TSUNAMI HAZARD TO HAWAII FROM A M9+ EVENT

SIMILAR TO 2004 INDIAN OCEAN TSUNAMI

Charles L. Mader

Mader Consulting Co., Honolulu, HI 96825-2860

ABSTRACT

The current Tsunami evacuation zones in Hawaii are based upon the tsunami flooding history of the last 150 years.

The Fritz surveys after the December 26, 2004 Indian Ocean Tsunami found the death zone was the areas below 10 meters and less than 1 kilometer from shore and that all areas below 5 meters above sea level and within 3 miles of shoreline need to be evacuated. The only current evacuation zone in Hawaii that would be adequate for a M9+ tsunami similar to the 2004 Indian Ocean Tsunami is that of Hilo, Hawaii.

Hawaii is especially vulnerable to M9+ tsunamis from the Japan Trench, the Marianas Trench and the Tonga Trench in addition to those from the Aleutian and Chile trenches. The current Hawaii Tsunami evacuation zones leave tens of thousands of Hawaiians at risk from a Tsunami similar to the 2004 Indian Ocean Tsunami.

INTRODUCTION:

Dr. Herman Fritz surveys of the December 26, 2006 Indian Ocean tsunami are described in Reference 1. He found that the death zone was the area below 10 meters and less than 1 kilometer from shore. He reported that on Sri Lanka most witnesses described three main waves. The first wave knocked them off their feet, the second wave picked them up and carried them, often up to 50 km/hr, and the third wave bore them up to 15 meters high or sucked them under. He concluded from the surveys that evacuation zones should include

1. All areas below 15 meters above sea level and within 0.25 mile of shoreline or along rivers.

2. All areas below 10 meters above sea level and within 1.0 mile of shoreline or along rivers.

3. All areas below 5 meters above sea level and within 3 miles of shoreline.

These three areas that need to be evacuated are called the Fritz criteria and has been used by Meadows in Reference 2 to define the areas in the Hawaiian islands that would be vulnerable to a M9+ event similar to the 2004 Indian Ocean tsunami.

The April 1, 1946 tsunami was caused by a 7.5 magnitude earthquake off the Aleutian Islands located about 60 miles SW of Scotch Cap, Unimak Island where the tsunami destroyed the lighthouse and radio towers located more than 30 meters above sea level as described in Reference 3.

The tsunami which arrived in Hawaii destroyed three wide valleys and what occurred is historical evidence that the Fritz criteria is also appropriate for Hawaii.

1. In Waipio Valley, Hawaii the tsunami run-up amplitude was 12 meters and swept 1 mile up the valley pulling away homes and people leaving only foundations of the buildings.

2. In Waikolu Valley, Molokai the tsunami run-up amplitude was 16.4 meters and destroyed farms and buildings up the entire valley.

3. At Makapuu Point, Oahu the tsunami run-up amplitude was 11.1 meters and after three waves it had destroyed the nearby ranch buildings leaving only foundations.

The May 23, 1960 tsunami was caused by an 8.5 magnitude earthquake occurring near Peru, Chile. At Hilo, Hawaii the first peak of the tsunami was followed by a second peak 36 minutes later and then by a third peak, with a run-up amplitude up to 8.5 meters high, about 20 minutes later which was a bore at the Hilo Harbor twice as high as the previous waves. The 1960 tsunami completely destroyed all of Hilo near the ocean and the area was turned into a park.

A numerical study of tsunami wave generation, propagation and flooding is described in Reference 3 and the same codes were used to evaluate the potential tsunami hazard to Hawaii from tsunamis generated by M9+ events in the Tonga Trench, the Marianas Trench and the Japan Trench. The results of the study are available in Reference 4.

NUMERICAL MODELING

Tongan Trench

The generation and propagation of a tsunami by an earthquake in the Tongan trench was modeled using the SWAN code and is described in Reference 4. The tsunami wave was generated from an earthquake 210 kilometers wide, 1100 kilometers long and 50 meters uplift located at 20 S, 175 W which approximates the size of the 12/26/2004 Ocean earthquake.

The tsunami generation and propagation was modeled using a 20 minute ETOPO grid for the Pacific Ocean. The tsunami wave created by the earthquake had a period of 1000 to 3000 seconds and maximum amplitudes in deep water of 2.5 meters in the Gulf of Alaska, 2.0 meters off Japan, 3.2 meters off Oahu and 4.5 meters off the California coast These values are upper limits as the long wave equations do not include dispersion which would reduce the wave amplitude with distance from the source. The amplification of a tsunami wave when it interacts with the shore is two to three times the deep water wave amplitude.

