. This is as true for the Large tsunami scenario as it is for XXL. Without the ability to cross Indian Creek and assuming evacuees remain on the roads, the nearest safety destination is the water tower. Regardless of which tsunami zone is chosen, the water tower is a poor safety destination for reasons previously discussed. Therefore, we present Large BTW results for bridges “out” and “in” to further emphasize the improvements that come from ensuring the creek can be crossed via one of the current bridges (Jerrys Flat Rd and campground footbridge) or some alternative route (i.e., fording creek on foot or a new seismically retrofitted bridge). Without bridges, evacuees at the campground must travel at a minimum speed of ***jog*** to reach the water tower in the Large tsunami scenario (**Figure 3-31**, top left). If Indian Creek can be crossed, however, the minimum speed for the area drops to ***slow walk*** (**Figure 3-31**, top right). **Figure 3-31**, bottom presents the inundation zones for the XXL and Large scenarios, highlighting the differences in the tsunami zones.

Figure 3-31. ***Beat the Wave*** **modeling in Indian Creek for the Large tsunami scenario. (top left) Bridges out (top right Bridges in. (bottom) XXL and Large tsunami inundation zones. Note that the XXL zone extends under the Large zone.**

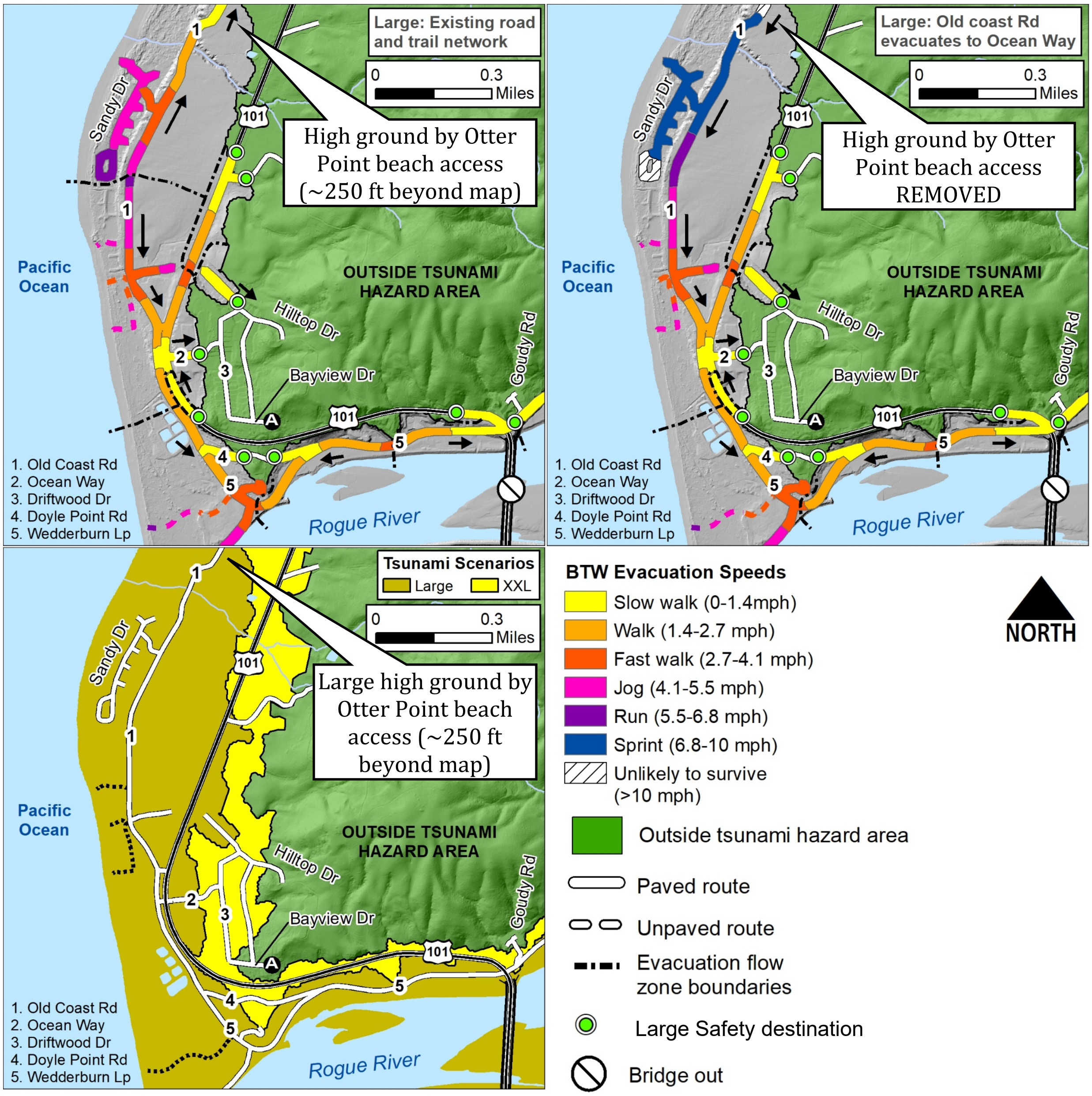


3.6.3 Rogue Shores and Wedderburn

As discussed at the start of this section, evacuating to the Large tsunami zone reduces required travel distances to safety while adding a small level of risk that the tsunami could be larger and thus extend beyond that zone. The nearest point of safety from the Large tsunami for Rogue Shores is reached at the Otter Point beach access, ~0.5 miles north on Old Coast Rd (**Figure 3-32**, bottom). The second closest high ground is on Ocean Way, ~0.8 miles from Rogue Shores. While there is no XXL high ground on or near Old Coast Rd, XXL high ground can be reached on Ocean Way by continuing east another ~1,000 ft. **Figure 3-32, top left** demonstrates the significant decrease in evacuation speeds when safety is reached on Old Coast Rd compared with the XXL current conditions scenario (**Figure 3-9**, top left), with Sandy Dr going from ***unlikely to survive*** to predominantly ***jog***. The choice to evacuate to a closer but slightly less secure safety destination reflects an individual's risk tolerance. Thus, another approach is to focus on reaching safety outside of the Large zone on Ocean Way and, once there, continue to evacuate east until one reaches the XXL tsunami limit. **Figure 3-32, top right**, however, demonstrates the ineffectiveness of this plan, with Sandy Dr still requiring minimum speeds of ***sprint*** to survive. **Figure 3-32**, bottom presents the inundation zones for XXL and Large, highlighting the differences in the tsunami zones.

As seen elsewhere in the region, minimum evacuation speeds required to reach safety from the Large tsunami zone for Wedderburn are significantly reduced when compared with the XXL current conditions scenario, from ***sprint*** to ***walk/fast walk*** (**Figure 3-32**, top left). However, the western half of Wedderburn is characterized by terrain challenges similar to those seen at Rogue Shores in that safety from the Large scenario can be found on Doyle Point Rd (and Highway 101), which is not the same route one would take to seek XXL high ground on Ocean Way. However, as discussed in section 3.3.4, there is a shortcut from Doyle Point Rd to Highway 101 that effectively makes the evacuation route for the Large and XXL scenarios the same, with safety from Large reached along the same route that ultimately reaches safety from XXL on the other side of Highway 101.

