PEDESTRIAN TRAVEL-TIME MAPS FOR UNALASKA/DUTCH HARBOR, ALASKA: An anisotropic model to support tsunami evacuation planning

by
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ABSTRACT

Tsunami-induced pedestrian evacuation for the community of Unalaska/Dutch Harbor 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 the tsunami hazard zone boundary and to predetermined assembly areas. Pedestrian travel-time maps are computed for two cases: for travel across all viable terrain or by 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, 2008). 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 (2015) for an overview of the tsunami hazard in the Unalaska area.

The city of Unalaska has not experienced significant waves during previous historic tsunami events; however, a small tsunami was observed here in 1957. The potential occurrence of damaging tsunamis at this location is evaluated by Nicolsky and others (2015) to develop tsunami hazard maps, as future earthquakes in the area could have different patterns of energy release. The tsunami evacuation routes developed by Data Directions Consulting Group for Unalaska including the port of Dutch Harbor are shown in figure 2. Several fish-processing facilities have developed their own evacuation plans using nearby elevated areas that are easily accessible, while other facilities may face more of a challenge to evacuate due to their location. Special attention is given to timing routes to safety from certain sites (personal communication with Fire Chief Zac Schasteen, Unalaska Department of Public Safety, 2014). The community of Unalaska/Dutch Harbor is a National Weather Service designated Tsunami-Ready Community and has a detailed evacuation policy (Appendix A) developed by the Department of Public Safety (http://www.ci.unalaska.ak.us/publicsafety). Regular testing of the seven tsunami warning sirens takes place every Saturday at noon and on the 15th of every month at noon. The general advice given to residents is to "immediately evacuate to high ground if the sirens activate for several minutes, or if they follow an earthquake strong enough to knock you off of your feet and lasting longer than 30 seconds."

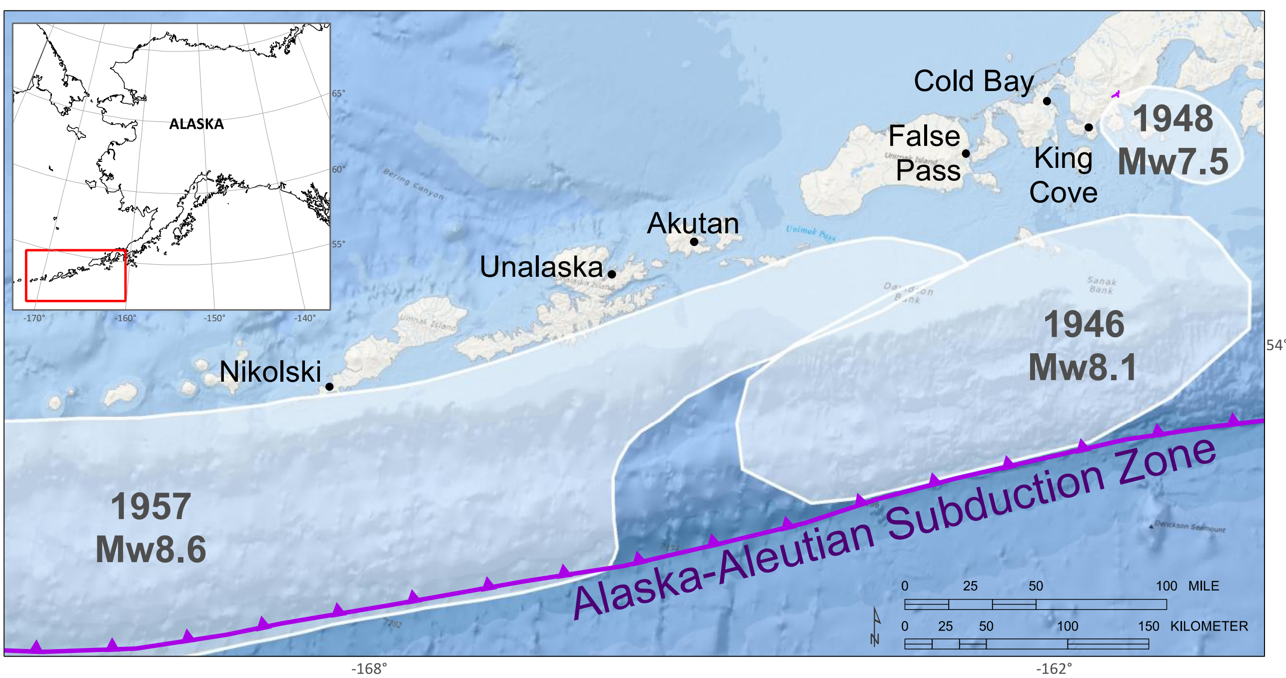


Figure 1. Map of the eastern Aleutian Islands and the southern tip of the Alaska Peninsula, identifying major active faults (dark purple lines) and the rupture zones of the 1946, 1948, and 1957 earthquakes (light shaded areas).

In this report, we employ the pedestrian evacuation modeling tools developed by U.S. Geological Survey (Wood and Schmidtlein, 2012, 2013; Jones and others, 2014) to provide guidance to emergency managers and community planners in assessing the time required for people to evacuate out of the tsunami-hazard zone. The overview of employed pedestrian evacuation modeling tools, required datasets, and the step-by-step procedure is provided in Macpherson and others (2017).

