PEDESTRIAN TRAVEL-TIME MAPS FOR WHITTIER, ALASKA:
An anisotropic model to support tsunami evacuation planning

by

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ABSTRACT

Tsunami-induced pedestrian evacuation for the community of Whittier is evaluated using an anisotropic modeling approach developed by the U.S. Geological Survey. The method is based on path-distance algorithms and accounts for variations in land cover and directionality in the slope of terrain. We model evacuation of pedestrians to exit points from the tsunami hazard zone boundary. The pedestrian travel is restricted to the roads only. Results presented here are intended to provide guidance to local emergency management agencies for tsunami inundation assessment, evacuation planning, and public education to mitigate future tsunami hazards.

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INTRODUCTION

Subduction of the Pacific plate under the North American plate has resulted in numerous great earthquakes and has the highest potential to generate tsunamis in Alaska (Dunbar and Weaver, 2015). The Alaska–Aleutian subduction zone (figure 1), the fault formed by the Pacific–North American plate interface, is the most seismically active tsunamigenic fault zone in the U.S. Refer to Nicolsky and others (2011a) for an overview of the tsunami hazard in the Whittier area.

The most recent earthquake that triggered a significant tsunami in Whittier occurred on March 27, 1964; for this event, tsunami waves were as high as 7.6 m (25 ft) (Lander, 1996). In addition to the major tectonic tsunami generated by the ocean floor displacement between the trench and coastline, local tsunamis were generated by landslides across coastal Alaska. They arrived almost immediately after shaking was felt, leaving no time for warning or evacuation.

Whittier experienced heavy damage from local, landslide-generated tsunami waves (Kachadoorian, 1965). A tectonic tsunami was not noticed by local residents and its effects on the port remain unknown. The town sustained extensive damage and 13 people perished in the tsunamis. Because of Whittier's history of locally generated tsunamis, the potential of future similar events must be included in tsunami hazard evaluations (Nicolsky and others, 2011a).

