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Pedestrian Evacuation Time Analysis for Crescent City, CA

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Del Norte Local Transportation Commission

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CONTENTS

I. Introduction

A. Purpose/Background

The purpose of this project is to create pedestrian evacuation time maps for Crescent City, California as part of a feasibility study to assess pedestrian walking times using a hypothetical evacuation route (Route I) that would bisect Hwy 101 and Elk Valley road. The second part of this project evaluated whether the proposed Route II is a viable option for people located near the Crescent Beach Motel. Pedestrian evacuation time maps will illustrate how long it will take pedestrians to evacuate, by foot, to the closest safe evacuation zone in the event of a near-field (locally generated) tsunami from the Cascadia subduction zone (Figure 1). The first evacuation time map will display walking times under current conditions and the second will display walking times after Route I was included in the pedestrian evacuation time model.

The benefit to having an evacuation time map for pedestrian evacuation is that it can spatially demonstrate problematic areas; areas in which pedestrian walking times are outside of an acceptable time range. Both pedestrian evacuation time maps will help highlight areas that are located outside of an acceptable time range for evacuation because time is very critical when trying to avoid tsunami inundation.

Currently the residents of Crescent City and surrounding areas are at a high risk from a locally generated tsunami. A tsunami inundation map for emergency planning was developed by the California Emergency Management Agency, California Geological Survey, and the University of Southern California (Figure 2). This inundation map shows the extent to which a tsunami was modeled to inundate the area. The low relief in topography exposes them to the dangers of high velocity waves associated with a tsunami. Some locations around Crescent City have a particular problem in that during a real tsunami evacuation, they might not be able to reach a safe zone quick enough by foot. It's important to investigate how long it would take Crescent City evacuees to reach a safe destination by foot with and without the aid of an alternative evacuation route, and whether that time frame is realistic in the event of a real tsunami evacuation.

The updated work plan submitted with the Del Norte Local Transportation Commission (DNLTC) included four main tasks:

- Task 1 included creating a pedestrian evacuation time map for the study extent under current conditions.
- Task 2 was to create a pedestrian evacuation time map for the study extent that included the proposed pathway, Route I, by DNLTC.
- Task 3 included a detailed report that accompanied the two evacuation time maps.
- Task 4 included a copy of all of the pertinent GIS data.

The optimal evacuation route isn't always a straight line between two points. This line could intersect with physical obstacles such as buildings, lakes, rivers, or steep elevation. The best evacuation route should be based on the time it would take to get from one point to a desired final destination (i.e. a safe evacuation zone) while taking into account these physical obstacles. Therefore, it is necessary to calculate the distance between two points using two parameters: geometric distance and cost (e.g. time and energy); this concept is referred to as Cost Weighted

Distance (CWD) (Laghi, Cavalletti, 2004). The CWD concept is used to generate a Cost Surface by calculating the distance between each cell and the evacuation zone (Laghi, Cavalletti, 2004).

Coastal Risk Analysis of Tsunamis and Environmental Remediation (CRATER) published a user's manual for their GIS software entitled "Evacuation Routes Tools ArcGIS toolbox" (Laghi, Cavalletti, 2004). Laghi and Cavalletti designed several toolbox models that allow users to create pedestrian evacuation time maps based on this methodology and software. Laghi and Cavalletti's methodology is preferred for this project in that if a large, greater than 8 in magnitude, CSZ earthquake did occur, it would most likely damage or completely destroy the road network in Crescent City due to the affects of liquefaction and strong ground-shaking. For this reason it would be safer and quicker for evacuees to pursue a tsunami evacuation zone on foot rather than taking a car on possibly damaged roads.

B. Scope of Work

The scope of work conducted as part of the pedestrian evacuation time analysis for the DNLTC included the following:

- The development of a land-use layer from high resolution 2009 National Agriculture Imagery Program (NAIP) imagery for use in the pedestrian evacuation time model.
- Reclassifying the land-use layer using similar speed conservation values obtained from Graehl's pedestrian evacuation time analysis of the Samoa Peninsula, California (2008).
- Acquiring a digital elevation model (DEM) for the study area to create a slope map.
- Reclassifying the slope map to similar speed conservation values from (Graehl, 2008).
- Creating an inverse evacuation speed map to calculate the time it would take to walk across 0.5 square meter sized cells.
- Generating two evacuation time maps; one *without* the proposed route and another *with* the proposed route.
- The two evacuation time maps were then compared with one another.
- Calculating pedestrian walking times using predefined pathways along both the existing roads and on the proposed Route I.

C. Background Information/Reference Materials

Source and reference information for the pedestrian evacuation time analysis included:

- A 10 meter DEM for Crescent City downloaded from the USGS Seamless Data Downloader.
- Evacuation Routes Tools and methodology from Laghi & Calvetti.
- Digital raster graphic (DRG) of Crescent City downloaded from USGS Seamless Data Downloader.
- 2009 NAIP imagery for Crescent City downloaded from Cal-Atlas Geospatial Clearinghouse.
- 2009 Tsunami Inundation Map for Emergency Planning for Crescent City and Sister Rocks Quadrangles from California Emergency Management Agency, California Geological Survey, and University of Southern California.
- Location of proposed routes by Del Norte Local Transportation Commission.

II. Project Area

The Crescent City study extent, 9.8 km^2 in size, is located in Del Norte County in Crescent City, California (Figures 3). The tsunami inundation map for emergency planning was first orthorectified to the 2009 NAIP imagery and then secondly traced using heads-up digitizing in ArcGIS. The portion of the tsunami inundation line that intersected within the study area was included in the analysis. Everything inland of the tsunami inundation line was deemed as the safe evacuation zone.

Two evacuation routes were proposed by the DNLTC (Figure 4). Route I is a hypothetical evacuation route that bisects Hwy 101 and Elk Valley Road. This alternative pathway begins behind Curly Redwood Lodge off Hwy 101 and extents northward across Hambro Forests Products property where it connects up to Elk Valley Road. The pathway was digitized to be exactly 10 feet wide as to comply with the Federal Highway Administration (FHWA) shared-use path guidelines (FHWA, 2010). The placement of Route I may be ideal for decreasing the time it would take individuals to reach the safe evacuation zone on Elk Valley Road by not having to walk northwest first to reach the intersection of Hwy101 and Elk Valley Road.

The proposed Route II takes advantage of existing roads beginning from the Crescent Beach Motel and ending eastward near Martin Ranch (Figure 4). Route II was assessed using both evacuation time maps to observe if the inclusion of Route I had any effect with the feasibility of this route and to agree/disagree that this is the best route for evacuation for individuals at the Crescent Beach Motel.

A relatively dense population exists near the strip of motels and restaurants along Hwy 101, within the Harbor District, and along Crescent Beach. Influx of people to these locations may be great depending on the time of day and on special events. Many people work, live, and recreate around these areas and could potentially be severely impacted by a locally generated earthquake and tsunami.

Several marshes and areas of dense vegetation are positioned in the center of the study extent. This area is potentially a barrier to pedestrian evacuation. In the event of a real tsunami evacuation, most people will likely not cross this area because it is too costly in terms of time. This area limits the direction a person can evacuate. People will have to either head north or south along Hwy 101 to reach a safe evacuation zone. So depending on where an individual is located, assuming they are along Hwy 101 after a great earthquake, will determine which direction they should evacuate. People that recreate along Crescent Beach should know which direction they need to travel in the event of a locally generated tsunami.

III. Methods

Pedestrian walking times are calculated using a 'least costly path' method. In other words, it calculates, from any point in the study area, the quickest path to a safe evacuation zone. This is analogous to a drop of water moving down a hillside to reach a stream; it will flow downhill in the steepest direction, slowing down when it encounters obstacles, and speeding when it has no resistance. That drop can be timed, assuming an average downhill speed, and those times displayed using a gradational color scheme. Maps that display evacuation times in this manner are useful to gauge evacuation times for a particular extent. Hypothetical evacuation routes can also be looked at using this methodology. This helps to highlight areas that have evacuation times beyond an acceptable time frame and to see how hypothetical evacuation routes can influence pedestrian evacuation times.

To complete a pedestrian evacuation time analysis the following is required:

- ArcGIS >9.0 software
- Spatial Analyst and 3D Analyst extensions
- Evacuation Routes Tools ArcGIS toolbox (Laghi, Cavalletti, 2004)
- Digital elevation model(s)
- Land use data for the project's area

A. Raster Land Use Creation

To begin the analysis a vector land use polygon shapefile was constructed for the Crescent City area (Figure 5). This was achieved by first determining what land use features were of utmost importance to this study. Land use features that have the greatest effect on walking speed are ocean, wetlands, jetty, rocks, buildings, marsh upland areas, dense vegetation, beach/sand, grass/dirt, and roads/paved surfaces; in order from most to least costly. These features were digitized using 2009 1 meter resolution NAIP imagery gathered from the USGS Seamless data downloader. The high resolution imagery allows features to be digitized at scales less than 1:1,000. To insure good polygon topology, the Editor Toolbar was used along with setting appropriate topology rules and snapping tolerances.

The following procedures used in the analysis involved working mainly with raster layers, so the vector land-use polygons had to be converted into a raster dataset. This was done using the ArcGIS Conversion Tool – Feature to Raster. The output cell size for this raster dataset, 0.5 meters, was chosen by finding the smallest polygon width and then dividing that by two.