Figure 3-32. ***Beat the Wave*** **modeling in Rogue Shores and Wedderburn for the Large tsunami scenario. (top left) The complete inundation zone is used, which includes a small section of high ground on Old Coast Rd just north of the map. This safety destination is the nearest high ground for Rogue Shores. (top right) High ground on Old Coast Rd removed, forcing Rogue Shores to seek high ground on Ocean Way. (bottom) XXL and Large tsunami inundation zones. Note that the XXL zone extends under the Large zone.**



3.7 Liquefaction

As discussed in section 2.2, liquefaction is a site-specific hazard associated with earthquake shaking. Because we do not have the ability to predict precisely where liquefaction will occur, we present a conservative view of its effects guided by knowledge of the liquefaction potential (a function of the underlying geology and water table) along those streets that have a moderate or high liquefaction susceptibility. This entails modeling paved roads as if they were made of loose sand. This approach simulates the difficulty evacuees could encounter when trying to evacuate across roads covered with sand and mud produced from sand boils and other liquefaction features. Liquefaction BTW results demonstrate faster evacuation speeds required to reach high ground throughout the region when compared to the current conditions scenario. Evacuation speeds are especially large for locations far from high ground such as those adjacent to the beach. Results for all communities are presented in **Figure 3-33** through **Figure 3-40**. We recognize that liquefaction potential will be spatially variable throughout the region. We present these results merely to demonstrate that any impediments to immediate and swift evacuation will affect survivability.

Figure 3-33. ***Beat the Wave*** **modeling in North Gold Beach for a liquefaction scenario where roads and trails are significantly more difficult to walk on. All roads inside the XXL inundation zone are classified as having moderate to high liquefaction susceptibility except for Tom Cat Hill Rd (Madin and Burns, 2013).**

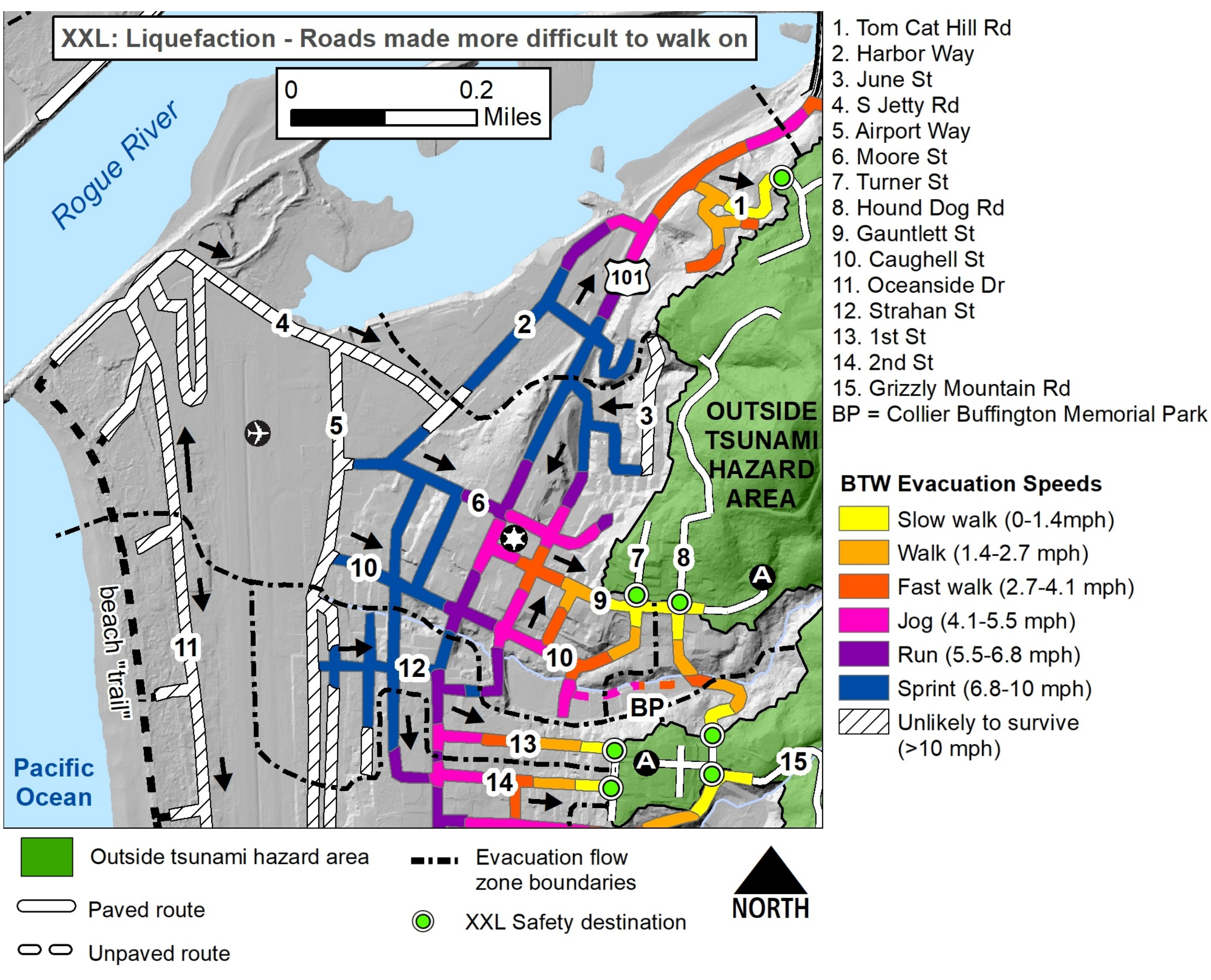


Figure 3-34. ***Beat the Wave*** **modeling in Central Gold Beach for a liquefaction scenario where roads and trails are significantly more difficult to walk on. All roads inside the XXL inundation zone are classified as having moderate to high liquefaction susceptibility except for southbound streets off 11th St (e.g., Wallace St) (Madin and Burns, 2013).**

