RELATIVE TSUNAMI HAZARD MAPPING FOR HUMBOLDT AND DEL NORTE COUNTIES, CALIFORNIA

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Abstract

Tsunami hazard maps are constructed using a raster-based geographical information systems (GIS) approach to depict the relative tsunami hazard of coastal Humboldt and Del Norte County in northern California (http://www.humboldt.edu/~geodept/earthquakes/rctwg/toc.html). In contrast to maps depicting hazard by a single inundation line, the raster model allows a gradational scale. Elevation, normally used for 2.5D surfaces, is substituted with safety units. Hazard is displayed as a safety index, a continuous gradational color scale ranging from red (high hazard) through orange (medium), yellow (low) to white (no hazard). Hazard-elevation relations were developed using existing numerical modeling, paleoseismic studies, historical flooding, FEMA Q3 zone A flood maps, and impacts of recent tsunamis elsewhere. Hazard units are further modified by distance to open water. The raster model is primarily based on topography, so the parameters may be easily adjusted and integrated into the model, as new hazard-elevation relations are developed through numerical modeling or other methods. An advantage to this approach is that tsunami hazard maps can be constructed even when numerical modeling does not exist and can be readily adjusted as new information/modeling results become available. The GIS framework facilitates ready adaptation by planners and emergency managers and offers a broad range of scale options. The maps are intended for educational purposes, to improve awareness of tsunami hazards, and to encourage emergency planning efforts of local and regional organizations by illustrating the range of possible tsunami events. The maps have been adopted by the Humboldt County Office of Emergency Services as part of their tsunami hazard mitigation plan.

Introduction

Humboldt Bay, the lower Eel River Valley, and Crescent City (Fig. 1: CSZ, Humboldt and Del Norte Counties) are located on the western edge of the North America Plate near the southern end of the Cascadia subduction zone (CSZ). Based on paleoseismic records along coastal North America (Atwater and others, 1995) and historic records in Japan (Satake and others, 1996), earthquakes generated by rupture on the CSZ have generated tsunami. In addition to locally generated tsunami hazard, teletsunami from Chile (1960) and Alaska (1964) had devastating effect in Crescent City. Coastal northern California communities will fare greater disaster success (will better successfully survive coastal disaster) when people are better educated about tsunami safety and preparedness. People generally have some sense of geography, cultural and physical. Maps are effective tools to help educate people about hazard safety. Since potential tsunami fiscal damage and casualty development dwarfs any other man-made or natural disaster (Priest, 1995), and education is so effective at reducing these casualties (Dengler and Preuss, 2003, Dengler, 2005), the inexpensive methods used in this study attain a high value.