B. DEM and Slope Analysis

One of the biggest factors in evacuation speed is the degree of slope (Laghi, Cavalletti, 2004). A person walking or running on a steep slope will exert more energy and take more time than if they were on a flat surface. A 10 meter DEM was used to determine the slope within the study extent (Figure 7). This was done using the ArcGIS Spatial Analyst Extension – Surface Analysis – Slope toolset. The slope was then resampled to 0.5 meters to match that of the land use resolution.

C. Reclassification

The next step was to reclassify the land-use and slope layers by assigning appropriate walking speed values (Figure 6 and 7). The speed values were based on land use features. For example, a person walking on the beach will be slower than a person walking on a road, thus the speed values will be different. Compared to walking on a sandy surface such as the beach, a person might be slowed down by as much as 30%, while a person walking on a paved surface, such as a road, will not have an effect on walking speed. The Reclassify Land Use and Reclassify Slope Toolset was used to input the new walking speed values.

The land use raster dataset was reclassified to similar values that were obtained from walking speed averages that were calculated after conducting field work out on the Samoa Peninsula (Graehl, 2008). All values were normalized according to my walking speed over a section of flat pavement; this is analogous to the 100% speed conservation value. Refer to the table in figure 6 for the complete list of speed conservation values.

A similar approach was used to reassign corresponding values to the slope layer; the steeper the slope, the slower the walking speed. The values are based on my own personal experiences while working in extremely steep terrain; areas greater than 45 degree slopes. Refer to the table in figure 7 for the list of reclassified slope values.

D. Inverse Evacuation Speed Map

The Evacuation Speed Map Toolset was used to create the Inverse Evacuation Speed Map (Figure 8). This toolset combines both the reclassified land-use and slope raster datasets with an average walking speed of 1 meter per second. The result is a cost-weighted-surface (CWS) that contains the time it would take to walk across each cell, in terms of seconds per meter.

E. Evacuation Time Map*s*

The Evacuation Time Toolset was used to generate the final CWS map. On this CWS, each cell corresponds to how much it would cost, defined in terms of time, to get to the closest safe evacuation zone. The Evacuation Time Map output was in units of seconds; this was due in part to the units used for the average walking speed. The time map was then divided by 60 using the ArcGIS Spatial Analyst – Raster Calculator to have the walking speed represented in minutes rather than seconds. Walking time was grouped in blocks of five minute intervals and displayed with a green to red color scheme. Both maps detail the time needed to go from any location in the study area to the nearest safe evacuation zone following the least costly path. Refer to figures 9 and 10 for the Evacuation Time Maps.

IV. Results

The Evacuation Time Maps illustrate pedestrian evacuation times in minutes based on land use characteristics, slope, geometric distance, and on an average walking speed of 1 meter per second (Figure 9 and 10). Evacuation times generally increase outward as the distance from the safe evacuation zone increases. However, in some areas slope and land use characteristics have far more of an influence on evacuation times than distance. Land use features such as wetlands have a dramatic effect on pedestrian evacuation times. As it would be expected, pedestrian evacuation times varied throughout the study extent. Times ranged from zero to 138 minutes (~2.3 hours). The areas with the longest times are either located the farthest distance away from a safe evacuation zone or lie near or within a wetland area and are symbolized as black on the evacuation time maps.

A. Evacuation Time Map Comparison of Route I

The proposed evacuation Route I decreased walking times adjacent to and southward from the south end of Route I (Figure 10). Pedestrian walking times did not change in any other location. This can be observed by noticing that the 15.1-20 minute time band (colored yellow on figure

10) extents out geographically further when compared to the same time band in figure 9. The same is true for the 20.1-25 and 25.1-30 minute time bands. The inclusion of Route I had the largest effect for the areas around Curly Redwood Lodge, Harbor District, and along the north Crescent Beach area.

B. Evacuation Time Map Comparison of Route II

Proposed Route II was not influenced with the addition of Route I included in the pedestrian evacuation time model (refer to figures 9 and 10). This makes sense because none of the land use features changed in this vicinity. What is most noticeable about Route II is that it would take people at the Crescent Beach motel ~15.1-20 minutes to evacuate to the closest safe evacuation zone. The closest safe evacuation zone can be reached by walking south on Hwy 101 to Sand Mine road out towards Martin Ranch. Notice how the 5.1-10 minute time band 'V' inwards along Sand Mine road implying that this is the quickest pathway to reach a safe zone. The model results confirm that Route II is a viable option for people evacuating from the Crescent Beach Motel.

C. Predetermined Evacuation Path Locations & Walking Times - Route I

Predetermined routes were explored to calculate how long it would take individuals walking from a known point to a safe evacuation zone along current roadways. Two routes were drawn that had their starting points directly across from the Curly Redwood Lodge; one route would follow Hwy 101 north to Elk Valley road and the other would cut through the marsh and Hambro Forest Products property north along Route I to Elk Valley road (Figure 11). Both predetermined paths would end at the same point where the safe evacuation zone intersects Elk Valley road. Walking times were then calculated using geometric distance times an average walking speed of 1 meter per second (the same average walking speed used in the pedestrian evacuation time model). This method does not incorporate walking over different land use features or include slope in walking time calculations. This method gives crude estimates of walking time that can be used to judge the effectiveness Route I.

The predetermined pathway, illustrated as a red line in figure 11, has a total length of 1,852 meters; this equates to roughly 31 minutes of walking time. The other predetermined pathway using Route I, shown as a yellow line, has a total length of 1,347 meters; this calculates to ~22 and a half minutes. The difference in walking times between the two pathways is ~8 minutes and 26 seconds. This means that it would save people starting near the Curly Redwood Lodge about 8 and a half minutes of walking time to reach the safe evacuation zone along Elk Valley road.

D. Predetermined Evacuation Path Location & Walking Time - Route II

A predetermined pathway for evacuation was drawn from the Crescent Beach Motel east towards the safe evacuation zone located near Martin Ranch (Figure 12). The total length of this route is ~888 meters which would take a person almost 15 minutes to walk. The starting point for this predetermined pathway is nearly on top of the 15 minute mark generated from the pedestrian evacuation time model. It is important to note that there is another pathway for evacuation for people around Crescent Beach Motel; individuals can walk solely along Hwy 101 south to reach the safe evacuation zone but it would take longer to walk there since it is geographically farther away. This route is the best route for evacuation for people near the Crescent Beach Motel.

V. Summary and Conclusions

Pedestrian walking times decreased with the addition of Route I in the model. The areas that benefited the most by the addition of Route I was near the vicinity of Curly Redwood Lodge and the Harbor District. Nearly all of the Harbor District was within the 20.1-25 minute time interval when Route I was used compared to only about a quarter covered by the same interval without Route I. A predefined pathway that uses Route I, near Curly Redwood Lodge, showed that there was a savings in walking time of about 8 and a half minutes when compared to a predefined pathway that uses the current roadways as an evacuation route.

The proposed Route II is the best evacuation route from the Crescent Beach Motel since it's geographically the closest to a safe evacuation zone and that it takes people inland quicker which diminishes their exposure to a tsunami. Both the pedestrian evacuation time model and predefined Route II illustrate that it would take about 15 minutes to reach a safe evacuation zone.

In both evacuation time maps, there is a time divide that exists near the north end of Crescent Beach. This divide is useful because it helps to illustrate which direction is the quickest way to travel to reach a safe evacuation zone. The time divide changed when Route I was included in the model; the 25.1-30 minute intervals became closer together. The south side of the divide did not change in either of the evacuation time maps.

VI. Discussion

Both methods of calculating pedestrian walking speed show that Route I, does in fact, help people reach a safe zone quicker than if there were no alternative evacuation route but it only helps decrease walking times in a few areas. The people that would benefit most from Route I would be located within the Harbor District. There were no changes in walking times for areas north of the Lighthouse Inn along Hwy 101 meaning that Route I would not decrease their walking times. This is important to realize because there are motels, businesses, and restaurants that are along this portion of Hwy 101 which can, on occasion, contain many people.

Personal communication with Prof. Lori Dengler revealed that there is a portion of high ground on Whaler Island that she thinks is safe from tsunami inundation and that would be an appropriate evacuation area for people working in and around the Harbor District. I chose not to include this in the pedestrian evacuation time model because it is in disagreement with the tsunami inundation map for emergency planning that was developed by the California Emergency Management Agency, California Geological Survey, and the University of Southern California. If we do, however, consider that people in the Harbor District already have a safe area, then it is superfluous that Route I would be of any benefit to people in this area (even though it seems counterintuitive to tell people to run *towards* the ocean to reach a safe area).

Considering that the Harbor District benefits the most from having access to Route I, and that people in the Harbor District already have a potential safe area on Whaler Island, I would recommend not to build Route I. Even if there was not a safe area on Whaler Island, Route I would only decrease walking times for a relatively small area.

Route II is the best way to evacuate from the Crescent Beach Motel because it not only is the shortest route but it takes a person inland quicker which decreases their hazard exposure. If for some reason Sand Mine road becomes obstructed, people can always evacuate using Hwy 101. Northwest of Crescent Beach Motel up to the end of the 25.1-30 minute time band (colored red on figures 9 and 10) people will still want to evacuate along Route II. Any further north a person will cross the time divide and will want to evacuate in the opposite direction to another safe evacuation zone. Knowing where this divide is located may help emergency planners determine the best direction for future evacuation.