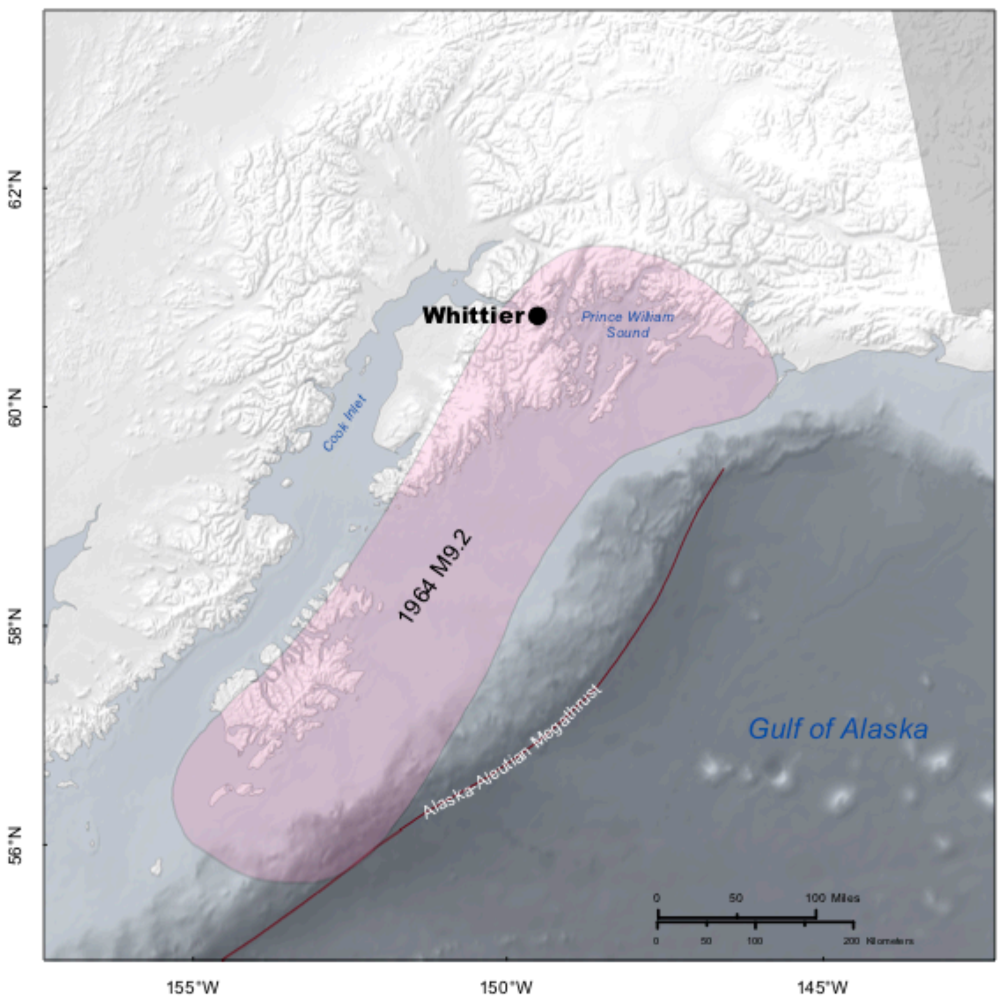

Figure 1: Map of south-central Alaska, showing the location of Whittier and the rupture zone of the 1964 M_w9.2 Alaska subduction zone earthquake (shaded area).

In this report, we employ the pedestrian evacuation modeling tools developed by the U.S. Geological Survey (USGS) (Wood and Schmidtlein, 2012, 2013; Jones and others, 2014) to provide guidance to emergency managers and community planners in assessing the amount of time required for people to evacuate out of the tsunami-hazard zone. An overview of the pedestrian evacuation modeling tools, required datasets, and the step-by-step procedure used is provided in Macpherson and others (2017, this series). The maps of pedestrian travel time can help identify areas in Whittier on which to focus evacuation training and tsunami education.

COMMUNITY PROFILE

The port of Whittier is near the western end of Passage Canal, about 96 km (60 mi) southeast of Anchorage at approximately 60°46' N latitude and 148°41' W longitude (Figure 1). The port was built in the early 1940s to provide an all-weather terminal for the Alaska Railroad. Whittier has become a focal point for the flow of supplies and equipment from tidewater to Anchorage and the interior of Alaska. The damage to Whittier coupled with destruction of ports in Seward and Valdez impeded post-1964 earthquake supply distribution to other affected areas of the state (Kachadoorian, 1965).

Since 1964, the port of Whittier has developed considerably; its economy has diversified to include tourism, commercial fishing and processing. Whittier hosts more than 40 cruise ships per year, is a port for the state ferry system (Alaska Division of Community Advocacy, 2005), and its availability as an all-weather port make it an important supply center for interior Alaska. Further information could be obtained from the Alaska Community Database maintained by the State of Alaska Division of Community and Regional Affairs of the Department of Commerce, Community, and Economic Development (DCCED/DCRA, 2015).

TSUNAMI HAZARD

Tsunami hazard assessment for Whittier was performed by numerically modeling several hypothetical scenarios (Nicolsky and others, 2011a). The worst-case scenarios for Whittier are thought to be thrust earthquakes in the Gulf of Alaska on the Aleutian Megathrust with magnitudes ranging from M_w9.0 to M_w9.3 combined with submarine slope failures in the Passage Canal.

Nicolsky and others (2011a) estimate that is takes approximately 30-60 minutes for tsunami waves generated in the Gulf of Alaska outside Prince William Sound to travel into the Whittier harbor. However, massive underwater slope failures typically generate large waves that are usually observed while the ground is still shaking (up to 5 minutes). Waves can cause flooding in 1-3 minutes after the first shock. In this report, we look at the landslide-only and combined landslide plus tectonic tsunami scenarios. Modeled extents of the potential inundation in the Whittier downtown area for both scenarios are computed by Nicolsky and others (2011a) and shown in Figure 2.