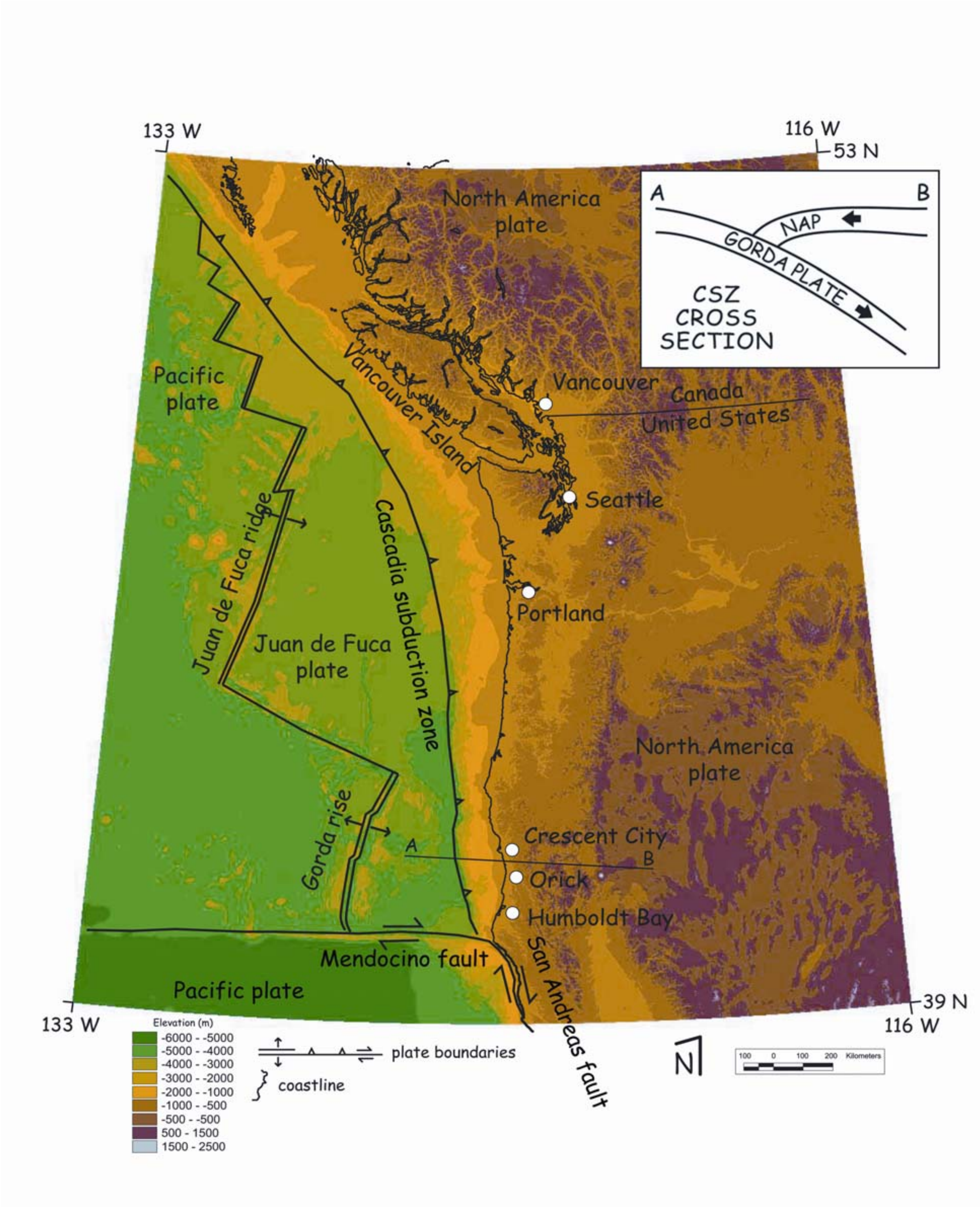

Figure 1. Cascadia subduction zone (CSZ) and other plate boundaries. Color represents elevation as shown in the legend (Haugerud, 1999). Crescent City, Orick, and Humboldt Bay are in California. Schematic cross section A-B shows CSZ configuration of Gorda and North America plates.

Past inundation projections for the Humboldt Bay region (Toppazada and others, 1995, Bernard and others, 1994) depicted hazard as a single line that potential users found difficult to apply. More recently hazard mapping efforts were developed using a TIN to model hazard (Dengler and others, 2003). Both the Humboldt Bay and the lower Eel River Valley regions have previously been mapped with a similar method using a triangulated irregular network (TIN) model. This project was used to develop the relations between hazard, elevation, and distance to the open coast. One limitation of this method is that it is a cumbersome data model to edit and modify. This paper discusses the methods used to display tsunami hazard gradationally to promote a better understanding of the tsunami hazard and foster regional tsunami planning efforts.

Methods

Relative tsunami hazard is displayed on maps as a color gradient that represents gradually decreasing hazard. The wide range of tsunami hazard is partitioned into three levels based on three different sources of tsunami. Hazard-elevation relations are used to display the hazard through these three levels.