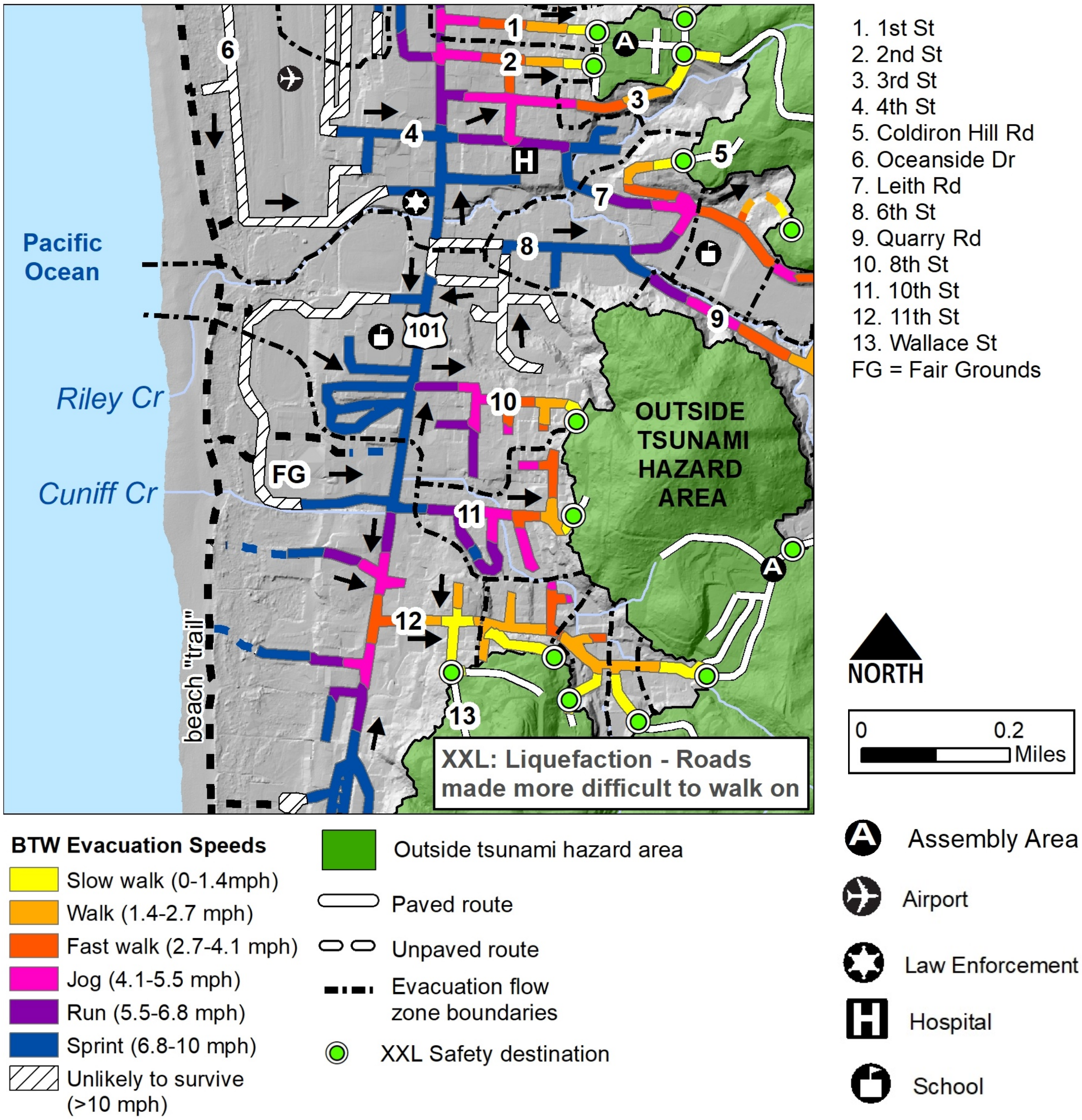


Figure 3-35. ***Beat the Wave*** **modeling in South Gold Beach for a liquefaction scenario where roads and trails are significantly more difficult to walk on. All roads inside the XXL inundation zone are classified as having moderate to high liquefaction susceptibility (Madin and Burns, 2013).**

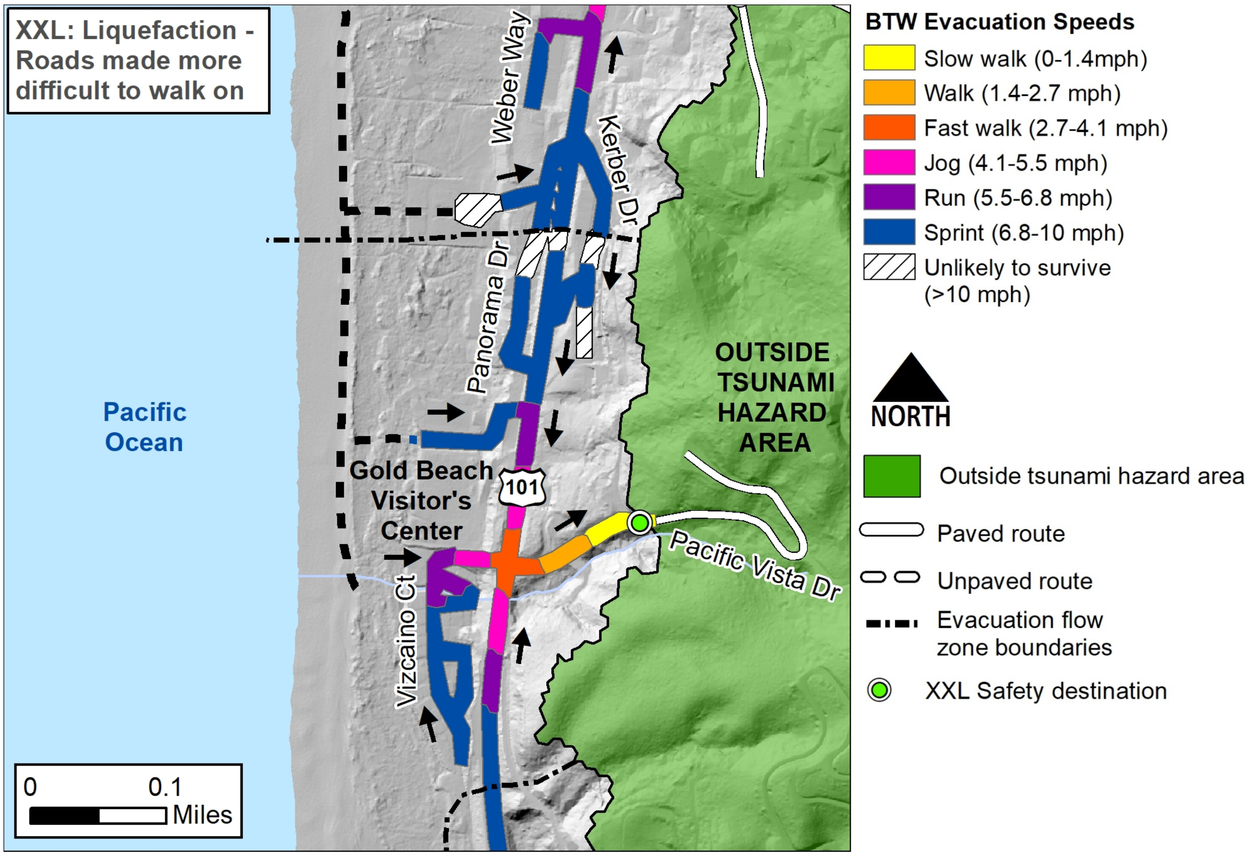


Figure 3-36. ***Beat the Wave*** **modeling in North Hunter Creek for a liquefaction scenario where roads and trails are significantly more difficult to walk on. All low-lying roads inside the XXL inundation zone are classified as having moderate to high liquefaction susceptibility including Highway 101, Hunter Creek Rd, and both RV parks (Madin and Burns, 2013).**