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CALCULATED DEEP WATER WAVE HEIGHTS

FOR Mag 9+ TONGAN TRENCH TSUNAMI

No	Depth	Location	MAX Amplitude	MIN Amp	Arrival
1	3703	Gulf of Alaska	+2.5	-2.0	12.5 hr
2	5989	Japan	+2.0	-2.0	10.3 hr
3	4685	Australia	+12.0	-6.0	3.3 hr
4	4787	Lima, Peru	+1.8	-3.0	12.8 hr
5	3001	New Zealand	+3.0	-1.5	2.8 hr
6	4321	Hawaii	+3.2	-4.0	7.2 hr
7	3556	California	+4.5	-2.0	11.7 hr

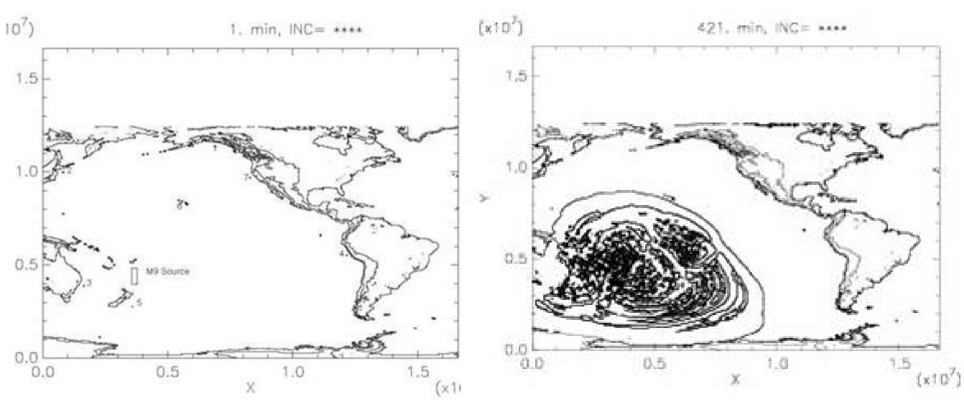


Figure 1. The M9+ Tonga Trench Tsunami.

Marianas Trench

The generation and propagation of a tsunami by an earthquake in the Marianas trench was modeled using the SWAN code and is described in Reference 4. The tsunami wave was generated from an earthquake 210 kilometers wide, 1100 kilometers long and 50 meters uplift located at 15N, 146 E which approximates the size of the 12/26/2004 Indian Ocean earthquake.

The tsunami generation and propagation was modeled using a 20 minute ETOPO grid for the Pacific Ocean. The tsunami wave had a period of 1000 to 3000 seconds and amplitudes in deep water of 1.5 meters in the Gulf of Alaska, 5.0 meters off Japan, 2.0 meters off New Zealand, 1.0 meter off Australia, 10 meters off Oahu, and 2.4 meters off the California coast. The amplification of a tsunami wave when it interacts with the shore is two to three times the deep water wave amplitude.

CALCULATED DEEP WATER WAVE HEIGHTS

FOR Mag 9+ MARIANAS TRENCH TSUNAMI

No	Depth	Location	MAX Amplitude	MIN Amp	Arrival
1	3703	Gulf of Alaska	+1.5	-2.5	8.3 hr
2	5989	Japan	+5.0	-3.5	0.8 h
3	4685	Australia	+1.0	----	8.3 hr
4	4787	Lima, Peru	+4.5	-3.0	18.8 hr
5	3001	New Zealand	+2.0	----	12.5 hr
6	4321	Hawaii	+10.0	-10.0	6.6 hr
7	3556	California	+2.4	-2.5	10.3 hr