Pedestrian evacuation times beyond 30 minutes are of concern and should be considered in evacuation planning. The 'bad' areas are caused primarily due to geometric distance away from a safe evacuation zone and wetlands that cause extremely slow speed conservation values. These areas should be looked at carefully because they lie outside of an adequate time frame for pedestrian evacuation.

VI. Limitations of Analysis

This report was prepared by a M.S. candidate student of Geology at Humboldt State University, and all analysis herein were based on data and information collected by Nicholas Graehl. The pedestrian evacuation time methodology was developed in graduate level GIS classes at Humboldt State University.

The use of this pedestrian evacuation time model in Crescent City should only be used for planning purposes. Analysis, data, and results presented in this report were carried out in 2010-2011 using the latest data available. Changes in site conditions might have occurred since that time, and the data are therefore the best approximations based on the available information. The findings of this report are valid as of the report submittal date. Nicholas Graehl is not responsible for changes in pedestrian evacuation times due to changes in the local conditions of the area with the passage of time, whether due to natural processes or to the works of man.

The interpretations and conclusions presented in this report are based on a study of inherently limited scope. Observations are semi-qualitative, confined to air-photo interpretation of limited resolution with limited exposure of ground features. The pedestrian evacuation time maps cannot be used to determine walking times along pathways that do not follow least costly routes.

It is important to note that this study used an average evacuation speed of 1 m/s but not everyone walks at an average pace of 1 m/s. In reality this time would vary. People of all physical abilities would evacuate at different speeds and have different speed conservation values. With that said, the final pedestrian evacuation time maps offer considerable insight because they model current and hypothetical situations to generate relative pedestrian evacuation times for use in emergency planning.

VII. Future Analysis and Recommendations

Further refinement of the pedestrian evacuation time model variables and parameters is recommended in order to develop a robust model that accurately characterizes pedestrian evacuation times for Crescent City. Recommendations for further analyses include:

1) The study extent could be expanded to the west to include the town of Crescent City. Other safe evacuation zones exist and it would be interesting to see how these would influence pedestrian evacuation times.

2) Other potential evacuation routes should be considered. Perhaps changing the location of proposed Route I or including multiple evacuation routes might help decrease walking times to safe evacuation zones.

3) The pedestrian evacuation time model could include walking speeds for people with all physical abilities. One way to approach this would be to set a range of average walking speeds; 0.5 meters per second to 1.5 meters per second. That range might help to better constrain the slow and fast paced individuals walking times. It would be hard to quantify evacuation times for those that rely on using wheel-chairs because land use speed conservation values would have to change. For example, sand would have to be reclassified to have a higher penalty for crossing over that land feature.

4) The evaluation of further pedestrian evacuation times could incorporate time of day as a factor for evacuation. When dark people have a hard time seeing where they need to go and that will slow a person's walking speed down dramatically. After a great earthquake, power will certainly be out and people will most likely be using flashlights. Having closely spaced reflecting evacuation route signs may help to alleviate this problem.

5) The evaluation of model performance should include some ground-truthing. This will determine the model's performance comparing walking speeds over difference land use features. This can easily be done by recording field walking values over different land use features and then normalizing those values to 100% speed conservation values (i.e. walking speed over flat topography on a paved surface).

6) The best possible tsunami evacuation route pre-event might not end up being the best route post-event. Ground conditions could greatly change after a great Cascadia subduction zone earthquake. A probabilistic or deterministic hazard assessment for the study area might highlight some additional issues that need to be mitigated such as liquefaction potentials or areas of intense ground shaking. Obstructions on the ground post-event might inhibit an individual's route to safety; downed power lines or fallen buildings may make some areas impassible.

7) Consulting with the Redwood Coast Tsunami Work Group to assess other possible alternatives for tsunami hazard mitigation and emergency planning.

8) This pedestrian evacuation time model should only be used as one tool among several to identify the best possible tsunami evacuation routes in the study area.

VII. References

California Emergency Management Agency, California Geological Survey, University of Southern California, 2009. Tsunami inundation map for emergency planning – Crescent City and Sister Rocks Quadrangle.

Federal Highway Administration [Internet]. Chapter 14 – Shared use path design, 2010 [cited 2010 December 31]. Available from: http://www.fhwa.dot.gov/environment/sidewalk2/sidewalks214.htm

Graehl, N.A., Dengler, L., 2008. Using a GIS to model tsunami evacuation times for the community of Fairhaven, California. Eos Trans. AGU, 89(53), Fall Meet.Suppl., Abstract OS43D-1324.

Laghi, M., and Cavalletti, A., 2004. Coastal Risk Analysis of Tsunamis and Environmental Remediation - Evacuation routes tools ArcGIS toolbox user's manual. Asian Disaster Preparedness Center, 98 p.

VIII. Figures

TECTONIC SETTING

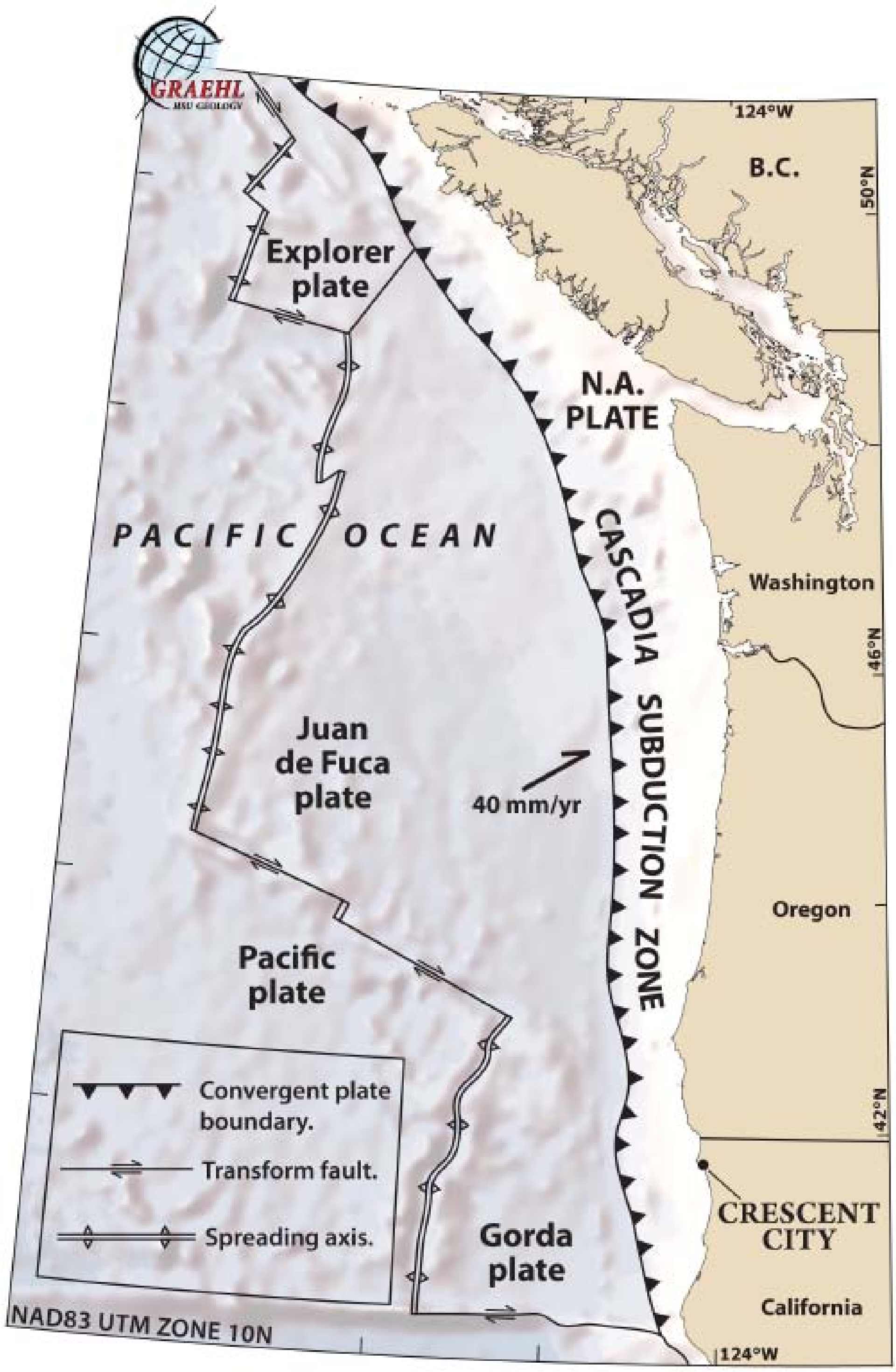


Figure 1. Pacific Northwest plate geometry showing the location of Crescent City relative to the Cascadia subduction zone (CSZ). Crescent City is approximately 80 miles east of the CSZ deformation front.