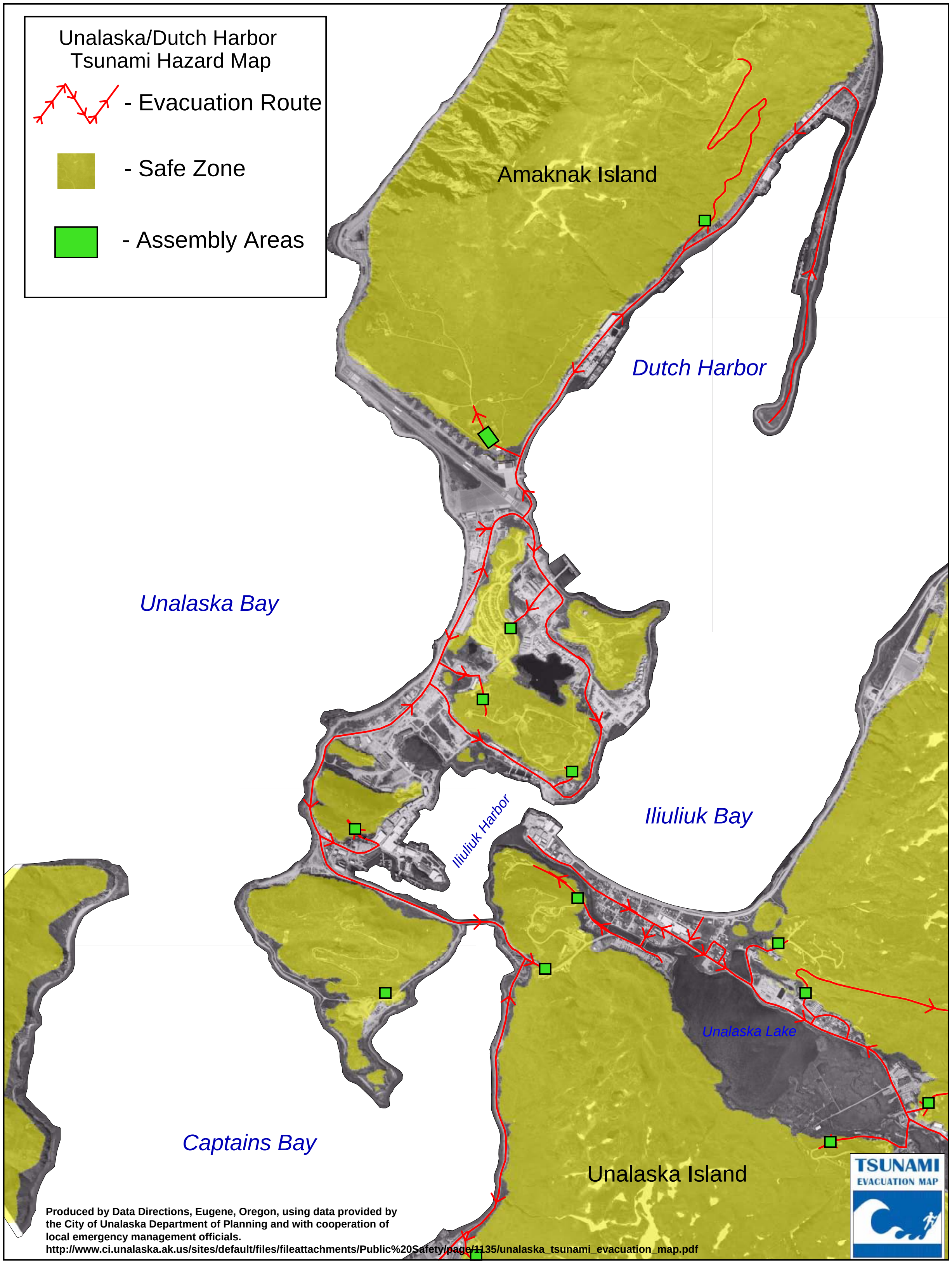


Figure 2. Tsunami hazard map for Unalaska, produced by Data Directions, Eugene, Oregon, using data provided by the City of Unalaska Department of Planning and with cooperation of local emergency management officials. The map is intended for emergency response reference purposes only and should not be used for site-specific planning. The Unalaska/Dutch Harbor Tsunami Safe Zone is defined as areas above 15.25 m (50 ft) in elevation.

The maps of pedestrian travel time can help identify areas in Unalaska and Dutch Harbor on which to focus evacuation training and tsunami education. The developed travel-time maps can also be used to examine the potential benefits of vertical evacuation structures, which are buildings or berms designed to provide a local high ground in low-lying areas of the hazard zone.

COMMUNITY PROFILE

The city of Unalaska (figure 3) is on Unalaska Island and neighboring Amaknak Island at 53°53'N, 166°32'W, or about 1,287 km (800 mi) west of Anchorage, and 3,138 km (1,950 mi) northwest of Seattle. Dutch Harbor lies within the city limits of Unalaska and is connected to Unalaska by a bridge, locally known as the "Bridge to the Other Side." Amaknak Island is home to almost 59 percent of the city's population, although it has less than 3 percent of its land area. The 2010 U.S. Census recorded the city population as 4,376, or 79 percent of the entire Aleutians West Census Area (DCCED/DCRA).

Figure 3. A view over Unalaska, toward the southeast along Bayview Avenue.

The community of Dutch Harbor includes Naval Operating Base and Fort Mears, U.S. Army, a U.S. National Historic Landmark, a high school and elementary school, several specialized health clinics, a library, public safety department, and many other community facilities. Most of the community's port facilities are on Amaknak Island, with three out of Unalaska's ten major docks operated by the city. For many years Dutch Harbor was ranked the largest U.S. fishing port by volume and dollar value of seafood catch. Several canning operations exist in the area: Westward Seafood (employing around 1,000 people), Alyeska Seafood (roughly 500 employees), and Unisea, with approximately 2,000 employees. The Unalaska/Dutch Harbor area is a critical element of Alaska's economy.

The state of Alaska owns a 1,250 by 30 m (4,100 by 100 ft) paved runway, where daily flights are scheduled. Because of the very harsh weather conditions around Unalaska Airport, about one-fifth of those flights are canceled. A seaplane base is also available. Every summer Dutch Harbor is the terminus port for the Alaska Marine Highway System and is an important resupply port for many marine vessels traveling in the northern Pacific Ocean.