Tsunami hazard mapping for the north coast of California considers three levels of hazard including both teletsunami and local tsunami sources. The most hazardous level is the area that has likely been inundated historically by teletsunami. The moderately hazardous area includes areas likely to be inundated during a Cascadia subduction zone rupture generated tsunami. The lowest hazard area includes areas likely to be inundated during a worst-case scenario CSZ rupture with associated submarine landslide generated tsunami.

Each of these three levels of hazard has an associated run-up elevation range (Dengler and others, 2003, Patton and others, 2004). On the open coast the high hazard run-up elevation is three meters, the moderate hazard run-up elevation is ten meters, and the low hazard run-up elevation is thirty-five meters (Table 1). Hazard-elevation relations are developed by correlating increasing hazard with increasing elevation. These hazard-elevation relations are described by the regression line in Figure 2. The safety index represents the range of tsunami hazard along the y-axis; elevation is along the x-axis. The equation of this line is used to convert elevation units to safety units.

Hazard area boundaries are initially defined for each zone above based on elevation:

Zone	Description	High	Moderate	Low	None
Open Coast	Everywhere within 3km of coast	0 - 3 m elev	3 - 10 m elev	10 - 35 m elev	above 35 m elev

Table 1. Elevation ranges for three hazard levels.

There is a difference in the hazard between the open coast and further inland. Similar to Priest (1995) we further refine this estimate of range of tsunami hazard by including a component of the equation that considers distance to the coast. A grid is generated with cells that have values that diminish linearly to zero, twelve km from the coastline. Using map algebra a ten-meter resolution digital elevation model (DEM) is converted from elevation units to safety units with an equation that includes expressions standing for the hazard-elevations relations and the coastline-distance relations.

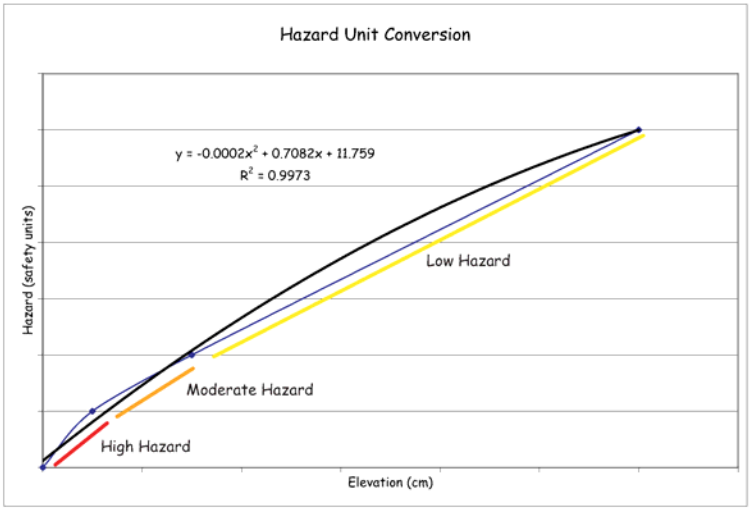

Figure 2. Hazard-elevation relations unit conversion graph. Elevation for three levels of hazard (Table 1) are correlated to the safety index. The regression line defines the relations used in the raster conversion of elevation units to safety units.

Another difference between the hazard along the open coast and that near more protected bodies of water, like Humboldt Bay, is the nature of the waves. The open coast is subjected to both elevated water levels and high velocity wave impact. In contrast, flooding within Humboldt Bay is more likely to resemble other flooding with locally high currents forced by changing water levels but no large wave impacts. In order to discriminate high-hazard on the open coast from high-hazard in tidally inundated areas that are protected from the coast, cross hatching representing high velocity wave hazard is displayed to a distance of 3km from the coastline. High velocity wave hazard is not displayed above 10 meters in elevation. Others have also limited how hazard is displayed based on topography (Priest, 1995).

Finally a color gradient including red, orange, yellow, and white are applied to the associated safety unit values. By adjusting the percent of CMYK values for each step between the levels of hazard, a smooth color gradient is applied to the safety surface.