TSUNAMI INUNDATION MAP

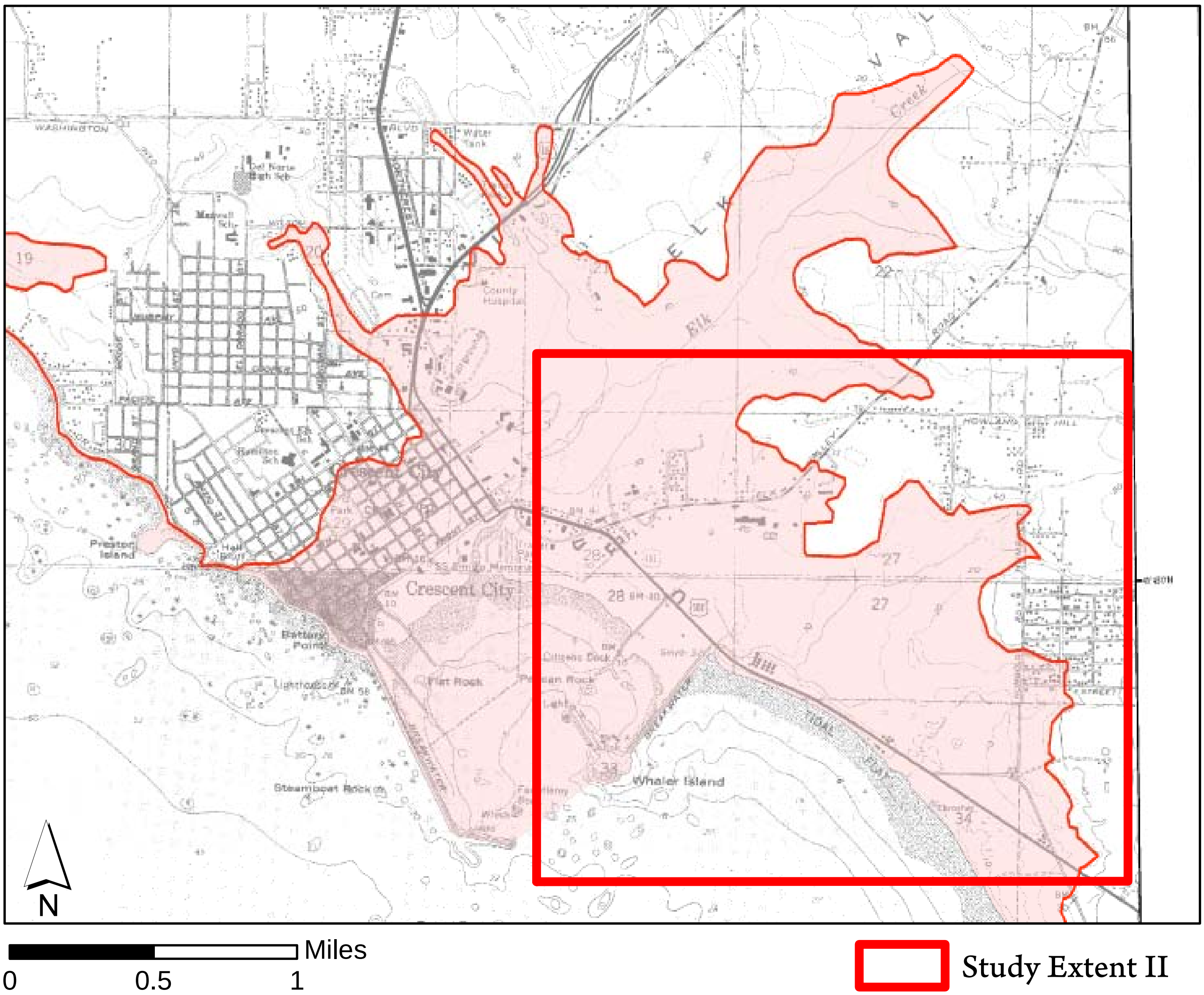


Figure 2. Tsunami inundation map for emergency planning for Crescent City and Sister Rocks Quadrangles developed by California Emergency Management Agency, California Geological Survey, and University of Southern California (2009). The red box denotes the extent of this study.

STUDY EXTENT & SAFE EVACUATION ZONE

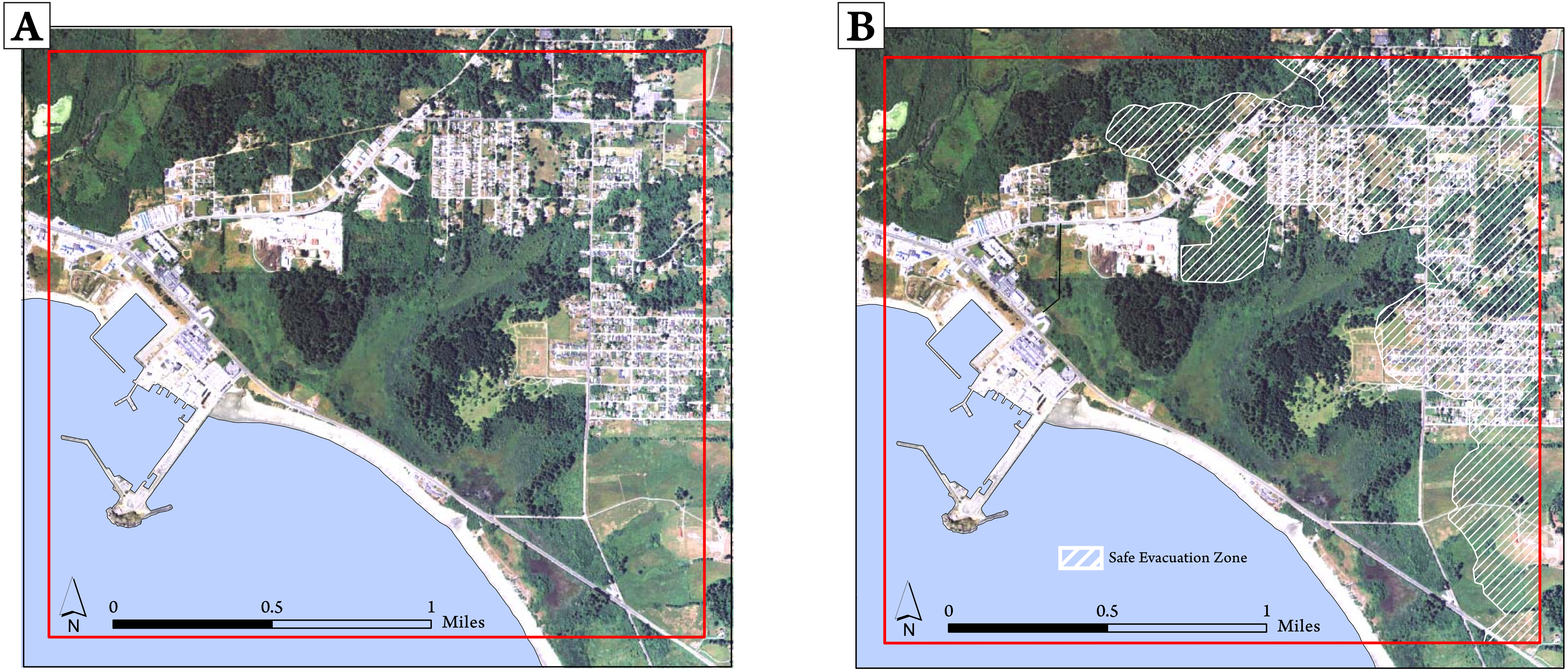
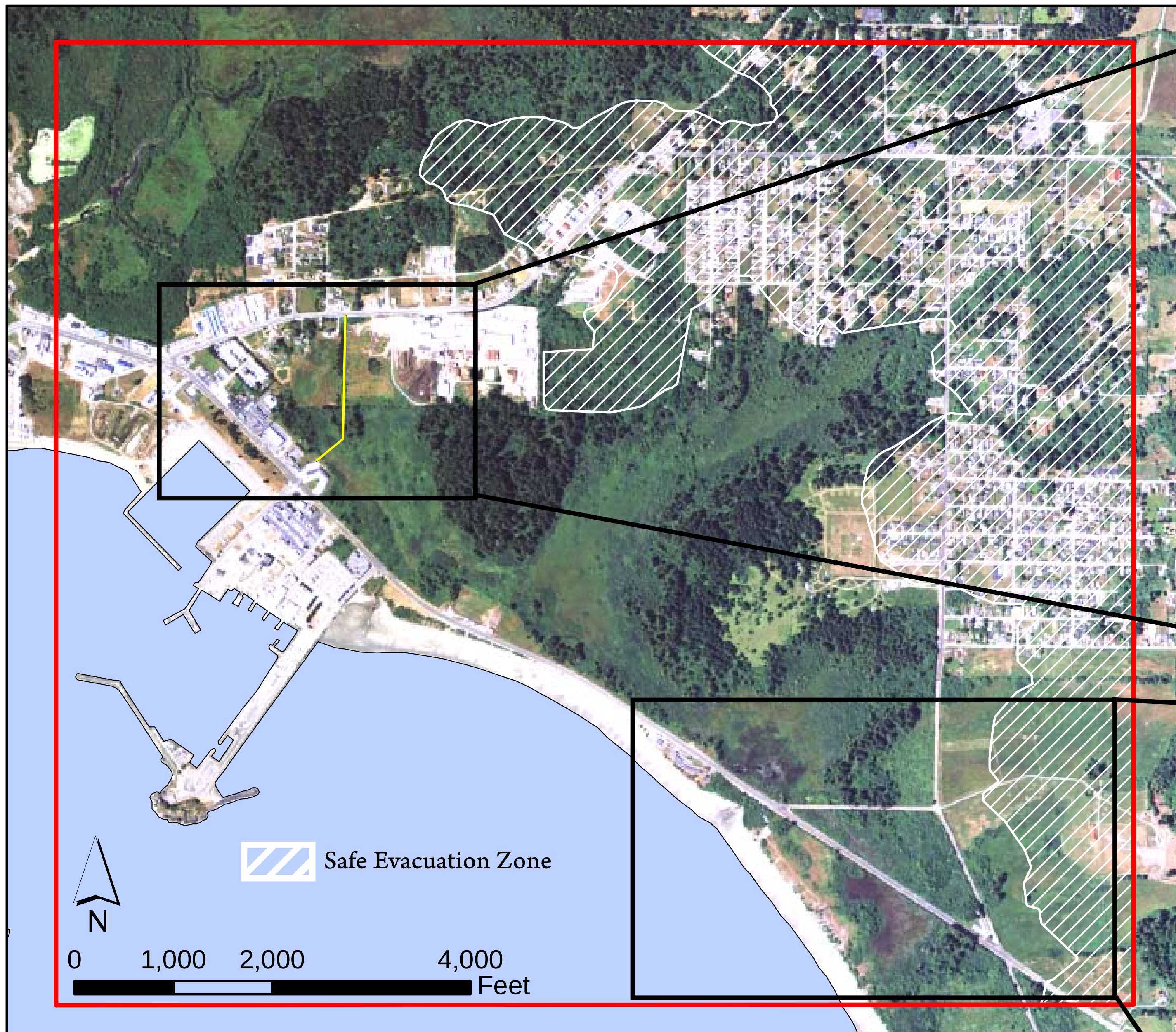