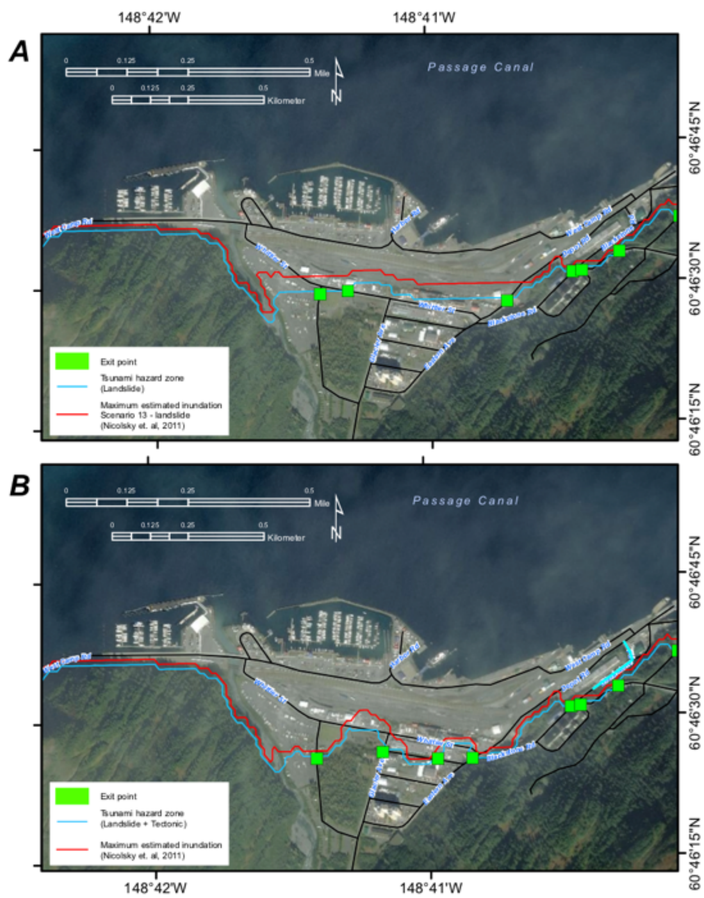

Figure 2: Modeled extent of the potential inundation (red line) and the tsunami hazard zone (blue line) for the landslide only scenario (top) and the combined tectonic and landslide scenario (bottom).

The hydrodynamic model used to calculate propagation and runup of tsunami waves is a nonlinear, flux-formulated, shallow-water model (Nicolsky and others, 2011b) that has passed the appropriate validation and verification tests (Synolakis and others, 2007; NTHMP, 2012). We emphasize that although the developed algorithm has met the benchmarking procedures, there is still uncertainty in locating an inundation line. Refer to Nicolsky and others (2011a,b) for an in-depth discussion of the uncertainty in the modeled tsunami hazard zone. For example, the accuracy is affected by many factors on which the model is based, including suitability of the earthquake source model, accuracy of the bathymetric and topographic data, and the adequacy of the numerical model in representing the generation, propagation, and runup of tsunamis.

To account for the above-mentioned uncertainties, we enlarge the modeled extent of potential inundation by adding a safety buffer. In particular, areas within 45 m (150 ft) of the inundation line and with elevations less than 110% of the local runup are thought to be a risk of flooding in the worst-case tsunami event.

The potential inundation extent together with the safety buffer is to be called the tsunami hazard zone, and is used for the evacuation map development. We note that the safety buffer does not extend further than 45 m (150 ft) from the inundation line and can increase the vertical elevation at most by 10%. The safety buffer is smaller in the areas with steeper topography. In rather flat areas, the safety buffer can reach the 45 m (150 ft) in the horizontal direction. Figure 2 shows the tsunami hazard zone in Whittier harbor represented by the blue line, also see Map Sheet 1 for a larger extent.