There are approximately 11.2 km (7 mi) of paved road, and 61 km (38 mi) of road total in Unalaska. According to traffic counts taken by the Alaska Department of Transportation and Public Facilities, the most heavily traveled roads in Unalaska are Airport Beach Road between 5th Street and East Point Road, 5th Street between Broadway Avenue and Airport Beach Road, and Broadway Avenue between 5th Street and Steward Road. These roads recorded an annual average daily traffic volume of approximately 3,000 cars.

TSUNAMI HAZARD

Tsunami hazard assessment for Dutch Harbor/Unalaska was performed by numerically modeling several hypothetical scenarios (Nicolsky and others, 2015). Worst-case hypothetical scenarios were defined by analyzing results of a sensitivity study of the tsunami dynamics related to various slip distributions along the Alaska–Aleutian subduction zone. The worst-case scenarios for Unalaska and Akutan are thought to be thrust earthquakes in the Fox Islands region with magnitudes ranging from Mw 8.8 to Mw 9.1, which have their greatest slip at 30–40 km (18–25 mi) depth. The maximum predicted wave in Iliuliuk Bay could reach 9 m (30 ft) and could cause widespread damage and flooding. The numerical simulations predict that the first wave could arrive as quickly as 30 minutes after the earthquake, whereas the highest wave might arrive 80–90 minutes after the earthquake. Significant wave activity could continue for at least 18 hours after the earthquake, and the predicted average time interval between successive waves is about 40 minutes.

The estimated extent of inundation in Unalaska and Dutch Harbor is shown by the hatched red line in figure 4. Much of the economic activity and infrastructure is within the hazard zone. Harbors, ports, canning facilities, the airport, and schools are all inside the zone. City Hall and the Office of Public Safety are above the estimated tsunami hazard zone.

The hydrodynamic model used to calculate propagation and runup of tsunami waves is a nonlinear, flux-formulated, shallow-water model (Nicolsky and others, 2011) that has passed validation and verification tests (Synolakis and others, 2007; NTHMP, 2012). We emphasize that although the developed algorithm has passed through the benchmarking procedures, there is still uncertainty in locating an inundation line. Refer to Nicolsky and others (2015) 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 depends, 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.

PEDESTRIAN EVACUATION MODELING

Pedestrian evacuation modeling and population vulnerability to tsunami hazards was 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 model pedestrian evacuation. We stress that the LCD focuses on the evacuation landscape, employing characteristics such as elevation, slope, and land cover to calculate the most efficient path to safety. Therefore, the computed travel times are based on optimal routes; the 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 the pedestrian travel-time maps. A brief overview of the PEAE and a step-by-step procedure to compute the pedestrian travel-time maps for the Alaska coastal communities are provided in Macpherson and others (2017). Data required for the PEAE includes the tsunami hazard zone, assembly areas, digital elevation model (DEM) of the community, and land-cover datasets. In the following subsections we describe the compilation of the datasets required to compute the travel-time maps, the scenarios we considered, and the modeling results for Unalaska.

We visited Unalaska and Dutch Harbor at the end of 2014 to gain knowledge of the physical setting, collect land-cover data, and collect other data necessary to validate the travel-time maps. We investigated several routes and recorded the time required to walk them. Details of walked routes and further information gathered on the site visit can be found later in this report in Appendix B.

Figure 4. Map of Unalaska, depicting key facilities, land cover, and the tsunami hazard zone (red line with hatch marks toward the potential inundation zone).

DATA COMPILATION AND SOURCES

All original datasets were projected to NAD83 Alaska State Plane Zone 10 m to allow us to compute the final evacuation times in meters per second. Original data sources are summarized in Table 1.

- **Tsunami Hazard Zone:** A hazard-zone polygon for PEAE was created using the modeled maximum estimated inundation line from all scenarios for Unalaska and Dutch Harbor (Nicolsky and others, 2015) as a boundary.
- **Assembly areas:** An assembly area may be an important building, or a place that has been agreed upon by the community as a gathering place in times of emergency, or could be just flat land that is out of the hazard zone. We chose assembly areas to be outside the tsunami hazard zone on the evacuation routes developed by Data Directions Consulting Group. The considered assembly areas are marked by green rectangles in figure 2.
- **Digital Elevation Model:** The DEM used in this study is consistent with the tsunami DEM used to compute the tsunami inundation in Unalaska/Dutch Harbor (Nicolsky and others, 2015). An original source for the topographic elevations is the 2012 Unalaska Tsunami DEM (Carignan and others, 2012) with a spatial resolution of about 16 × 16 m (52.5 × 52.5 ft). The original 2012 Unalaska Tsunami DEM was augmented with a real-time kinematic (RTK) GPS survey (Nicolsky and others, 2015) to reduce vertical errors near the shoreline. Note that the Tsunami DEM was re-sampled at 3 m (10 ft) resolution to improve the accuracy of the travel-time maps.
- **Land Cover:** Data obtained from the Unalaska GIS department (shown in figure 5) was modified by adding more building footprints for large tanks and by eliminating some artifacts and digitizing paths through some parking lots. The latter step was accomplished by using the GINA BLS WMS (http://wms.alaskamapped.org/) as source imagery.