Figure 3. A) The red box denotes the extent to which the pedestrian evacuation time analysis was completed for Crescent City. B) The safe evacuation zone was digitized from the CalEMA, CGS, and USC Tsunami Inundation Map for the Crescent City and Sister Rocks quadrangles and is symbolized by the white hatched pattern (2009).

PROPOSED EVACUATION ROUTES



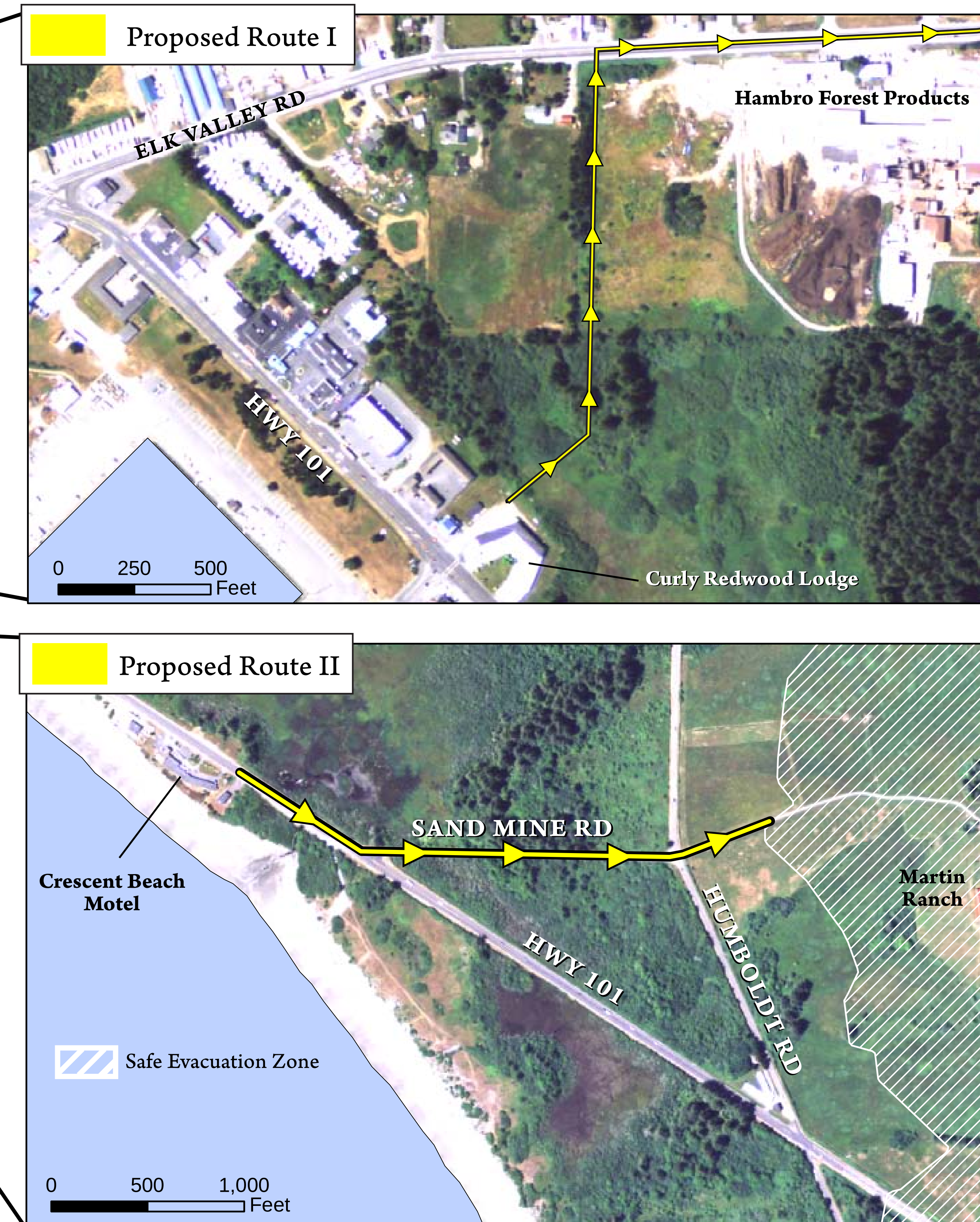


Figure 4. Two tsunami evacuation routes, Route I and Route II, were proposed by the Del Norte Local Transporation Commission. Route I is a proposed walking trail, 10 feet in width, that would bisect between HWY 101 and Elk Valley Road. Route II follows along a portion of HWY 101 and Sand Mine Road starting from Crescent Beach Motel.