PEDESTRIAN EVACUATION MODELING

Pedestrian evacuation modeling and prediction of population vulnerability to tsunami hazards were successfully applied to coastal communities in Alaska by Wood and Peters (2015). Also refer to Wood and Schmidtlein (2012, 2013) for an overview and limitations of the anisotropic, least-cost distance (LCD) approach to modeling pedestrian evacuation. We stress that the LCD focuses on the evacuation landscape, using characteristics such as elevation, slope, and land cover to calculate the most efficient path to safety. Therefore, computed travel times are based on optimal routes, and actual travel times may be greater depending on individual route choice and environmental conditions during an evacuation.

Recently, Jones and others (2014) developed the Pedestrian Evacuation Analyst Extension (PEAE) for ArcGIS, which facilitates development of pedestrian travel-time maps. A brief overview of the PEAE and a step-by-step procedure to compute the pedestrian travel-time maps for Alaska coastal communities are provided in Macpherson and others (2017, this series). Note that the data required for the PEAE include: either the tsunami hazard zone or exit points, digital elevation model (DEM) of the community, and land-cover datasets. In the following sections we describe datasets required to compute the travel-time maps, considered scenarios, and modeling results.

DATA COMPILATION AND SOURCES

The following section details the datasets that were obtained and/or created for the community to be used as input for the PEAE. In all cases we used the maximum composite tsunami hazard zone instead of a specific tectonic scenario. All datasets and layers were projected to NAD83 Alaska State Plane Zone 4 m to allow us to compute the final evacuation times in meters per second. The original sources of data are summarized in Table 1.

- **Exit points:** Exit points are located on the roads leading from the tsunami hazard zone to the assembly areas and shelters (e.g. the Hodge Building). Green rectangles in figure 2 (or Map Sheet 1) mark locations of the exit points in the downtown area.
- **Digital Elevation Model:** The DEM employed in this study is consistent with the tsunami DEM used by Nicolsky and others (2011a) to compute the tsunami inundation. The original source for topographic elevations is the National Geophysical Data Center (NOAA), with a spatial resolution

of about 13 × 16 m (44 x 54 ft). Note that the tsunami DEM was resampled using the PEAE tool to set the analysis cell size at 1 m (3.3 ft) resolution to improve the accuracy of the travel-time maps.

- **Land Cover:** A land-cover layer was created using the high-resolution imagery from DigitalGlobe world imagery through ESRI and verified by Geographic Information Network of Alaska (GINA) Best Data Layer (BDL) (http://www.alaskamapped.org/bdl/) including building footprints and water features. Roads and trails were added using high-resolution imagery and verified by data extracted from the OpenStreetMap API (OSM, 2015).

Table 1. Data sources of the input layers required for the Pedestrian Evacuation Analyst Extension.

Layer in PEAE	Data Sources
Tsunami Inundation Extent	Nicolsky and others (2011a)
Exit points	Located on the roads leading from the buffered inundation extent.
DEM	Nicolsky and others (2011a)
Land Cover	Digitized from imagery
Buildings	Digitized from GINA BDL & ESRI, Digital Globe imagery
Roads	Digitized from imagery and confirmed through OpenStreetMap
Water	Digitized from GINA BDL & ESRI, Digital Globe imagery
Imagery	Digital Globe imagery

EVACUATION SCENARIOS

We model the pedestrian evacuation time for two scenarios. We emphasize that the assumed base speed of the evacuee is set according to the “slow walk” option (0.91 m/s, 3 ft/s, or 2 mph) in the PEAE settings. Note that this is a conservative speed and many residents would be able to evacuate faster (1.52m/s “fast walk”, if not 1.79m/s “slow run”) than the modeled rate. However, soil liquefaction, darkness, freezing rain, ice and/or snow on the road can also significantly impact the walking pace of evacuees. Additionally, in the case of severe weather conditions or a thick snow cover, the evacuation might be confined to well-traveled roads and paths. We therefore assume that pedestrians will travel to the closest road and then stay on roads to leave the tsunami hazard zone. We also assume that individuals travel to the nearest exit point in the most optimal way. The latter requires tsunami evacuation signage along the roads. In this study we consider two scenarios:

Scenario 1. **Evacuation to the nearest exit point by roads only for a landslide induced tsunami**

Scenario 2. **Evacuation to the nearest exit point by roads only for a combined landslide and tectonic induced tsunami**

In both scenarios evacuation across the railroad track is not allowed, except for the designated crossings, since the railroad erects a fence separating the harbor area from the railroad track in the summer. Furthermore, one or several trains could be parked along the tracks, making additional obstacles to reach safety. The fence and parked trains can hinder attempts to reach safety, especially when cruise ship passengers disembark and embark on the vessel. During peak times, several thousands of tourists could be located in the tsunami hazard zone. Evacuation from the harbor area to safety using an underground tunnel is not an option, because one end of the tunnel is located inside the tsunami hazard zone.

MODELING RESULTS

We apply the methodology outlined in Macpherson and others (2017, this series) to compute the travel times according to the considered scenarios.

Modeling results for Scenario 1 (a landslide-generated tsunami arriving within a few minutes after the initial shock) are shown in Figure 3a. Modeled pedestrian travel time from the harbor area to a nearest exit points is upwards of 13 minutes, because evacuees need to travel west along W. Camp Rd. to the nearest railroad crossing, and then up along Whittier St. For evacuees at the Alaska Marine terminal it may take 20 minutes to reach an exit point. These travel times are high and the landslide-generated tsunami can flood the harbor area before the evacuees can reach safety.

Although the tectonic tsunami may produce a great extent of inundation, the tectonic wave arrives in about 30-60 minutes after the main shock (Nicolsky and others, 2011a). Results for Scenario 2 (tectonic + landslide-generated tsunami) are shown in Figure 3B. Pedestrian travel time is typically less than 30 minutes, except for the tip of wave breakers. The Alaska Marine terminal, railroad tracks and a section of W. Camp Rd. are colored in orange, which indicates travel times close to 20 minutes. Educational efforts could be more extensively focused on these areas in order to minimize the milling time and to prompt an evacuation at the first sign of the tsunami danger.