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

Layer in PEAE	Data Sources
Tsunami Hazard Zone	Nicolsky and others (2015)
Assembly areas	On evacuation routes developed by Data Directions Consulting Group
DEM	Nicolsky and others (2015)
Land Cover	NLCD 2011 edited
Buildings	Modified from Unalaska GIS department
Roads	Modified from Unalaska GIS department
Water	Modified from Unalaska GIS department
Imagery	GINA BDL WMS

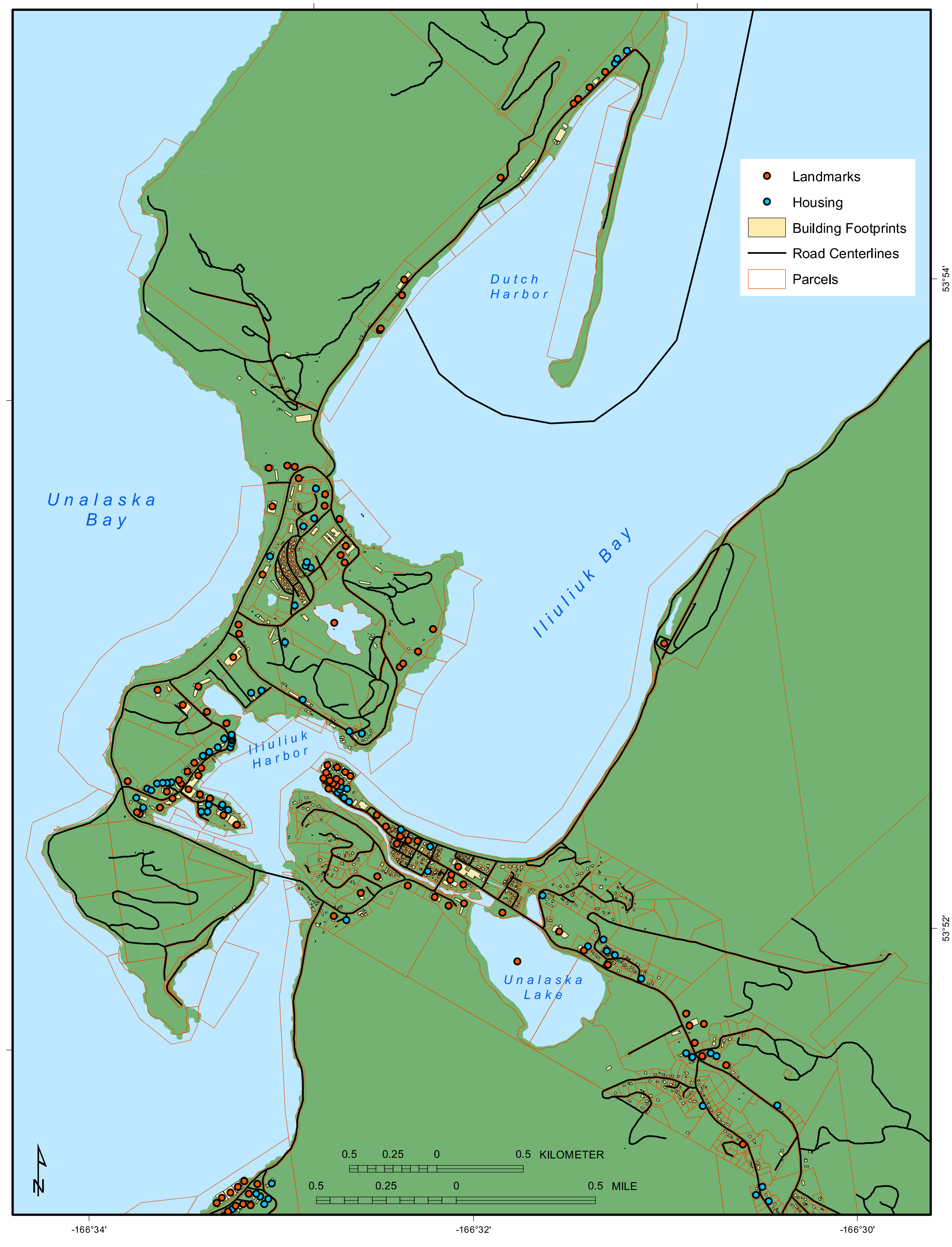


Figure 5. Map of Unalaska GIS data from the Unalaska Planning Office, including road centerlines, building footprints, parcel boundaries, named buildings, and landmark points.

EVACUATION SCENARIOS

We model the pedestrian evacuation time for four scenarios (Macpherson and others, 2017). We emphasize that the assumed base speed of the evacuee is set according to the “slow walk” option (0.91 m/s or 3 ft/s) in the PEAE settings. Note that this is a very conservative speed and many residents should be able to evacuate twice as fast (1.52 m/s [5 ft/s] “fast walk”, if not 1.79 m/s [5.9 ft/s] “slow run”) as the modeled rate.

Scenario 1. **Evacuation to the hazard zone boundary across all terrain**

Pedestrian evacuation from the tsunami hazard zone **over all viable surfaces** to the outer boundary of the hazard zone.

In the case of severe weather conditions or a thick snow cover, the evacuation might be confined to well-traveled roads and paths, therefore we assume that pedestrians will travel to the closest road and then stay on roads to leave the hazard zone.

Scenario 2. **Evacuation to the hazard zone boundary by roads only**

Pedestrian evacuation from roads and paths in the tsunami hazard zone **along the roads and paths** to the outer boundary of the hazard zone.

Several assembly areas along the evacuation routes by the Data Directions Consulting Group are considered (see figure 2). In the following two scenarios, we assume that pedestrians will travel to the closest assembly area.

Scenario 3. **Evacuation to the nearest assembly area across all terrain**

Pedestrian evacuation from the tsunami hazard zone **over all viable surfaces** to the nearest assembly area.

Scenario 4. Evacuation to the nearest assembly area by roads only

Pedestrian evacuation from roads and paths in the tsunami hazard zone **along the roads and paths** to the nearest assembly area.

MODELING RESULTS

We apply the methodology outlined in Macpherson and others (2017) to compute the travel times produced by the four scenarios. The pedestrian travel-time maps are shown on Sheets 1–4, corresponding to Scenarios 1–4.

In general, modeled evacuation times are relatively short, less than 10 minutes for most of the tsunami hazard zone. However, in all considered scenarios, evacuation times from the spit dock on Ballyhoo Road are considerably longer (28–69 minutes). Another area of concern, the Alyeska Seafoods facility, has evacuation times ranging from 4 to 28 minutes; this might be an area on which to focus evacuation training and tsunami education for residents and employees in this particular area. Most of the residential infrastructure on Amaknak Island is elevated above the hazard zone, but key linkages to other services and areas could be disrupted with all those routes passing through the hazard zone. Results for the Unalaska scenarios illustrate that many easily accessible hillsides contribute to short evacuation times. However, some evacuees on the hillside might be vulnerable to non-tsunami-related hazards such as severe weather conditions, ground failures, snow avalanches, etc.