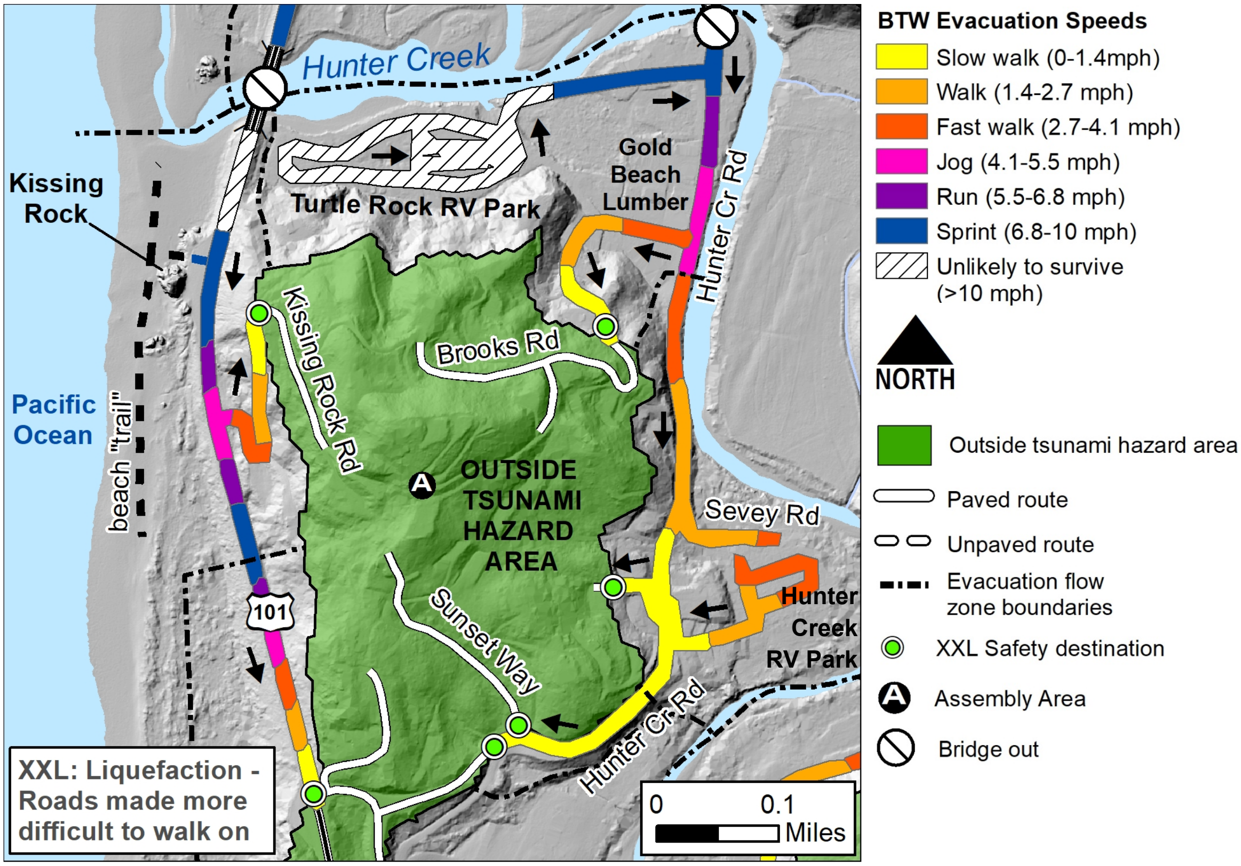


Figure 3-37. ***Beat the Wave*** **modeling in South Hunter Creek for a liquefaction scenario where roads and trails are significantly more difficult to walk on. All low-lying roads inside the XXL inundation zone are classified as having moderate to high liquefaction susceptibility including Hunter Creek Rd and Mateer Rd (Madin and Burns, 2013).**

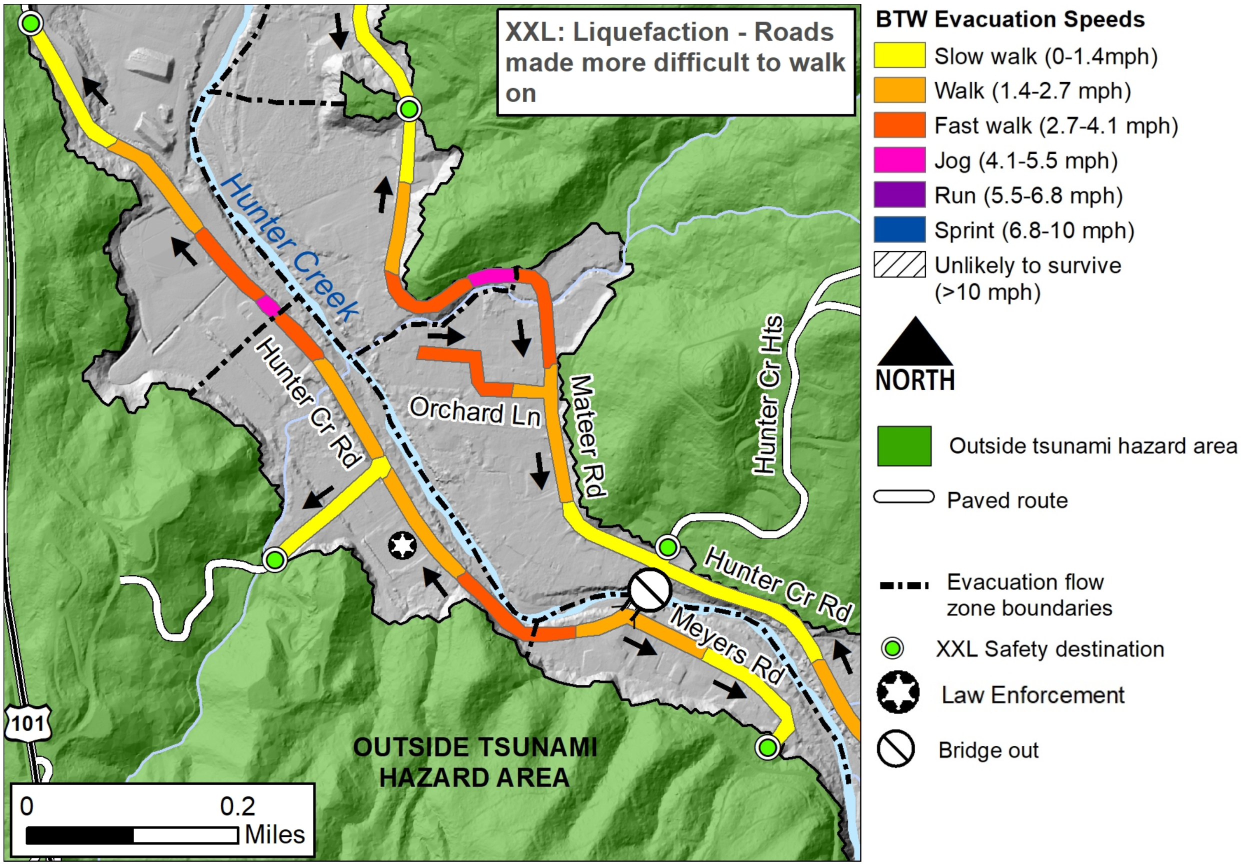


Figure 3-38. *Beat the Wave* modeling in Indian Creek for a liquefaction scenario where roads and trails are significantly more difficult to walk on. All low-lying roads inside the XXL inundation zone are classified as having moderate to high liquefaction susceptibility including Jerrys Flat Rd and the campground (Madin and Burns, 2013).