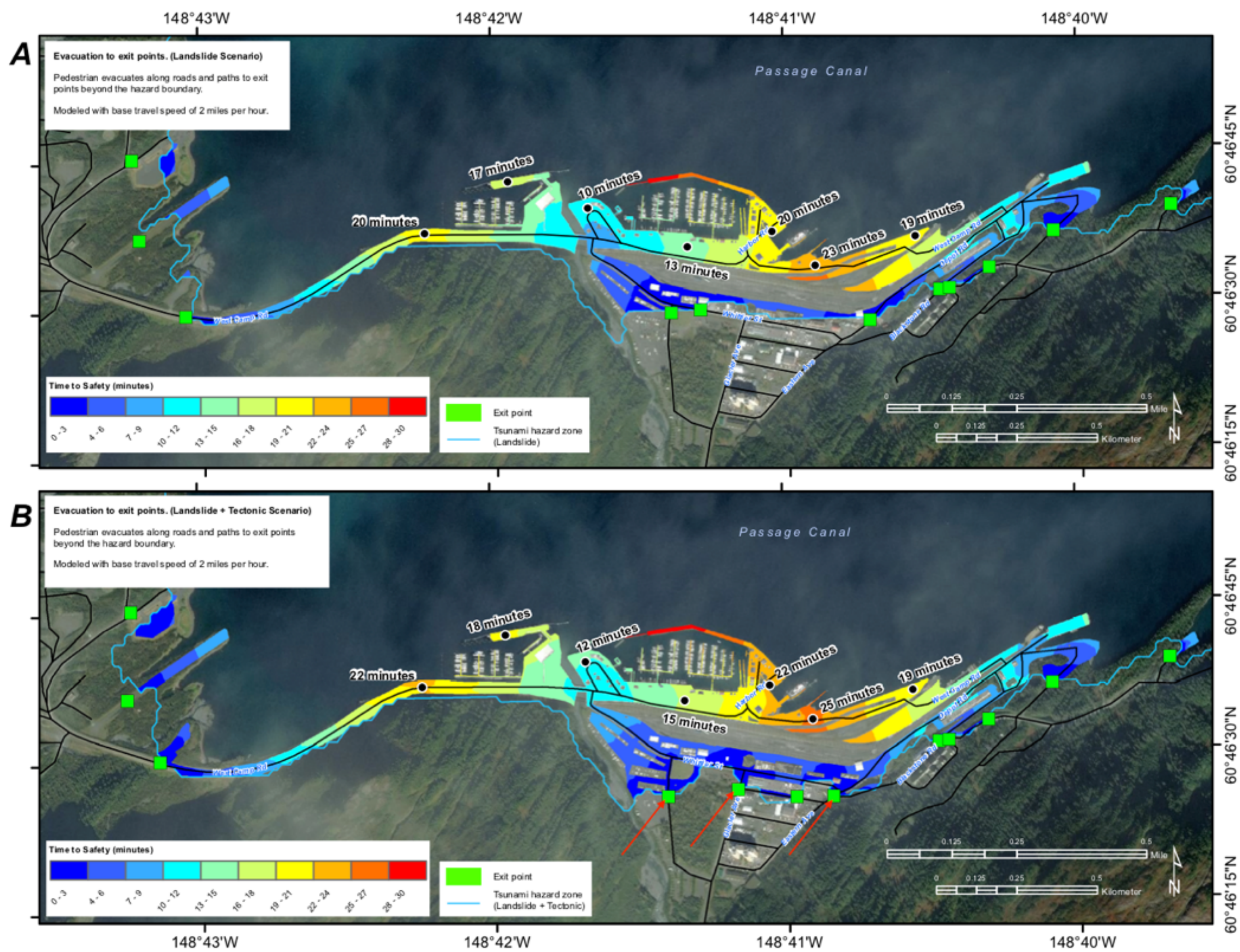

Figure 3: Travel time maps for pedestrian evacuation (A) for scenario 1, landslide-generated tsunami, (B) for scenario 2, combined landslide and tectonic tsunami (B). Red arrows point to exit points that have changed between the two scenarios.

SOURCES OF ERRORS AND UNCERTAINTIES

The modeling approach described in this report will not exactly represent an actual evacuation; like all evacuation models, the LCD approach cannot fully capture all aspects of individual behavior and mobility (Wood and Schmidtlein, 2012). The weather conditions, severe shaking, soil liquefaction, infrastructure collapse, downed electrical wires, and the interaction of individuals during the evacuation will all influence evacuee movement. Refer to Wood and Schmidtlein (2012, 2013), Jones and others (2014), and Macpherson and others (2017, this series) for an in-depth discussion of the limitations of the LCD approach in estimating the travel times to safety.

SUMMARY

Whittier is built between the mountains and ocean. Hence, there is a stretch on W. Camp Rd. from which evacuation may be challenging, since it would take a considerable amount of time for evacuees to reach a nearest exit point beyond the tsunami hazard zone, especially in the case of a local landslide-generated tsunami. Evacuation onto the mountain slope is not considered, because of the steep terrain and absence of emergency services. Potential rock falls and snow avalanches could be triggered by aftershocks leading to secondary causalities.

Evacuation from the harbor area could be improved by considering vertical evacuation structures or bridges above the railroad tracks. The erected fence might have emergency breaks, and parking of long trains along the harbor area during the arrival of cruise ships could be avoided.

Maps accompanying this report have been completed using the best information available and are believed to be accurate; however, the report's preparation required many assumptions. In most cases the actual walking speeds proved faster than those modeled. The information presented on these maps is intended to assist state and local agencies in planning emergency evacuation and tsunami response actions. These results are not intended for land-use regulation or building-code development.