MODEL VALIDATION

Validation of the results is an important component of each modeling study. We note that Wood and Schmidtlein (2012, 2013) and Jones and others (2014) indicate that modeling results might be sensitive to the spatial resolution of the DEM. Therefore, to ensure that our computations are accurate, we compare numerical calculations for Scenario 2 with site visit data (walking and timing the various routes confined to roads). While it is not feasible to walk every potential route to safety it is a good test to ensure that the model is producing reasonable times for pedestrian evacuation over the most likely paths to safety.

Two routes, shown in figure 6, were compared for Unalaska. Route 1 proceeds from the Spit, along Ballyhoo Road and up Ulatka Drive to the approximate assembly area limit. Route 2 follows West Broadway Avenue, over the Pedestrian Bridge and up Haystack Drive to estimate the most likely pedestrian evacuation route from Alyeska Seafoods. Real walking times and distances covered were recorded for each route and listed in Table 2.

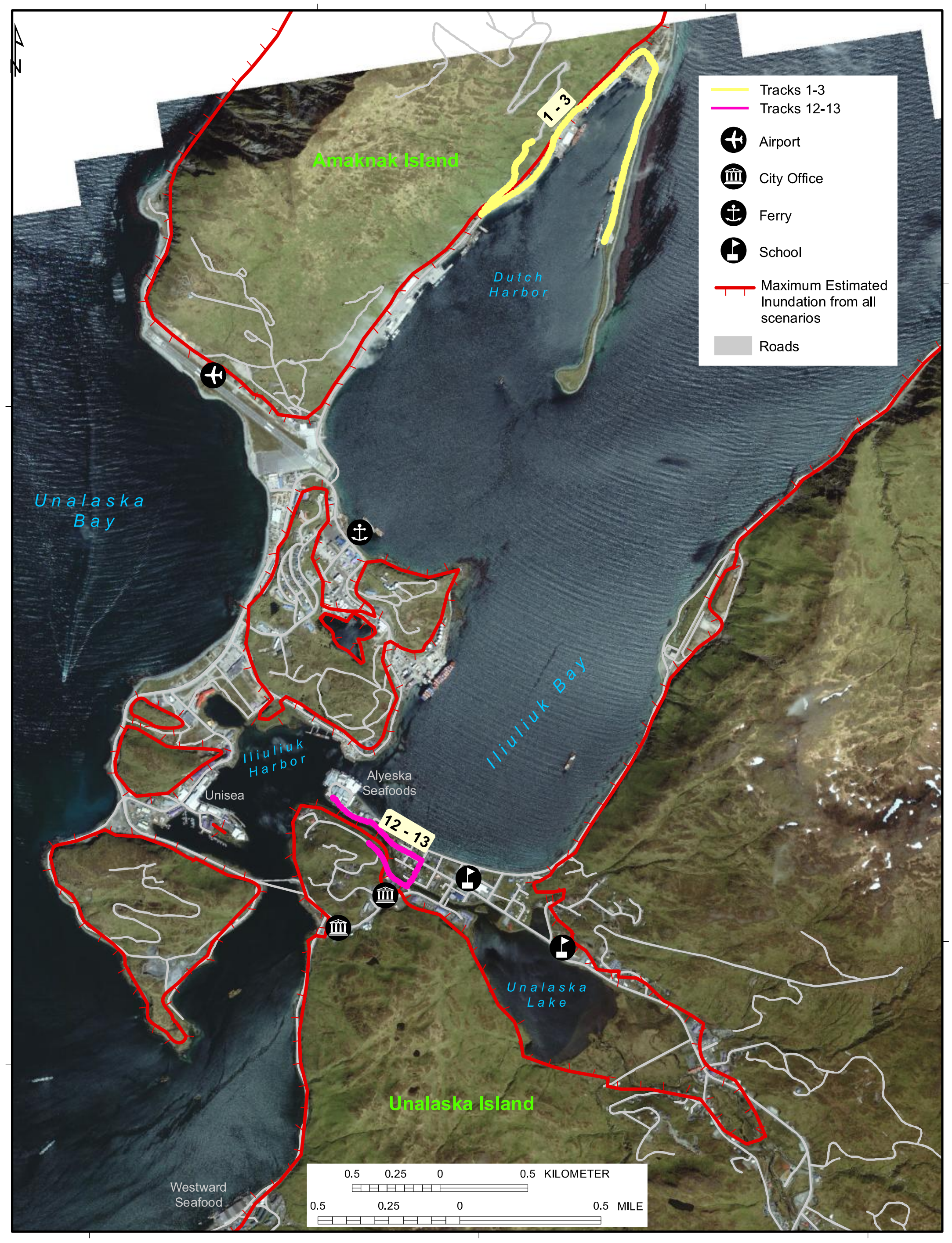


Figure 6. Tracks from site visit used to validate evacuation model times.

To compare the *in situ* measured walking times to the modeled results the measured walking times must be adjusted to account for the differences between the *in situ* walking speed and the modeled walking speed of 0.91 m/s (3 ft/s). We first note that it took about 42.5 minutes to walk 3,890 m (12,762 ft) along Route 1. Thus, an average *in situ* walking speed along Route 1 is about 1.52 m/s (4.99 ft/s). Therefore, if the same route had been traveled at a slower speed of 0.91 m/s (3 ft/s), then the travel time would be $42.5 \times 1.52 \div 0.91 \approx 71$ minutes. The *in situ* measured walking time, average speed, and adjusted travel times are listed in Table 1. The modeling results for Scenario 2 (evacuation by roads) indicate that it takes about 69 minutes to cover the same route. Similar calculations are performed to compare the measured and modeled travel times along the second route. In both cases, the model shows good agreement with the field observations.