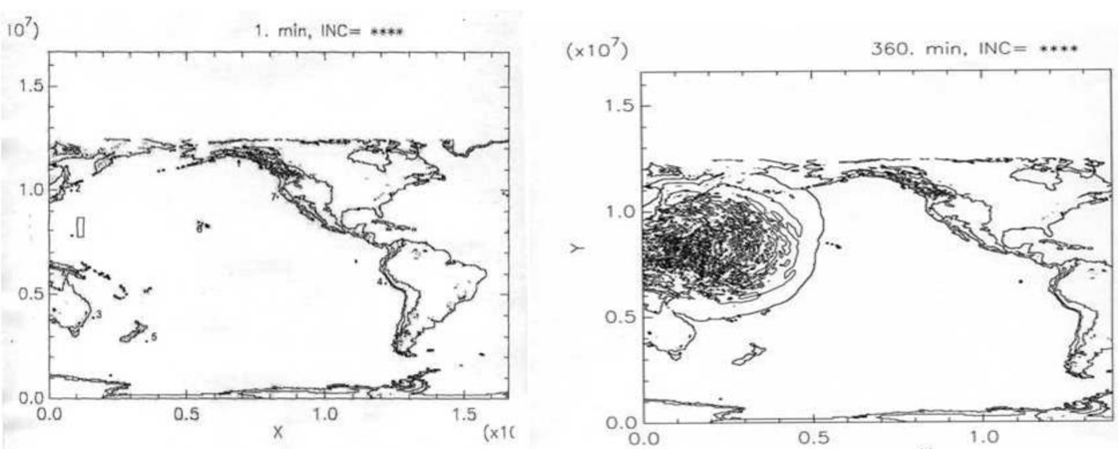


Figure 2. The M9+ Marianas Trench Tsunami.

Japan and Aleutian Trench

Tsunami wave amplitudes have been calculated for various locations in the North Pacific for the hypothetical sources of Dr. Gus Furumoto along the Aleutian subduction zone. The project was designed by Dr. Furumoto for his use when he was the Hawaii Civil Defense Scientific Advisor. He used 10 primary zones along the Aleutian subduction zone for which calculations have been performed. From the 10 primary zones he chose the proper combinations for the 1946, 1957, 1964 and 1965 tsunamis as a base line.

A magnitude 9+ event with area of 2004 Indian Ocean tsunami (1100 km long and 200 km wide) along the Japan trench was modeled for Dr. Dan Walker, who is the current Hawaii Civil Defense Scientific Advisor, using a 20 meter and 50 meter (to better approximate Indian Ocean event) source. The modeling was performed using the SWAN code which solves the nonlinear long wave equations as described in Reference 3. The problems scale as a function of the initial displacement which was taken as 20 meters which results in a 10 meter high wave at the source.

The tsunami generation and propagation was modeled using a 10 minute Mercator grid. The topography was generated from the 2 minute Mercator Global Marine Gravity topography of the earth of Sandwell and Smith of the Scripps Institute of Oceanography described in 5.   The grid is 720 by 426 cells with the left hand corner at 15 N, 135 E. The grid extends from 15 N to 65 N and from 135 E to 255. The time step is 15 seconds. The 10 minute grid is too course to model the tsunami wave profiles near the Hawaiian shorelines. To obtain the near shore tsunami amplitudes needed by Hawaiian Civil Defense, it will be necessary to use the Kowalik and Whitmore technique of embedding fine grids inside course grids that was used by Whitmore and Sokolowski (Reference 6) to obtain tsunami amplitudes near the coast.

The modeling further demonstrates the strong directionality of tsunami waves generated along the Aleutian subduction zone. The location of a tsunami buoy relative to the tsunami source and the target of interest is crucial to the evaluation of the tsunami signal by Hawaiian Civil Defense Advisors. Similar sets of calculations will be needed for all future tsunami buoy locations if they are to be useful for evaluating potential tsunami hazards.

FURUMOTO HYPOTHETICAL 20 M HIGH SOURCES
MAXIMUM AMPLITUDES and M9+ JAPAN TRENCH

							JAPAN TRENCH	
No	Depth	Location	1946	1957	1964	1965	M9+ 20 M	M9+ 50M
1	4442	Buoy 1	+4.0	+1.6	+1.0	+0.5	+0.8	+2.0
2	3188	Buoy 2	+1.3	+1.0	+1.2	+0.3	+0.9	+2.2
3	2727	E of Hilo	+3.0	+3.5	+0.5	+1.0	+3.4	+8.5
4	625	E of Kahulai	+3.6	+5.0	+0.5	+1.5	+5.0	+12.0
5	4871	N of Halewia	+2.2	+4.4	+0.5	+1.2	+4.0	+10.0
6	641	S of Honolulu	+2.4	+5.0	+0.5	+1.2	+6.0	+15.0
7	4817	N of Hanalei	+2.4	+6.0	+0.5	+1.2	+4.0	+10.0

Buoy 1 and 2 were deep ocean reporting wave gauges in the Gulf of Alaska and off Washington State in 1997.