ACKNOWLEDGEMENTS

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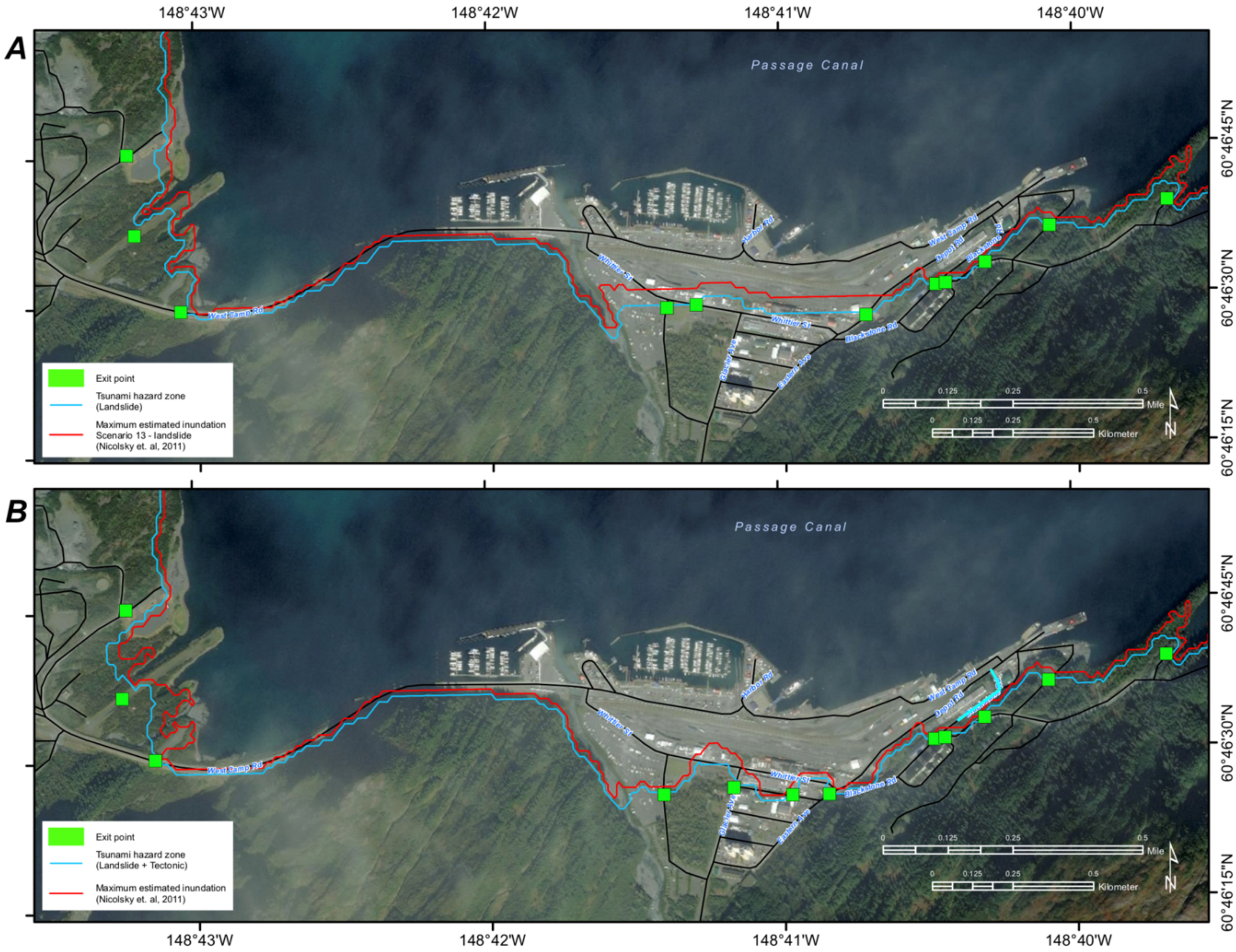
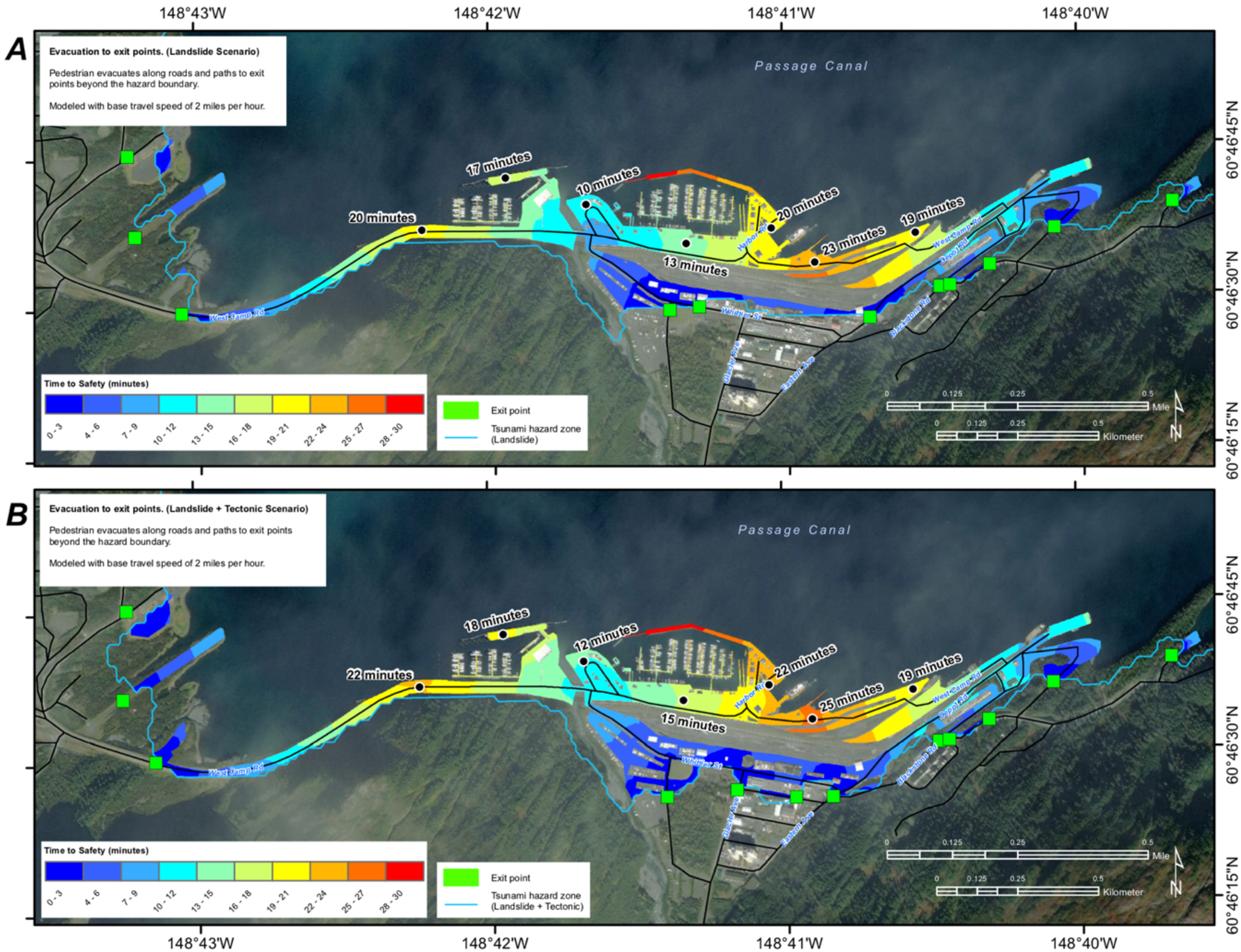


MAP SHEET 1: Modeled extent of the potential inundation and estimated tsunami hazard zone (A) for the landslide induced wave scenario and (B) for the combined landslide and tectonic tsunami scenario.



MAP SHEET 2: Travel-time map of pedestrian evacuation to exit points beyond the hazard boundary (A) for the landslide induced wave scenario and (B) for the combined landslide and tectonic tsunami scenario.