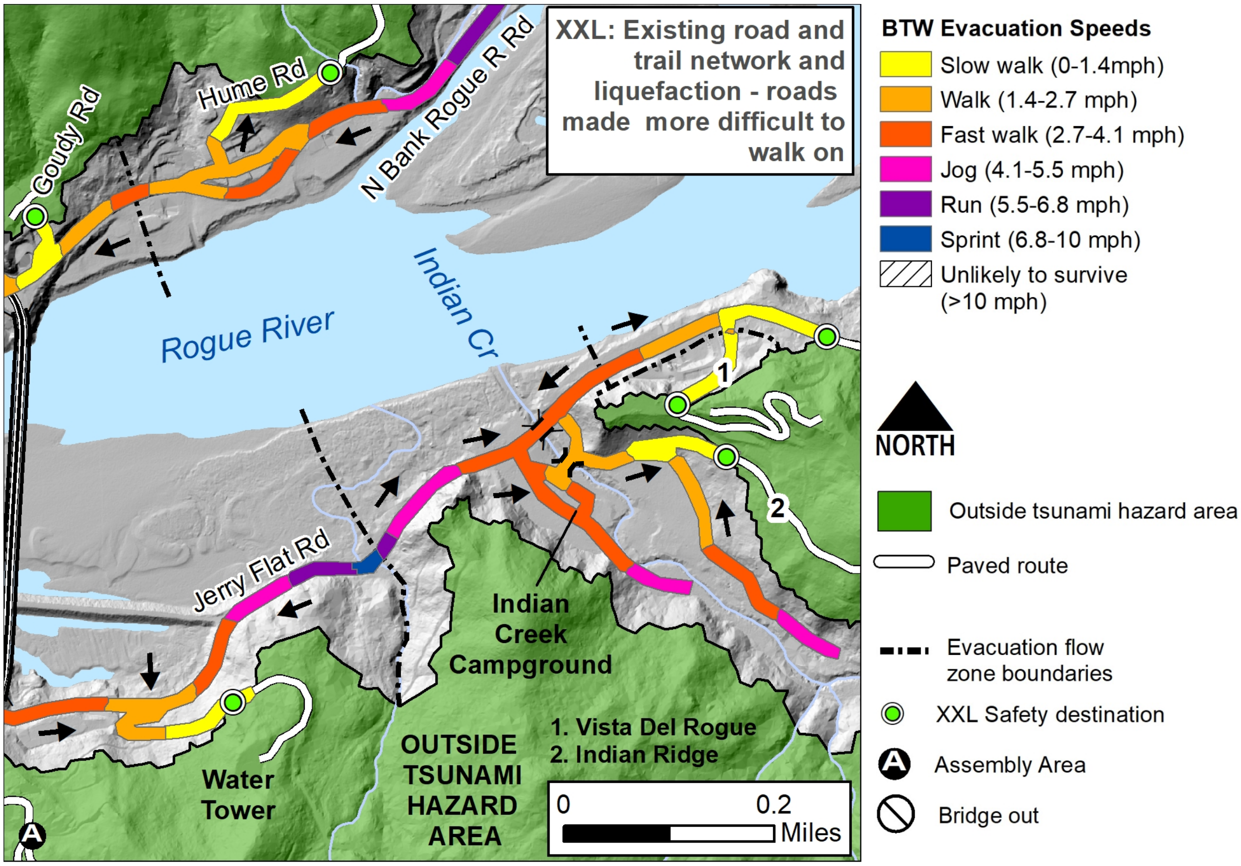


Figure 3-39. ***Beat the Wave*** **modeling in Rogue Shores for a liquefaction scenario where roads and trails are significantly more difficult to walk on. All roads inside the XXL inundation zone are classified as having moderate to high liquefaction susceptibility (Madin and Burns, 2013).**

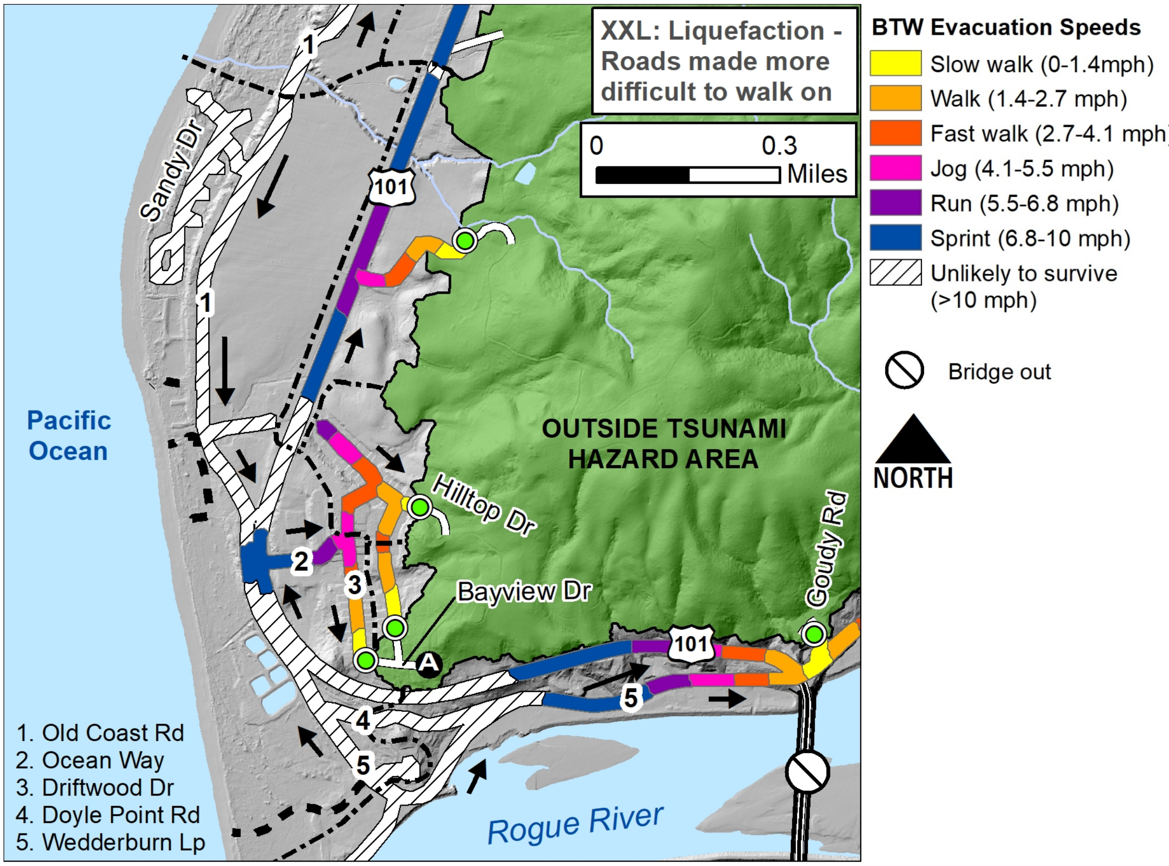
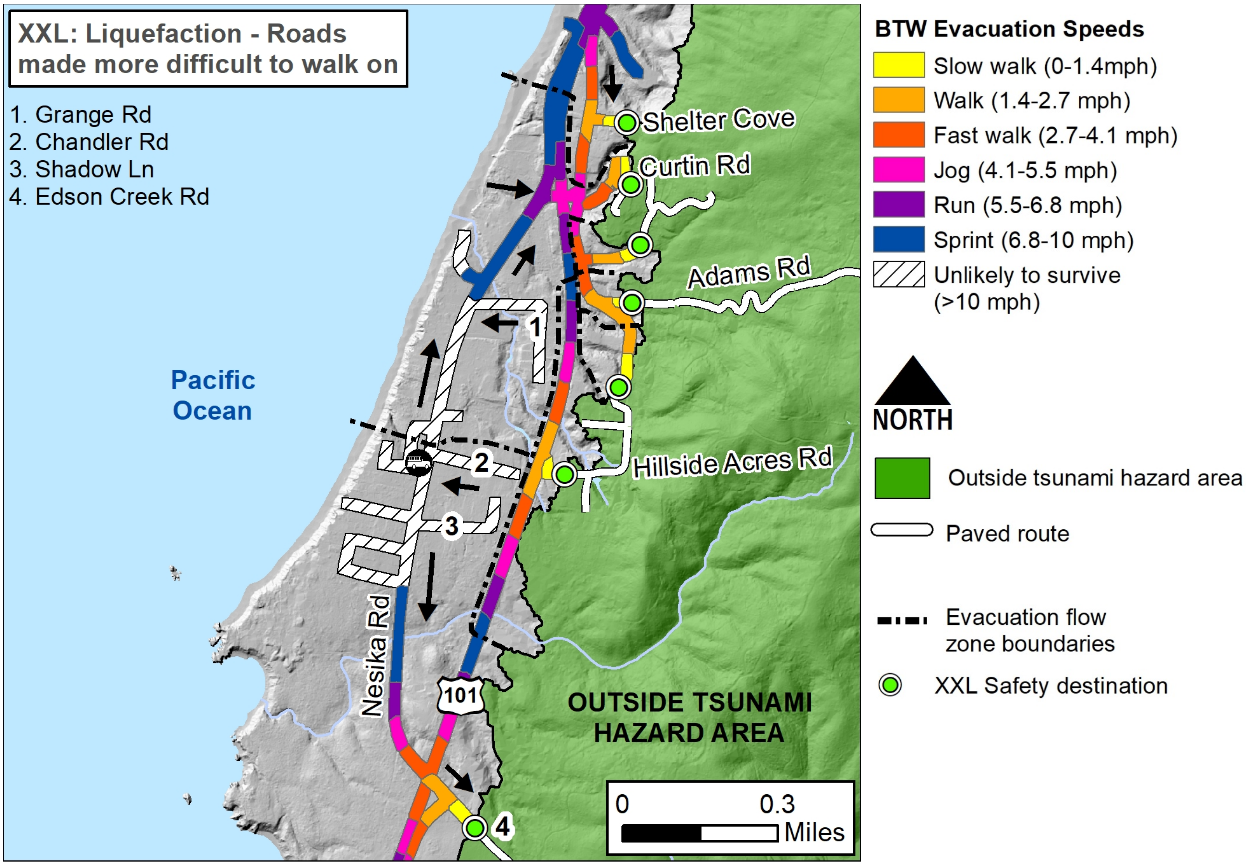