Numerical modeling has been performed for all 10 sources and similar tables and detailed computer results are available for all sources in a manual for use by the Hawaii Tsunami Advisor during a tsunami alert. As soon as the Tsunami Advisor knows the source location and the wave amplitude at a buoy located between the Aleutian trench and the Hawaiian islands, he can scale the pre-computed wave amplitudes to obtain an estimate of the expected tsunami wave amplitude near Hawaii and hence the potential hazard.

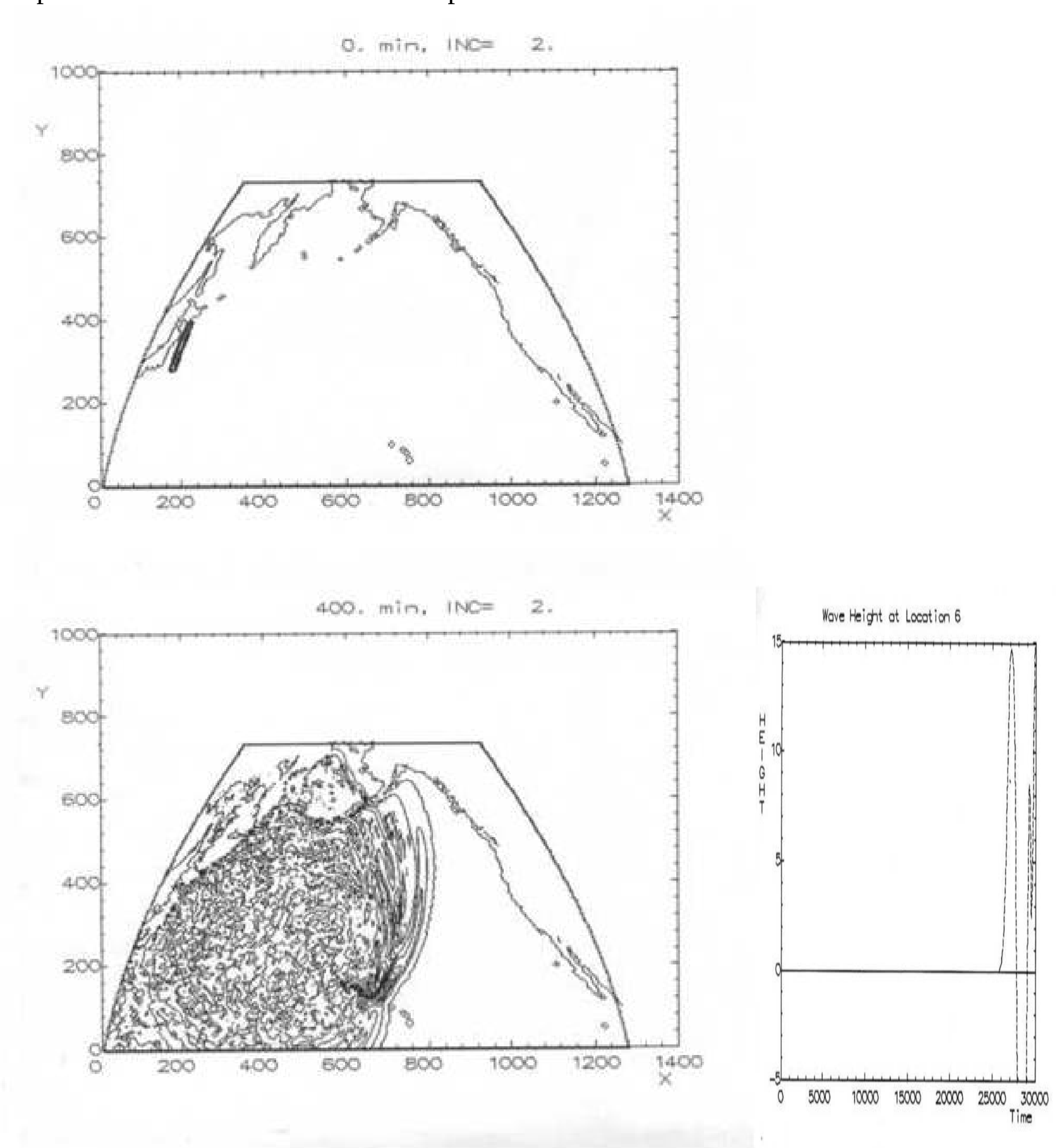
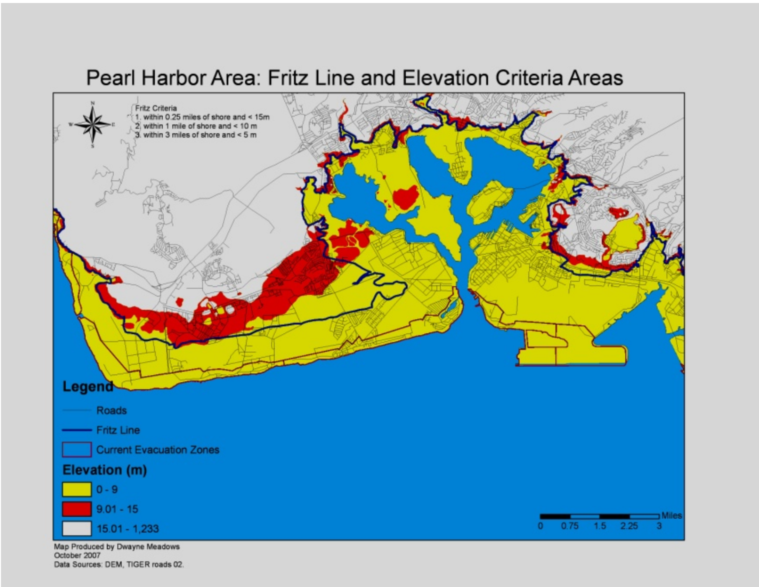
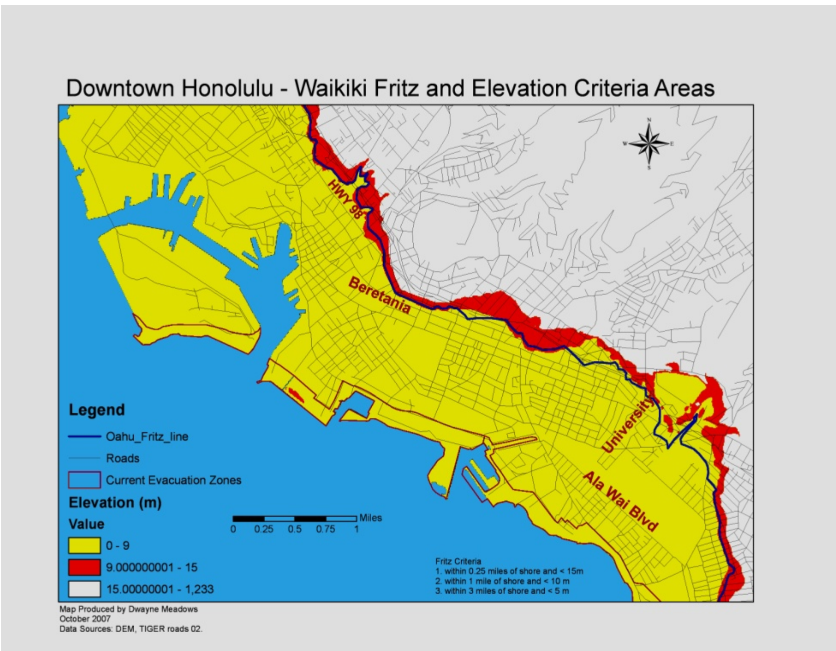