LAND-USE CREATION

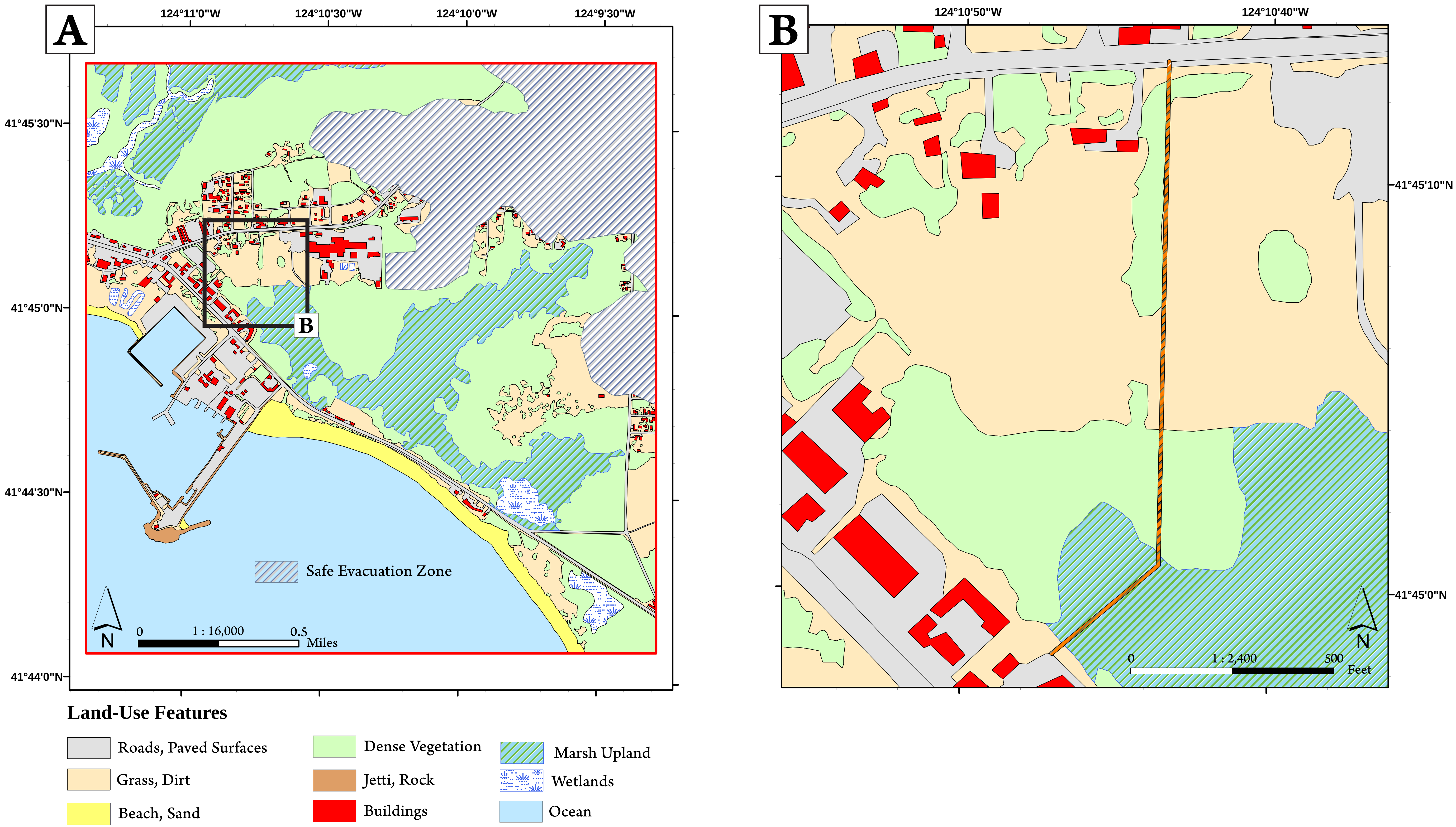
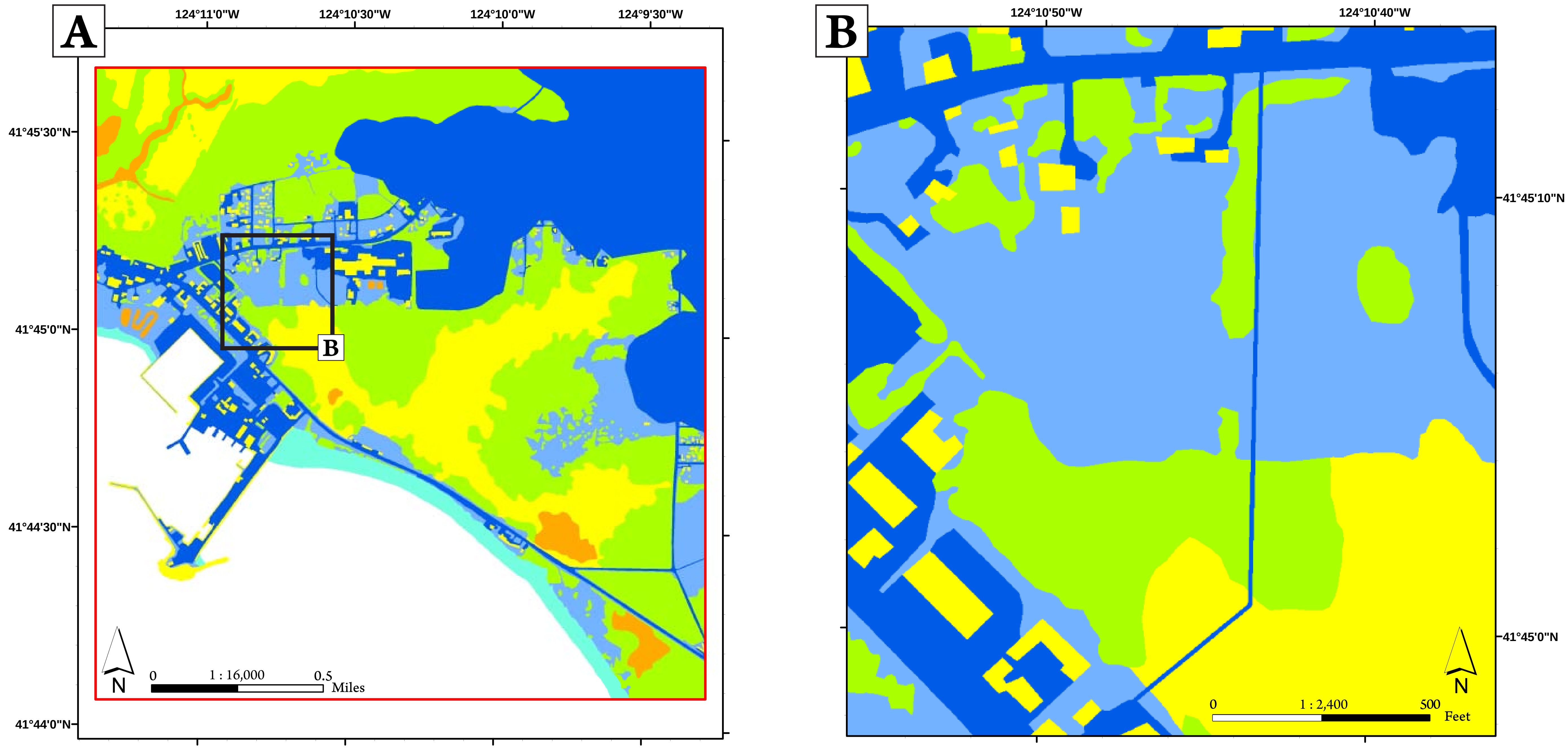


Figure 5. Land-use features were aggragated using characteristics that would most affect walking speed. These features were digitized from 2009 1 meter NAIP imagery at large scales, typically less than 1:1,000. B) This image illustrates the land-use features adjacent to the proposed evacuation route.

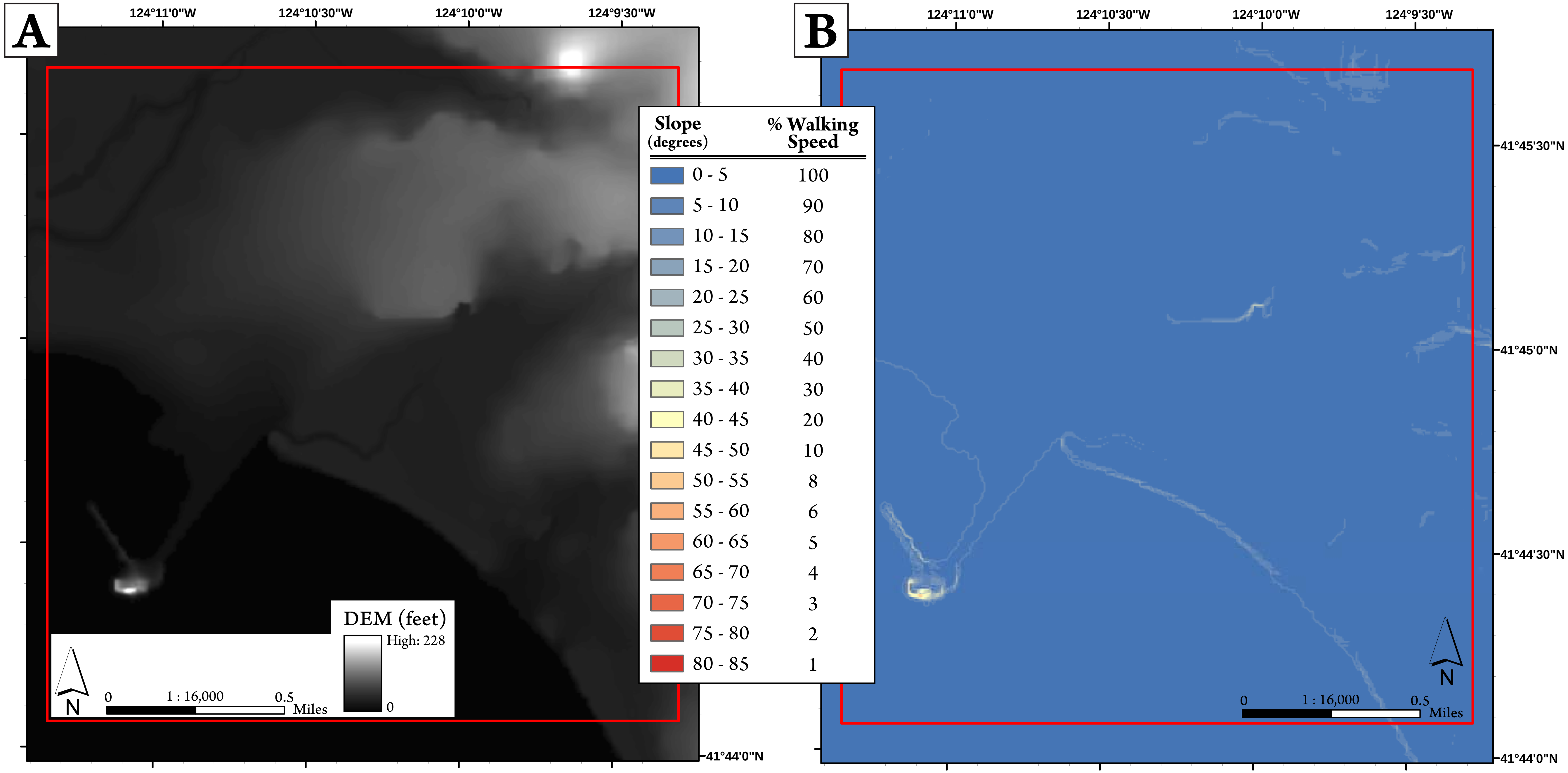
LAND-USE RECLASSIFIED



Land-Use Feature	% Walking Speed
Roads, Paved Surfaces, Hambro Evacuation Route	100
Grass, Dirt	85
Beach, Sand	70
Dense Vegetation	30
Jetti, Rocks, Buildings, Marsh Upland Areas	5
Wetlands	2
Ocean	0

Figure 6. Land-use features were reclassified based on walking speed conservation that were modified from (Graehl, 2008). For example, a person walking at 100% would be walking at 1 m/s while at 30% would be walking 0.3 m/s. A) Land-use features reclassified within study extent. B) Rclassified land-use features adjacent to the proposed evacuation route.