Figure 3-40. *Beat the Wave* modeling in Nesika Beach for a liquefaction scenario where roads and trails are significantly more difficult to walk on. All roads inside the XXL inundation zone are classified as having moderate to high liquefaction susceptibility (Madin and Burns, 2013).



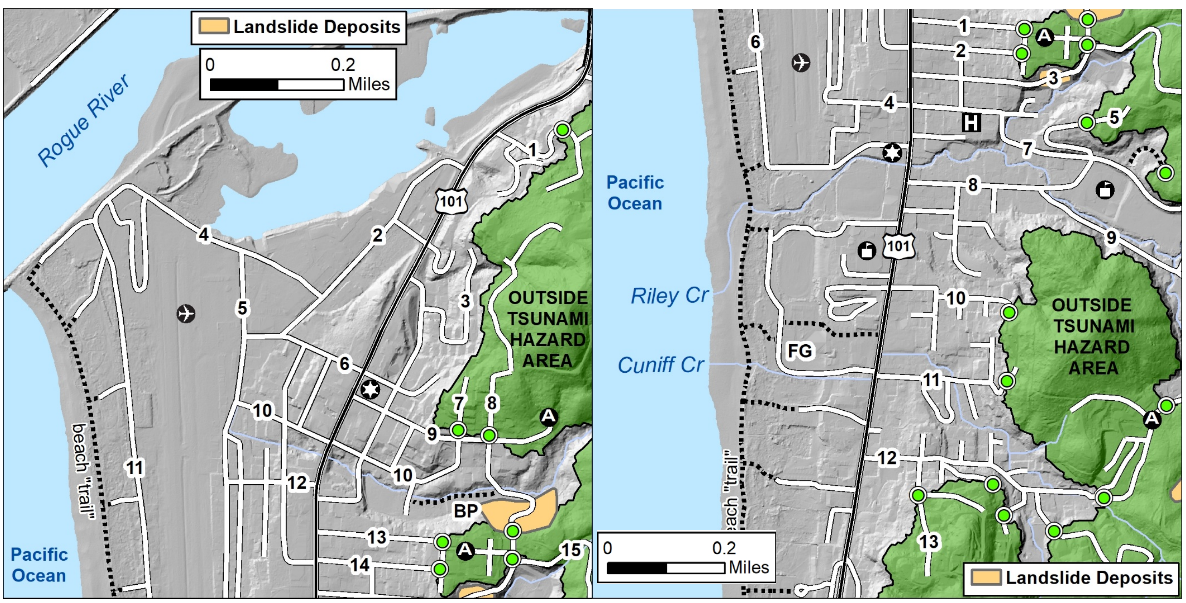
3.8 Landslides

While we do not know the precise probability or spatial distribution associated with landslides occurring during a CSZ earthquake, any number of landslides will undoubtedly occur during earthquake shaking, potentially blocking evacuation routes. However, it is more likely that landslide activity will make evacuation difficult in some areas but not impossible. A *Beat the Wave* landslide scenario involves removing a specific route and observing how evacuation speeds and/or routes are altered.

Because it is more likely that the earthquake will reactive existing landslides rather than create new ones, we use the Statewide Landslide Information Database for Oregon (SLIDO, version 4.2, https://www.oregongeology.org/slido/index.htm) to consider the potential for reactivation of historical landslides to impede evacuation. SLIDO data (**Figure 3-41** through **Figure 3-44**) shows the presence of several historical landslides intersecting evacuation routes. However, in all cases there are comparable alternative evacuation options such that results would be virtually unchanged from the current conditions scenario. For the reason, we do not consider any landslide *Beat the Wave* scenarios.

We present these data to demonstrate that additional impediments to immediate and swift evacuation may occur that are not addressed in this study and mitigation options should be evaluated. Research to understand the relationship between landslides and subduction zone earthquakes is ongoing. For more information, see Burns and others (2017) and Schulz and others (2012).