Figure 3. The M9+ Japan Trench Tsunami and wave profile South of Honolulu at 641 m.

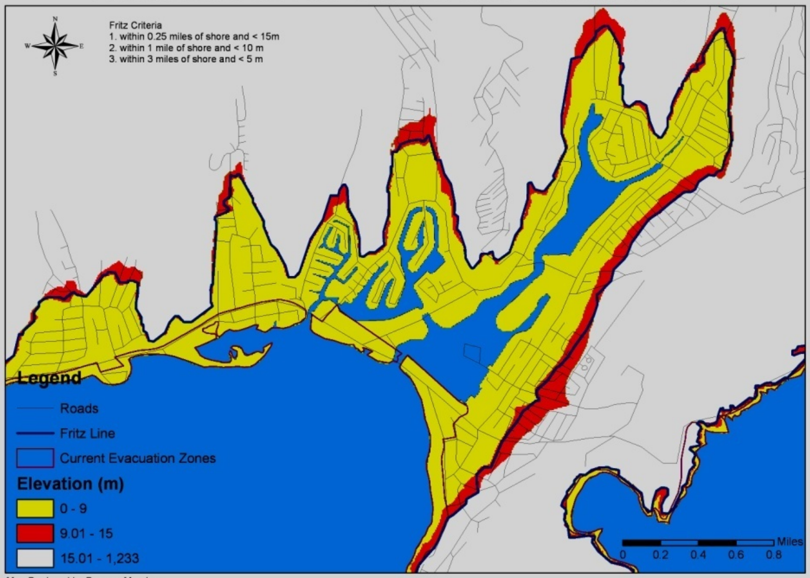
The M9+ Japan Trench tsunami is 10 meters high in deep water as it travels down the Hawaii Island chain and is the most hazardous source studied. The Hawaiian Islands are especially vulnerable to M9+ tsunamis generated in the Japan and Marianas trenches. M9+ tsunamis generated in the Tonga, Chile and Aleutian trenches can also be as destructive as the 2004 Indian Ocean Tsunami.