Results

Crescent City, Orick Valley, and the Humboldt Bay region have been mapped using this method. Products include placemats, county level hazard mitigation planning, and county fair educational posters.

Crescent City is the first region to be mapped with this method (Figure 3). Several places show how this mapping technique can adjust hazard based on the variables used. Low topography along Elk Creek is represented by higher hazard colors than the surrounding lower hazard, higher ground. The distance grid expression that reduces hazard with distance from the coast can be seen in Lake Earl that is safer on the east side since it is further from the coastline. A second way to see how the distance grid affects the safety index is by looking at the 10m contour line and how it converges and diverges from the safety index.

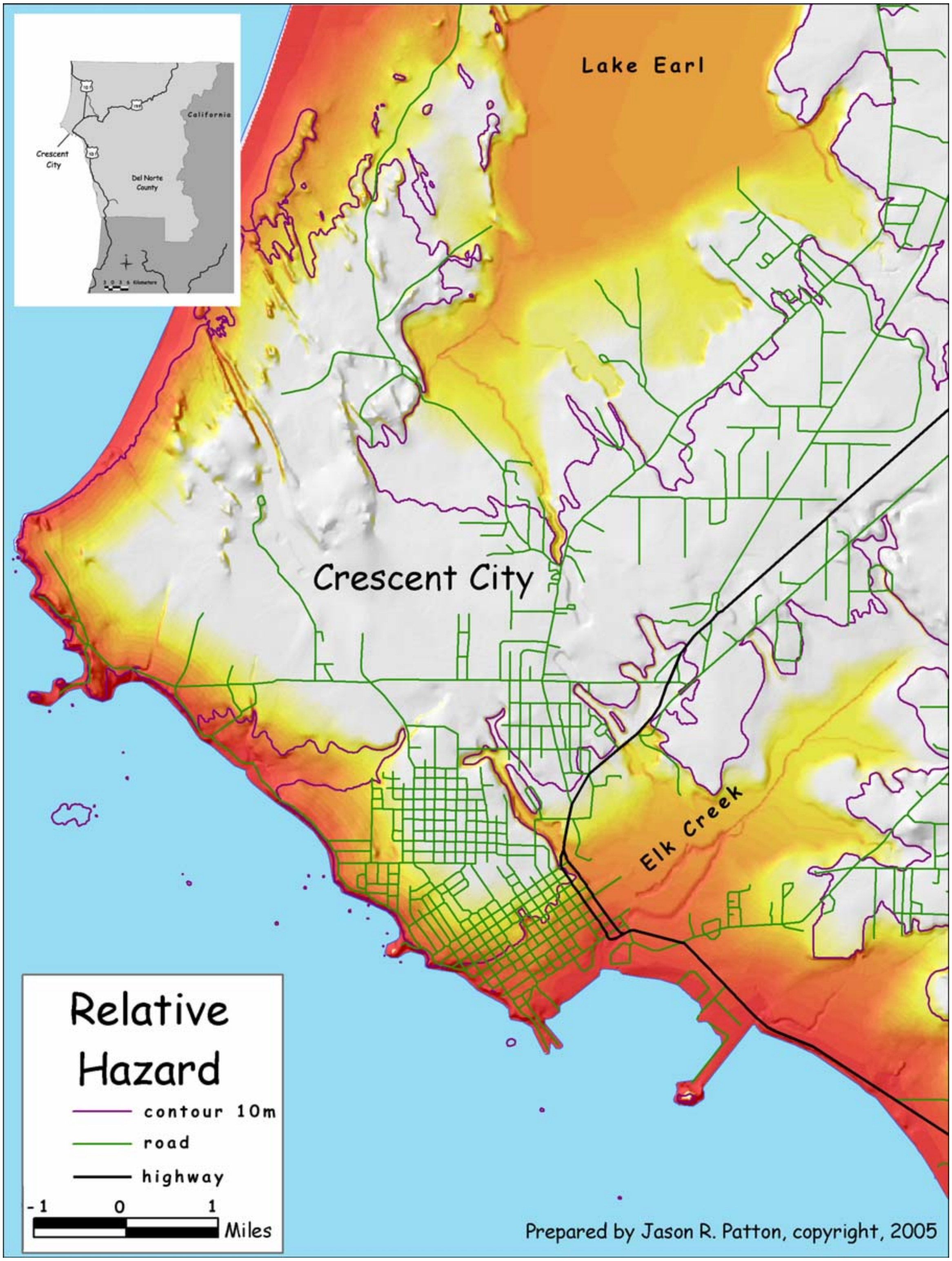

Figure 3. Crescent City relative tsunami hazard map. High velocity wave hazard is indicated by purple cross hatching. Ten m contour can be used to compare convergence of relative hazard in relation to distance to the coastline.

Orick Valley is the second map product generated with this method (Figure 4). The Orick Community Services District is using this map as part of their planning for NOAA Tsunami Ready Community Plan. Since much of the community is low lying and close to the coast, tsunami awareness and education is extremely important.

The Humboldt Bay and lower Eel River Valley regions have been updated with the GRID based method (Fig. 5). Humboldt County is currently adopting the Humboldt County Office of Emergency Services tsunami mitigation plan where a map series was produced with the results from this study.