Table 2. Measured and modeled travel time along two routes in the tsunami hazard zone.

Route	***In situ* measured walking time (minutes)**	**Walked distance (meters)**	**Average walking speed (meters/second)**	**Modeled time (minutes)**	**Recalculated *in situ* walking time (minutes)**
1	42.5	3,890	1.52	69	71
2	17.8	1,160	1.08	22	21

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, collapse of infrastructure, downed electrical wires, and the interaction of individuals during the evacuation will all influence evacuee movement. We employ a “slow walk” travel speed of 0.91 m/s (3 ft/s). Refer to Wood and Schmidtlein (2012, 2013), Jones and others (2014), and Macpherson and others (2017) for an in-depth discussion of the limitations of the LCD approach to estimate the travel times to safety.

SUMMARY

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. Overall, times generated by the model seem reasonable compared to actual walking times and routes. The pedestrian travel times should be used only as a guideline for emergency planning and response action. Some individuals less familiar with the area might take a less optimal route and will require more time to reach to safety. Additionally, in case of emergency, some individuals might require some time to recognize an imminent tsunami danger, and hence delay their evacuation. The information on this map 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.

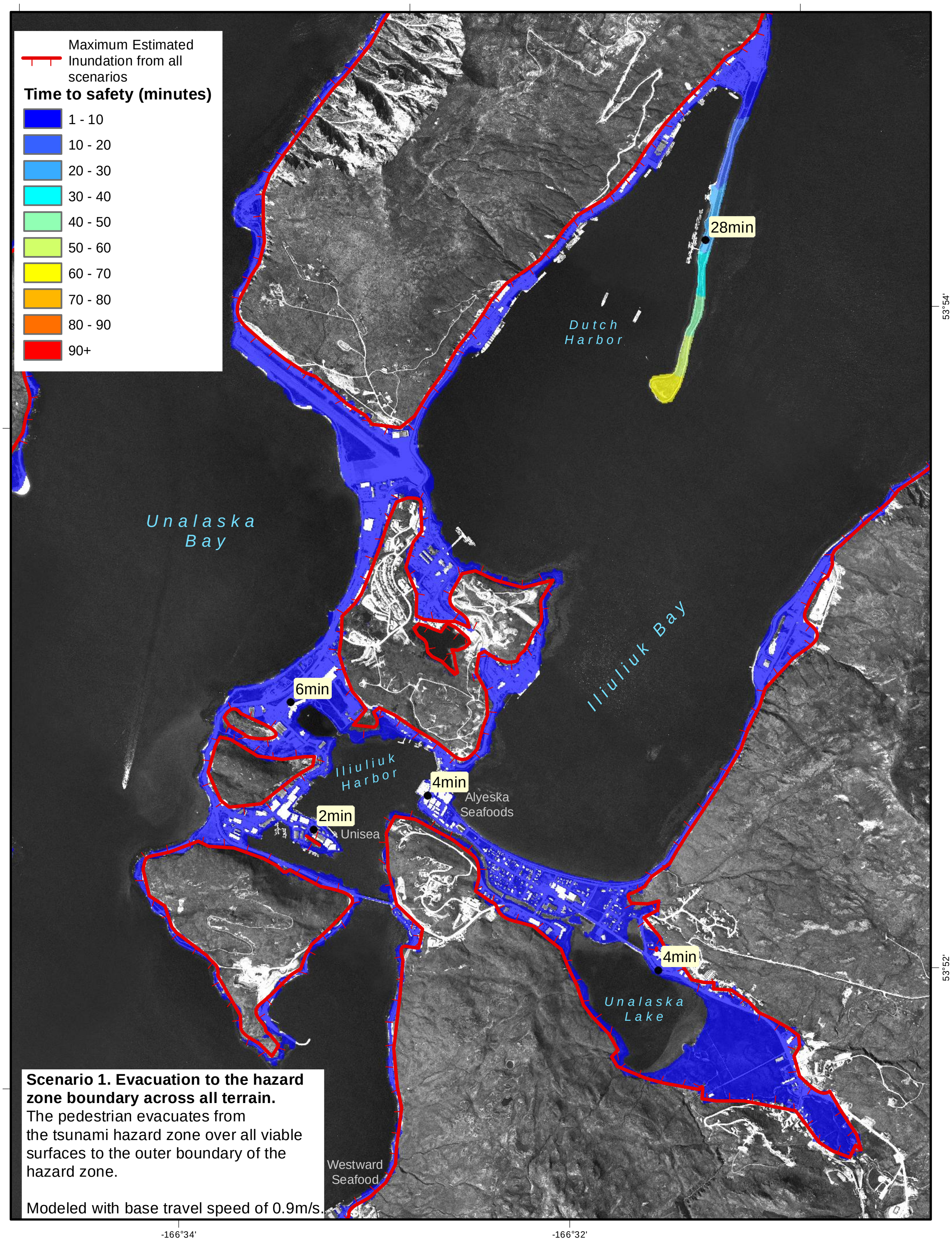
ACKNOWLEDGMENTS

Local knowledge was invaluable to this project and the members of the community were eager to discuss their plans and thoughts. Meetings with Fire Chief Zac Schasteen and other members of the Planning Office helped by sharing knowledge of the city's tsunami evacuation plan, GIS data, and insights into the community. This project received support from the National Oceanic and Atmospheric Administration (NOAA) under Reimbursable Service Agreement ADN 952011 with the State of Alaska’s Division of Homeland Security and Emergency Management (a division of the Department of Military and Veterans Affairs). A thoughtful review by Nathan Wood (USGS) improved the report and maps.