Figure 3-41. Mapped landslides (SLIDO 4.2) in (left) North and (right) Central Gold Beach.



1. Tom Cat Hill Rd
2. Harbor Way
3. June St
4. S Jetty Rd
5. Airport Way
6. Moore St
7. Turner St
8. Hound Dog Rd
9. Gauntlett St
10. Caughell St
11. Oceanside Dr
12. Strahan St
13. 1st St
14. 2nd St
15. Grizzly Mountain Rd

BP = Collier Buffington Memorial Park

Outside tsunami hazard area

XXL Safety destination

NORTH

Assembly Area

Airport

Law Enforcement

Hospital

School

1. 1st St
2. 2nd St
3. 3rd St
4. 4th St
5. Coldiron Hill Rd
6. Oceanside Dr
7. Leith Rd
8. 6th St
9. Quarry Rd
10. 8th St
11. 10th St
12. 11th St
13. Wallace St

FG = Fair Grounds

Figure 3-42. Mapped landslides (SLIDO 4.2) in (left) North and (right) South Hunter Creek.

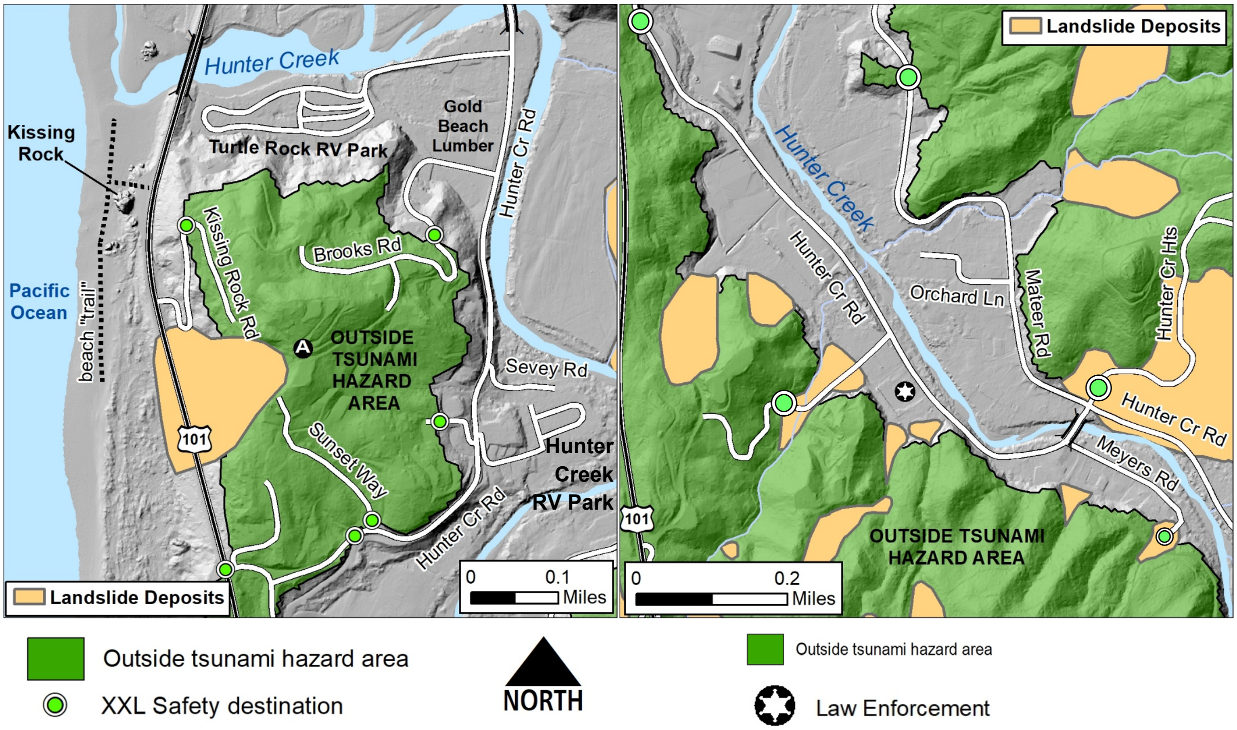


Figure 3-43. Mapped landslides (SLIDO 4.2) in (left) Indian Creek and (right) Rogue Shores and Wedderburn.

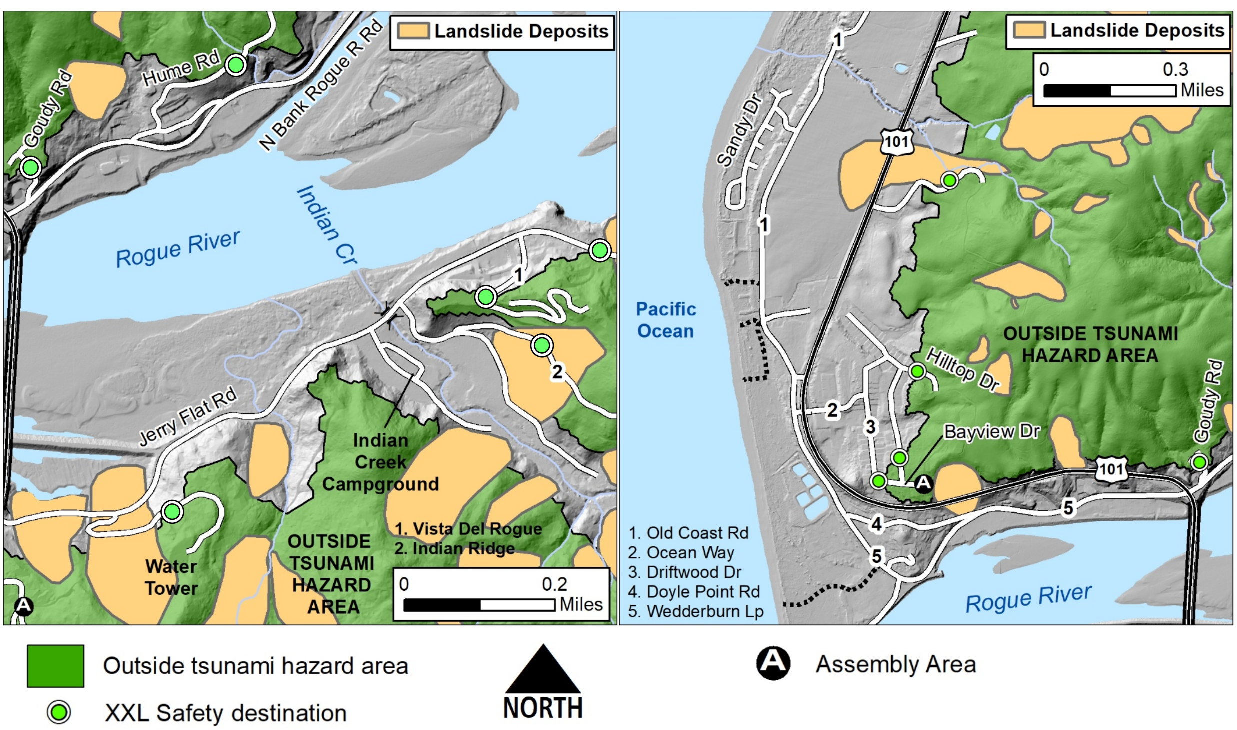
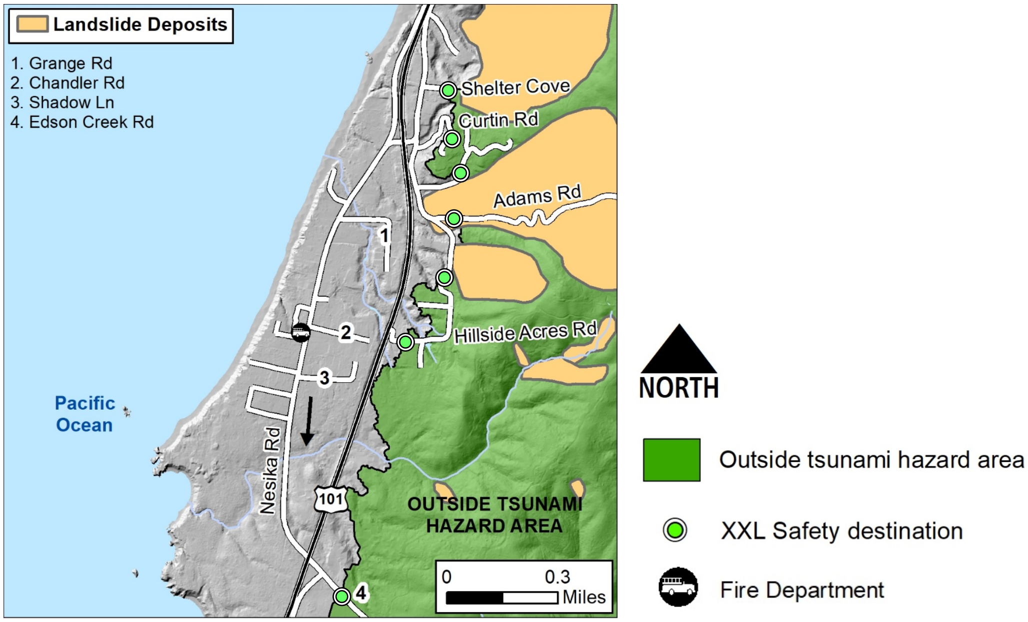