SPEED CONSERVATION FOR SLOPE



Slope (degrees)	% Walking Speed
0 - 5	100
5 - 10	90
10 - 15	80
15 - 20	70
20 - 25	60
25 - 30	50
30 - 35	40
35 - 40	30
40 - 45	20
45 - 50	10
50 - 55	8
55 - 60	6
60 - 65	5
65 - 70	4
70 - 75	3
75 - 80	2
80 - 85	1

Figure 7. A) A 10 meter digital elevation model (DEM) for the study extent was resampled to 0.5 meters for use in the analysis. Lighter grey colors represent higher elevations. B) A slope model was generated using the Spatial Analyst Extention in ArcGIS. Slope in degrees was classified by walking speed percentage values (refer to table above).

INVERSE EVACUATION SPEED

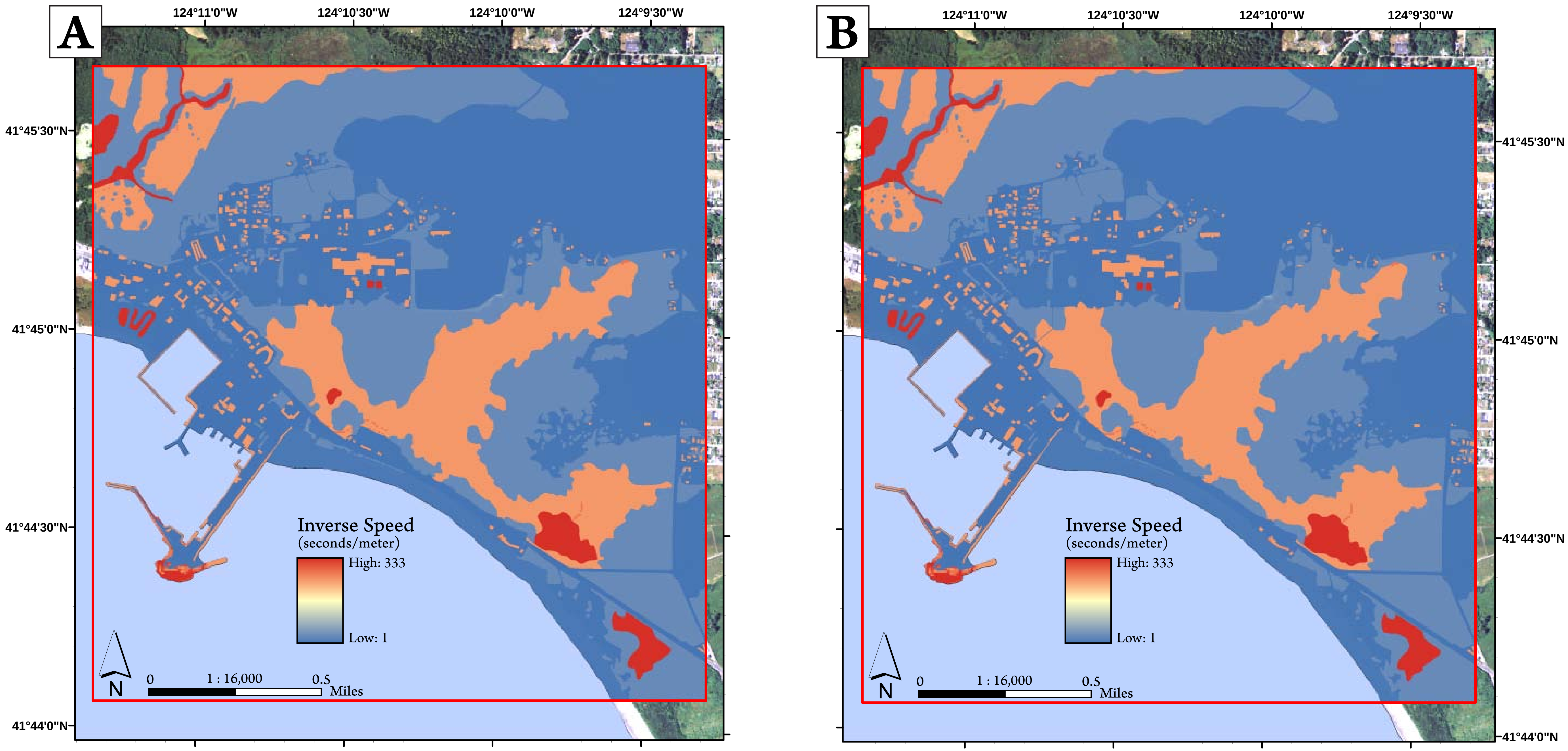


Figure 8. The Inverse Evacuation Speed Map was created by combining the reclassified Land-Use and Slope raster datasets with an average evacuation speed of 1 m/s. These maps illustrates the time it would take to walk across each cell (0.5 m). A) Inverse evacuation speeds *without* the proposed evacuation route. B) Inverse evacuation speeds *with* the proposed evacuation route.

EVACUATION TIME MAP *WITHOUT* PROPOSED ROUTE I

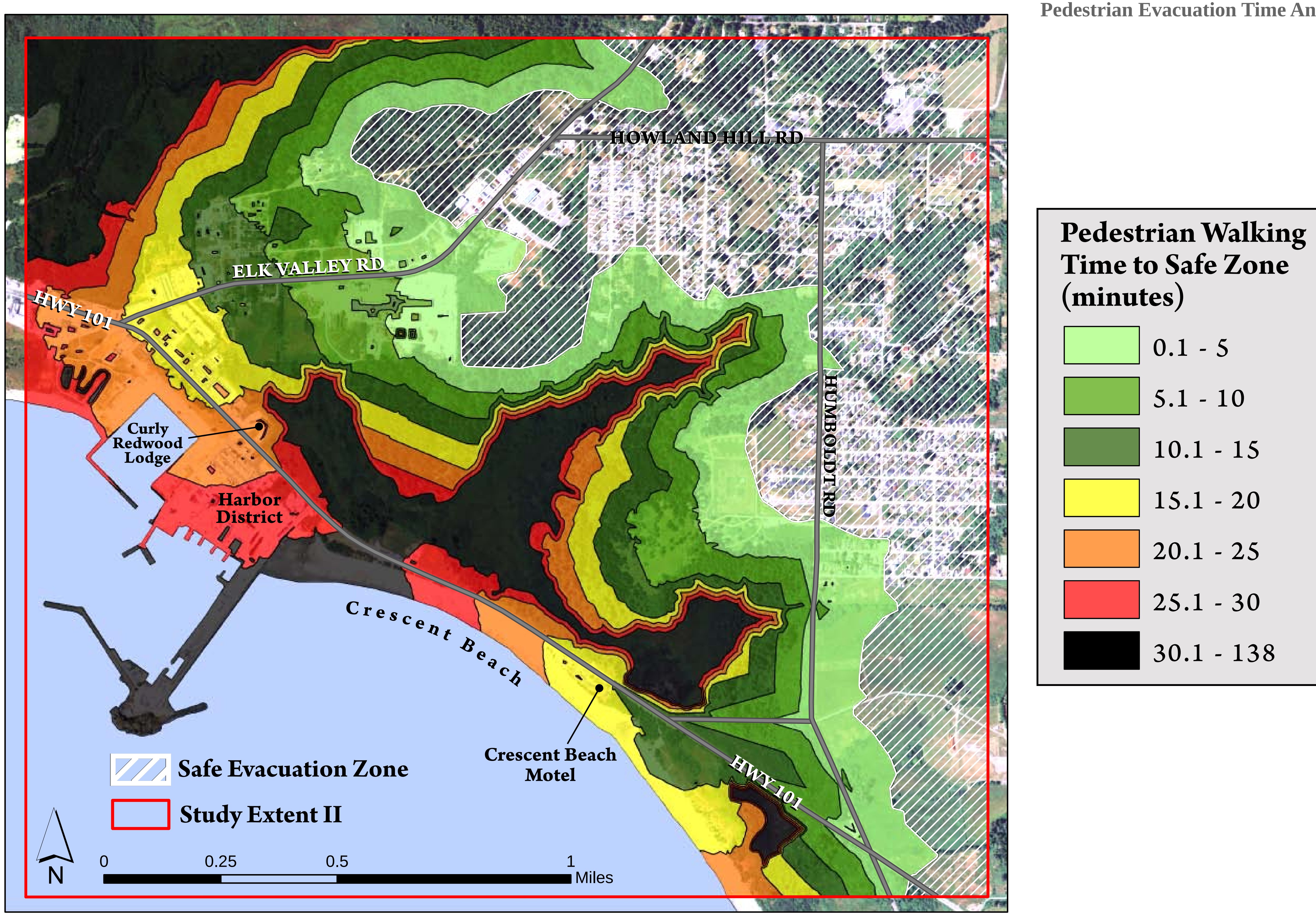


Figure 9. Pedestrian evacuation time map results without the proposed Route I. This map illustrates the time it would take to walk, in minutes, to the closest safe evacuation zone. Note that pedestrian walking times are symbolized as color bands where each color band represents five-minutes of walking time. Note that walking times greater than 30 minutes were grouped together and symbolized as black.