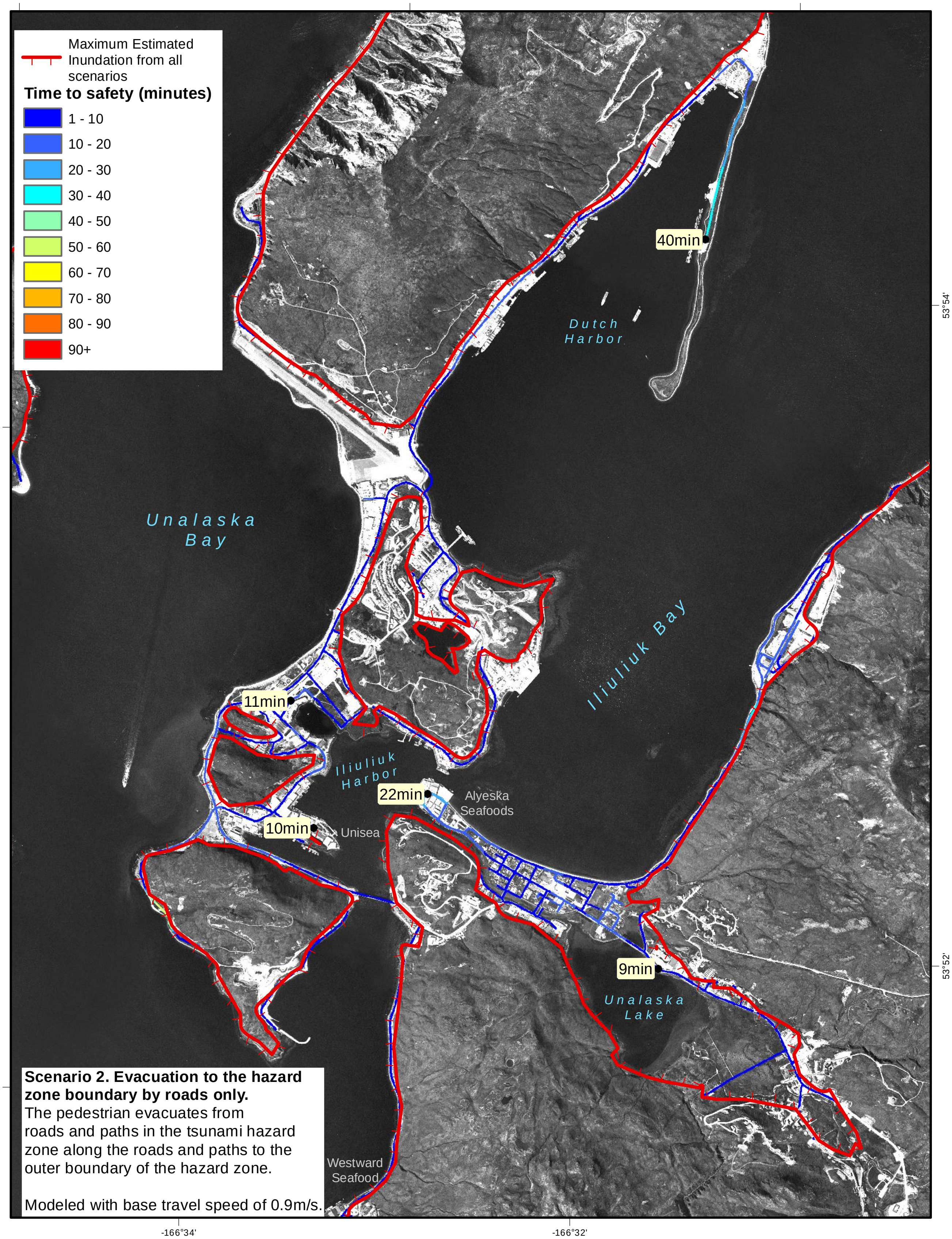
APPENDICES

APPENDIX A: Unalaska Tsunami Evacuation Plan

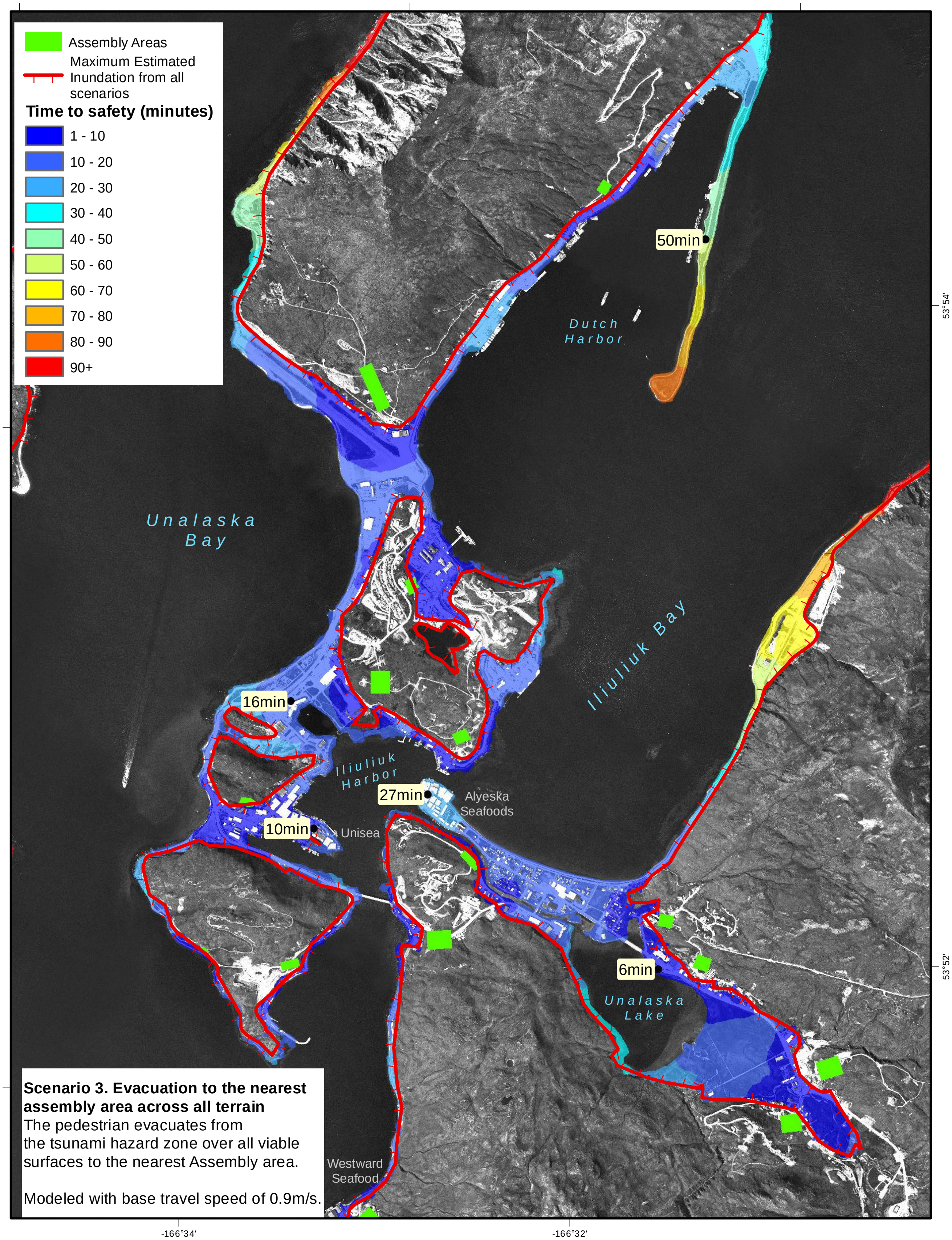
APPENDIX B: Site Visit Report for Unalaska/Dutch Harbor, Alaska