Figure 3-44. Mapped landslides (from SLIDO 4.2) in Nesika Beach.



4.0 CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study is to provide an assessment of tsunami evacuation difficulty in the area around Gold Beach. We accomplish this by implementing the *Beat the Wave* (BTW) approach to evacuation analysis developed by Priest and others (2015, 2016). This quantitative approach to community-wide evacuation analyses provides new insight for the area's risk reduction efforts. We note several important findings based on the results of this study:

- **Evacuation of the Gold Beach area in response to a Cascadia Subduction Zone tsunami will be very challenging.** This is primarily due to early wave arrivals, with the tsunami reaching the beach ~10-12 minutes after the start of earthquake shaking. Results show that evacuation is achievable only at relatively fast walking speeds (6 fps, or 4.1 mph) or greater. Evacuees in a few areas with especially lengthy distances to high ground must maintain a sprint (15 fps, or 10 mph) for the duration of the route to survive. This includes sections of Wedderburn, Nesika Beach, and Turtle Rock RV Park at the mouth of Hunter Creek. Evacuation for the seasonal visitor population will be especially challenging because visitors will likely have little to no awareness of the hazard and typically recreate and reside in areas along the ocean and river, which have the earliest wave arrivals. Rogue Shores is the most compromised community in the area. People here must travel ~1.3 miles to reach safety in the Rogue Hills neighborhood. To beat the wave to this destination, people must travel at a speed greater than 10 mph (15 fps). This is equivalent to a 6-minute mile pace, which is not realistically achievable for most of the population, especially considering bodily injuries that may have been incurred during earthquake shaking and navigation over fallen debris on roads.
- **Mitigation efforts will reduce loss of life from the tsunami.** Results show how mitigation efforts directed at reducing the distance to safety through "shortcuts" to high ground (i.e., vertical evacuation structures and evacuation trails) greatly improve the chances of achieving successful

evacuation. Rogue Shores benefits the most from a vertical evacuation structure due to the extremely fast speeds people must travel to reach high ground in time. A vertical evacuation structure in the City of Gold Beach will assist the largest number of residents and visitors because the city is where most of the regional population resides. However, modeling results show that any single structure improves evacuation for only a small region extending ~700-1,000 feet radially outward from the hypothetical structure. Multiple structures are probably needed to fully meet the needs of Gold Beach. In other areas requiring a sustained run to survive (sections of Nesika Beach and Wedderburn and Turtle Rock RV Park) evacuation speeds can be reduced by creating evacuation trails that greatly decrease overall distances to high ground.

- **Education and outreach will reduce loss of life from the tsunami.** Awareness is crucial to reducing loss of life from the tsunami by ensuring that residents and visitors alike know they must evacuate immediately after the earthquake ends. Results from our evacuation delay scenarios illustrate the reduction in travel speeds required to survive if people depart immediately following the earthquake versus waiting an additional 5 minutes. Most locations see a reduction of approximately one speed category (i.e., minimum travel speed of ***jog*** reduced to ***fast walk***), while South Gold Beach and Nesika Beach are reduced by two speed categories (i.e., ***run*** reduced to ***fast walk***). While we recognize there may be unavoidable reasons to delay evacuation following the earthquake, the reality that there is very little time to reach safety cannot be ignored. Leaving as soon as possible is key to survival.
- **Liquefaction, landslides, and other earthquake-induced hazards will further challenge evacuation.** Landslides, lateral spreading, and liquefaction are site-specific hazards associated with earthquake shaking. Because we do not have the ability to predict precisely where these phenomena will occur, we are able to perform only a cursory examination of how these hazards are likely to further challenge evacuation. Liquefaction BTW results demonstrate how faster evacuation speeds are required to reach high ground throughout the region when compared to current conditions (i.e., unobstructed paved roads). Areas with fast evacuation speeds under current conditions become even more challenging in this scenario (i.e., Rogue Shores), further reinforcing the need to examine mitigation options. Landslides will undoubtedly occur during the earthquake. However, as there are no known mapped slides with significant potential to block evacuation routes, we did not run a landslide scenario. We recommend site-specific evaluations along all key evacuation routes to ensure the routes remain accessible after the earthquake. In addition to landslides and liquefaction, lateral spreading as well as downed power lines and trees may impede swift travel toward safety.

There are several limitations to keep in mind when interpreting the results of this tsunami evacuation assessment:

- Evacuation is restricted to pathways rather than via cross county travel (e.g., through backyard or golf course). During an actual tsunami evacuation, people should take the fastest and safest route available to them.
- A 10-minute delay between the start of earthquake shaking and evacuation is incorporated into the model to account for the following actions:
  - the time in which earthquake shaking takes place (drop, cover, and hold for 3-5 minutes)
  - disorientation, shock, and collecting family members, go-bags, etc.
  - the time required to evacuate the building and reach the nearest road (navigating fallen debris inside building, exiting building, crossing fenced yard, etc.)

Regardless of walking speeds, physical limitations, and mitigation considerations, effective 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 routes 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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