EVACUATION TIME MAP *WITH* PROPOSED ROUTE I

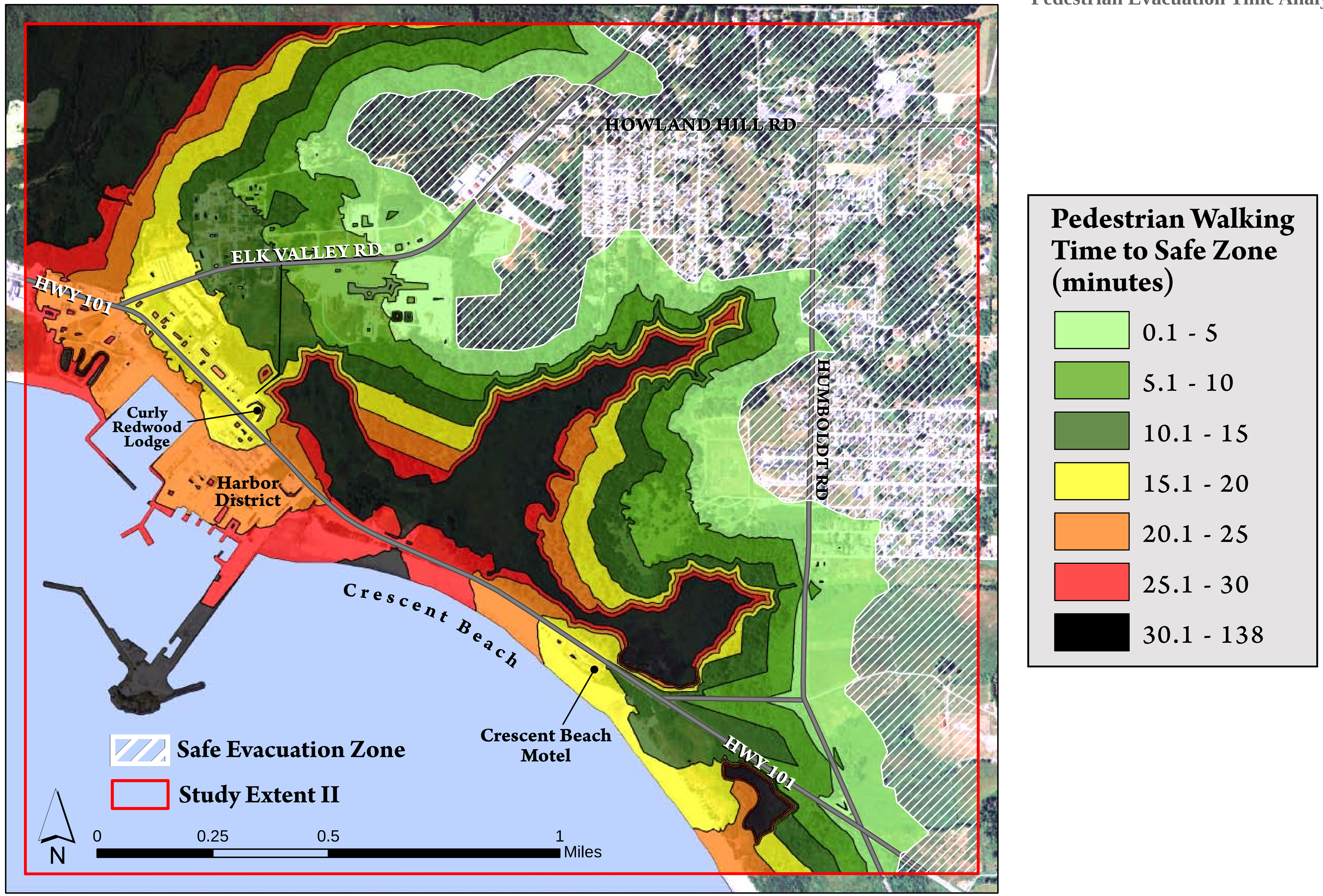


Figure 10. Pedestrian evacuation time map results *with* proposed Route I. Route I is symbolized by the thin black line slightly north of Curly Redwood Lodge. This map illustrates the time it would take to walk, in minutes, to the closest safe evacuation zone with Route I included in the model. Note that pedestrian walking times are symbolized as color bands where each color band represents five-minutes of walking time. Note that walking times greater than 30 minutes were grouped together and symbolized as black. Pedestrian walking times were decreased adjacent to the southern end of Route I and surrounding area including the area along HWY 101 near Crescent Beach.

PREDETERMINED PATHS & CORRESPONDING WALKING TIMES

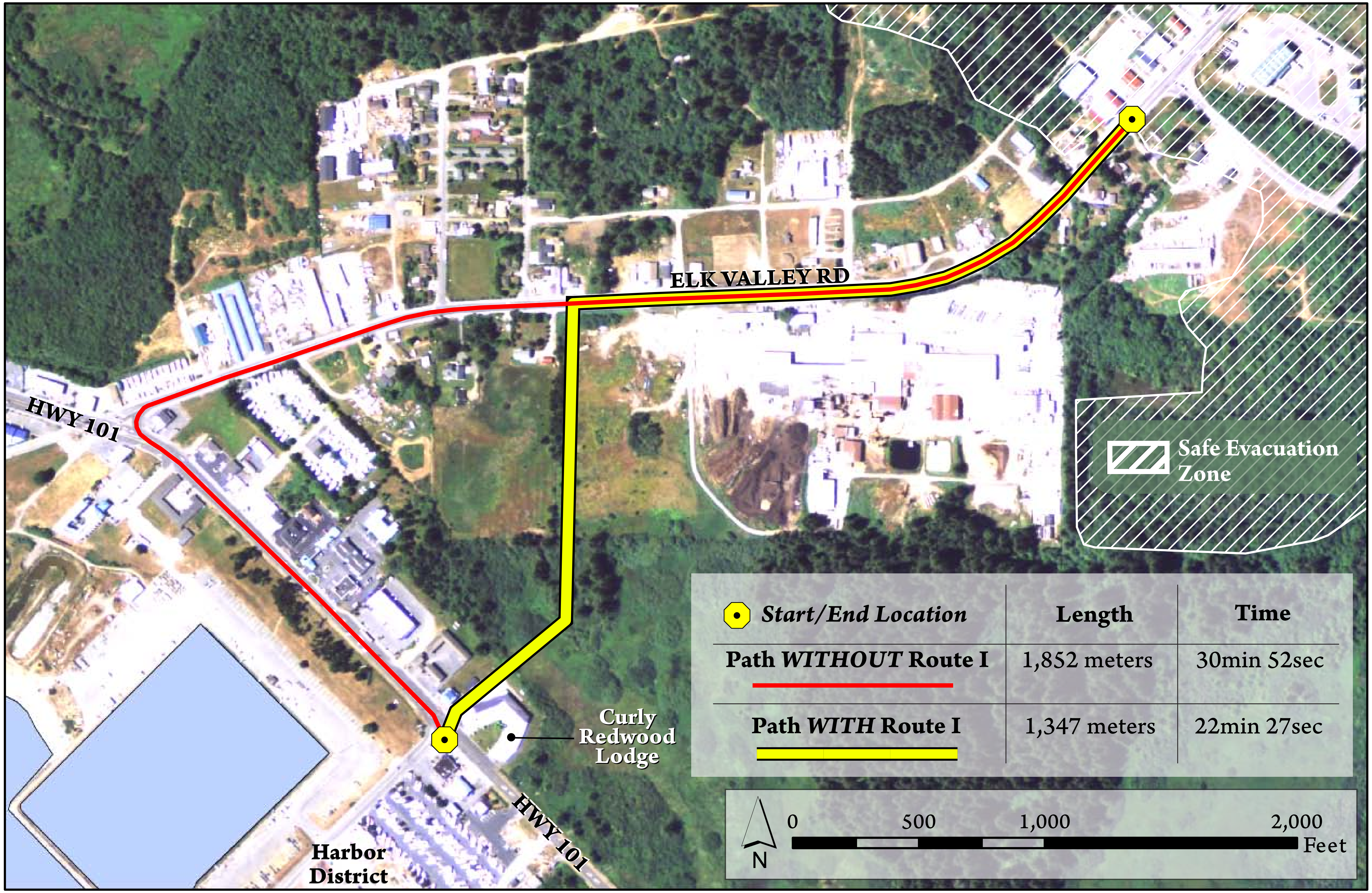


Figure 11. Two potential evacuation routes were drawn to calculate pedestrian walking times to a safe evacuation zone. The red line denotes a path that people might use under current conditions while the yellow line shows a path people might take when Route I is in place. Walking times were calculated by using the geographic distance times an average walking speed of 1 meter per second (the same average walking speed using in the pedestrian evacuation model). People starting to evacuate near Curly Redwood Lodge would save ~8 and a half minutes of walking time if they took Route I (yellow route) vs. taking the red route.

PREDETERMINED PATHS & CORRESPONDING WALKING TIMES

Figure 12.The predetermined pathway, shown above in red, illustrates the proposed Route II. This pathway would be the quickest route to a safe evacuation zone for people evacuating from the Crescent Beach Motel. This route is not only the geometrically shortest distance to a safe zone but it gets people inland quicker than if they were to evacuate south along Hwy 101.