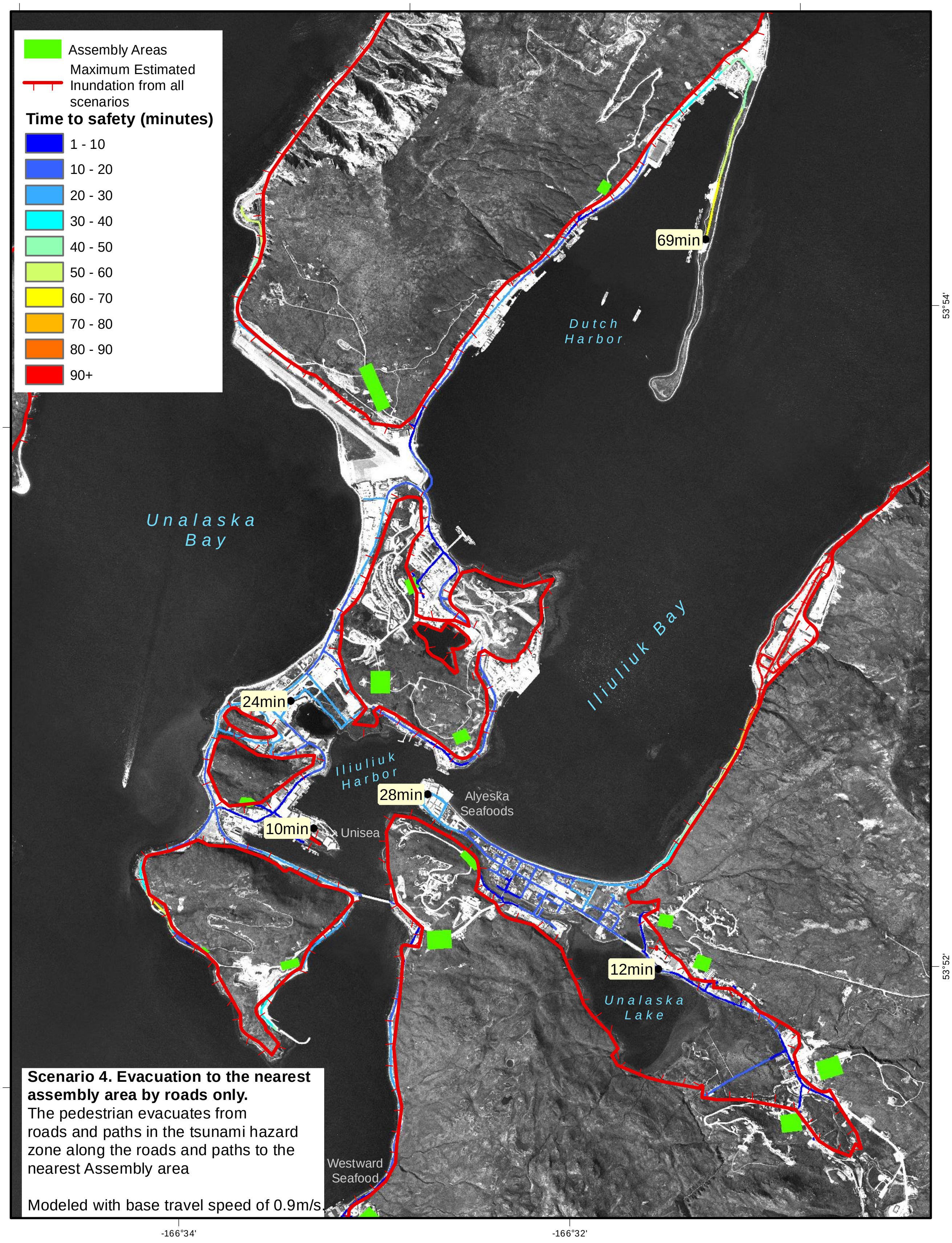
MAP SHEET 1: Travel-time map of pedestrian evacuation to the hazard zone boundary across all terrain



MAP SHEET 2: Travel-time map of pedestrian evacuation to the hazard zone boundary by roads only



MAP SHEET 3: Travel-time map of pedestrian evacuation to assembly areas across all terrain



MAP SHEET 4: Travel-time map of pedestrian evacuation to assembly areas by roads only

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