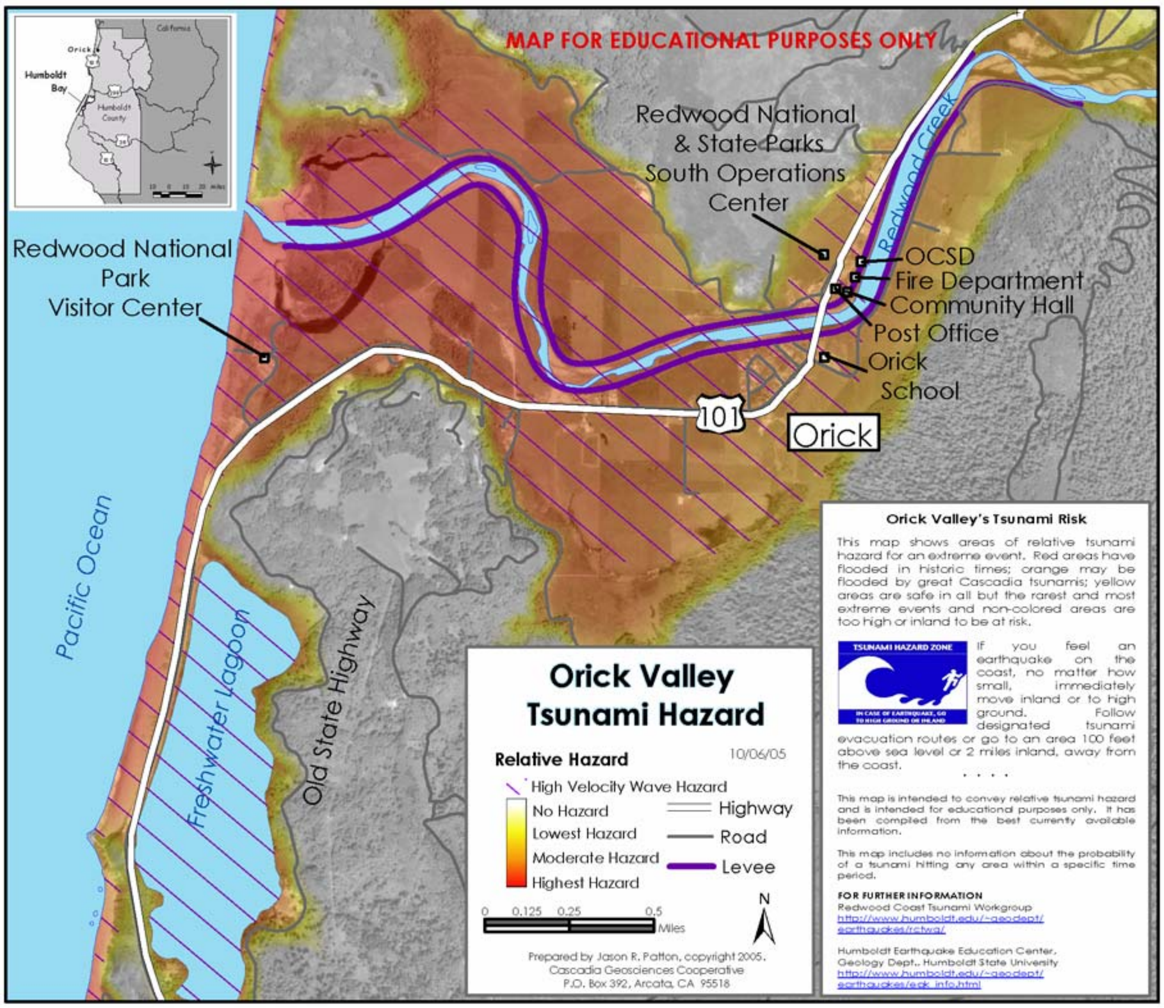

Figure 4. Orick Valley relative tsunami hazard map. This is very similar to the map used as placemats for a community fish fry as part of planning for the Orick community participation in the NOAA “Tsunami Ready Community” program. High velocity wave hazard is indicated by purple hatch marks. Orick is located in northern Humboldt County.