In Reference 2 Meadows presents maps of the inundation zones throughout the Hawaiian Islands that are within the death zone of a M9+ tsunami. The current Hawaii Tsunami evacuation zones are particularly inadequate for Honolulu, Pearl Harbor and Hawaii Kai on Oahu while the downtown Hilo zone is adequate since the historical tsunami flooding of Hilo is close to the Fritz criteria and the 9 meter elevation.



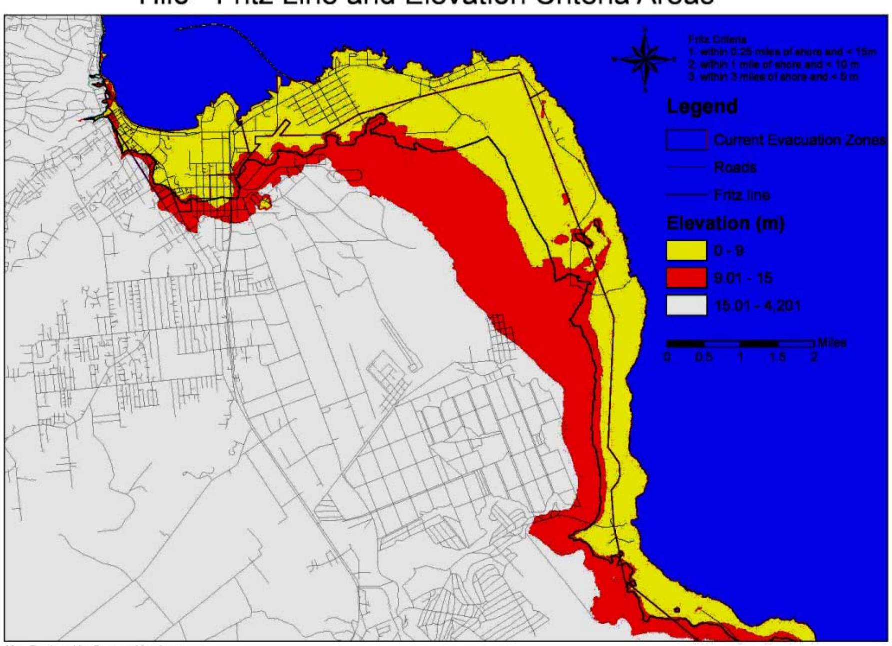


Hawaii Kai: Fritz Line and Elevation Criteria Areas



Map Produced by Dwayne Meadows
October 2007
Data Sources: DEM, TIGER roads 02.

Hilo - Fritz Line and Elevation Criteria Areas



Map Produced by Dwayne Meadows
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Data Sources: DEM, TIGER roads 02.

REFERENCES

1. Hermann Fritz, et al., "Observations by the International Survey Team in Sri Lanka," Science 308, 5728, 1595 (2005). Also www.gtsav.gatech.edu/cee/groups/tsunami/index and private communication.

2. Dwayne Meadows, "A Comparison of 3 Potential New Tsunami Evacuation Zone Criteria for Hawaii," A Report to the Hawaii Technical Review Committee Science Advisory Working Group. PDF file available at www.mccohi.com/tsunami/hihazard.pdf.

3. Charles L. Mader, "Numerical Modeling of Water Waves, Second Edition," CRC Press (2004) - includes CD-ROM.

4. "2010 DVD for Numerical Modeling of Explosives and Water Waves," Hawaii Tsunami Hazards study in directory nmwwdvd/classppt/sawg. Available free from Mader Consulting Co. Also at www.mccohi.com/tsunami/tsunami.htm.

5. W. H. F. Smith and D. T. Sandwell, "Global Seafloor Topography from Satellite Altimetry and Ship Depth Soundings," Science April 7, 1997.

6. Paul M. Whitmore and Thomas J. Sokolowski , "Predicting Tsunami Amplitudes Along the North American Coast from Tsunami Generated in Northwest Pacific Ocean During Tsunami Warnings," Science of Tsunami Hazards, 14, 147-166 (1996).