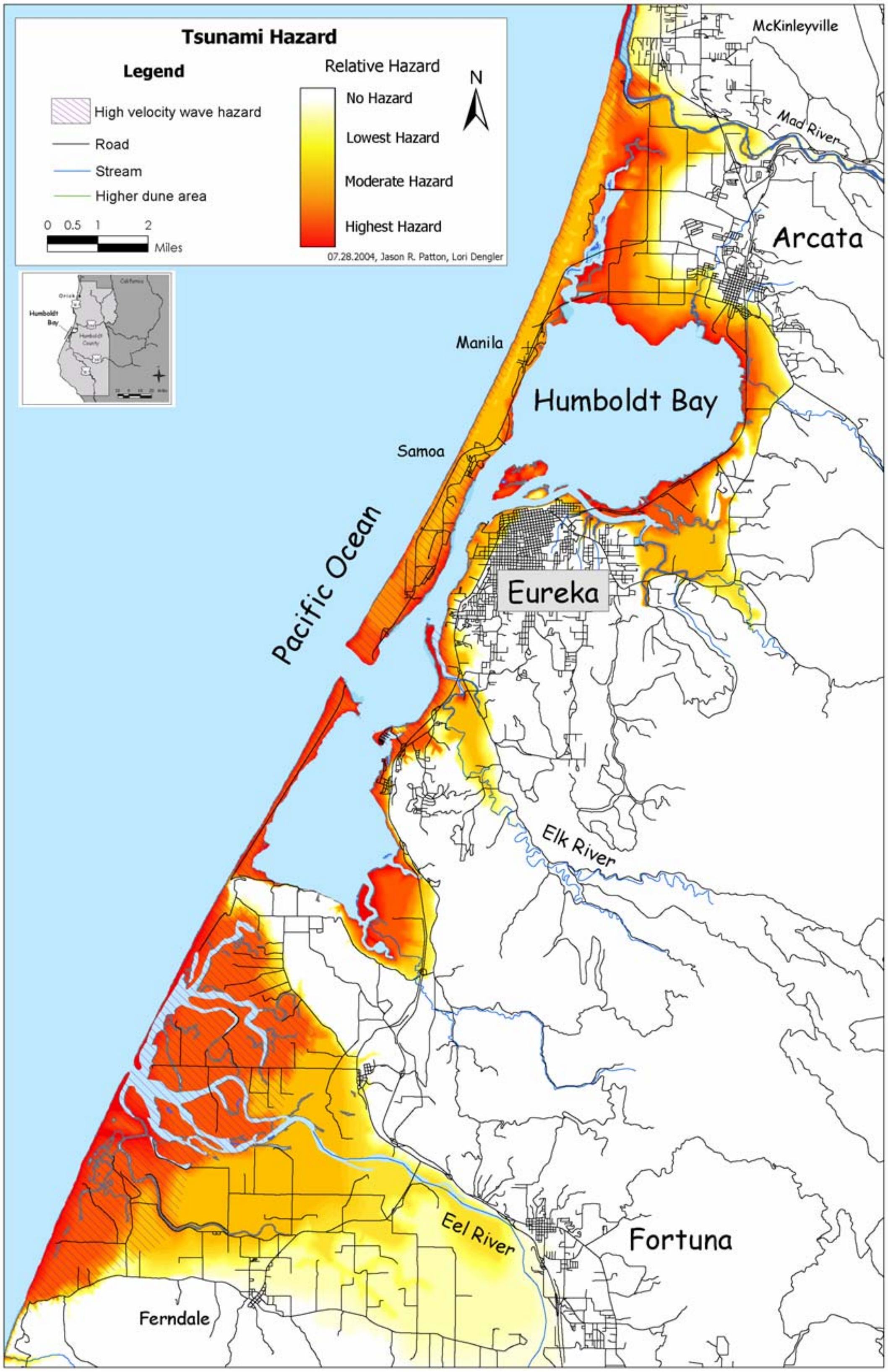

Figure 5. Humboldt Bay relative tsunami hazard map. High velocity wave hazard is indicated by purple hatches.

Discussion

Tsunami hazard can be determined using different methods including, but not limited to, numerical modeling, historic mapping, paleoseismic mapping, and mapping based on actual observations. Each of these methods has unique benefits and limitations. The benefits and limitations are based on what level of hazard is considered and how that hazard is displayed.

To date no direct relations have been developed between numerical models of inundation depth and hazard for this region. In the absence of numerical modeling, this method is a simple way to share essential material to communities in tsunami hazard zones. Once numerical modeling of inundation depth has begun, this study's model can be adjusted to incorporate the numerical modeling.

While many tsunami hazard maps represent single types of tsunami hazard, multiple levels of tsunami hazard are considered for north coastal California. Numerical models of single types of hazard cannot display these multiple levels of various hazards. Three lines would be required to display the hazard we display as a single color gradient. Three lines, with different relative hazard, would be confusing to the end user.

Single lines used in previous mapping efforts are unable to display the uncertainty in the level of hazard. In maps from this study, since there are no lines separating distinct areas of varying hazard, it is difficult for one to determine the precise location where one moves from one type of hazard to another because the hazard changes gradually. Uncertainty in the hazard-elevation relation is encompassed by the gradational nature of the color gradient.

Many benefits are realized while implementing this GIS-based relative tsunami hazard mapping effort. Relations of elevation are developed for three hazard levels: 1) historic/distant tsunami; 2) local (CSZ) tsunami generated; and 3) local (CSZ) tsunami generated by localized submarine seafloor deformation. Methods used in this paper are easily modified when relations between hazard criteria are further developed.

Conclusion

Relative tsunami hazard is clearly the best way to communicate geospatial relations of this hazard. Residents in low lying coastal areas have the opportunity to "see their house" on these maps, especially when panchromatic imagery (eg. DOQQs) is underlain below the safety index (Fig. 3). As effected regions are far reaching and emergency responders have limited affect in the immediate time following large earthquakes, people need to have these maps in their body of knowledge to ensure their survival.

Coastal communities along the coast of North America, Asia, Australia, South America, Africa, and Europe need to improve tsunami hazard education efforts by mapping hazard in the way discussed in this paper. A picture is worth a thousand words and this type of modeling can be achieved at very little cost since DEMs are available globally. An added bonus is that numerical simulation data can be incorporated into the model to further substantiate its certainty.

Acknowledgements

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