CHAPTER 18.
TSUNAMI

18.1 TSUNAMI DEFINED

The following definitions apply in the discussion of tsunami hazards:

- **Tsunami**—Tsunamis are series of traveling ocean waves of extremely long wavelength usually caused by displacement of the ocean floor and typically generated by seismic or volcanic activity or by underwater landslides.

18.2 GENERAL BACKGROUND

A tsunami consists of a series of high-energy waves that radiate outward like pond ripples from the area in which the generating event occurred. The sequence of tsunami waves arrives at the shore over an extended period. A tsunami approaching the shore may take three forms:

- Non-breaking waves that act as a rapidly rising tide
- A large, turbulent wall-like wave (bore)
- A series of partially developed waves.

Tsunamis are typically classified as either local or distant. Locally generated tsunamis have minimal warning times and may be accompanied by damage resulting from the triggering earthquake due to ground shaking, surface faulting, liquefaction, or landslides. This leaves few options except to run to high ground. Distant tsunamis may travel for hours before striking a coastline, giving the community a chance to implement evacuation plans.

In the open ocean, a tsunami may be only a few inches or feet high but can travel with speeds approaching 1,000 kilometers (about 600 miles) per hour. As a tsunami enters the shoaling waters near a coastline, its speed diminishes, its wavelength decreases, and its height increases greatly. However, the first wave usually is not the largest. Several larger and more destructive waves often follow the first one.

The configuration of the coastline, the shape of the ocean floor, and the characteristics of advancing waves play important roles in the destructiveness of the waves. Offshore canyons can focus tsunami wave energy and islands can filter the energy. The orientation of the coastline determines whether the waves strike head-on or are refracted from other parts of the coastline.

A wave may be small at one point on a coast and much larger at other points. Bays, sounds, inlets, rivers, streams, offshore canyons, islands, and flood control channels may cause various effects that result in greater damage than many people would expect. It has been estimated, for example, that a tsunami wave entering a southern California flood control channel could reach a mile or more inland, especially if it enters at high tide.

The first visible indication of an approaching tsunami may be recession of water (draw down) caused by the trough preceding the advancing, large inbound wave crest. Rapid draw down can create strong currents in harbor inlets and channels that can severely damage coastal structures due to erosive scour around piers and pilings. As the water's surface drops, piers can be damaged by boats or ships straining at or breaking their mooring lines. The vessels can overturn or sink due to strong currents, collisions with other objects, or impact with the harbor bottom.

Conversely, the first indication of a tsunami may be a rise in water level. The advancing tsunami may initially resemble a strong surge increasing the sea level like the rising tide, but the tsunami surge rises faster and does not stop at the shoreline. Even if the wave height appears to be small, 3 to 6 feet for example, the strength of the accompanying surge can be deadly. Waist-high surges can cause strong currents that float cars, small structures, and other debris. Boats and debris are often carried inland by the surge and left stranded when the water recedes.

Outflow following inundation also creates strong currents, which rip at structures and pound them with debris, and erode beaches and damage coastal structures. As tsunamis reach the shoreline, they may take the form of a fast-rising tide, a cresting wave, or a bore. The bore phenomenon resembles a step-like change in the water level that advances rapidly (from 10 to 60 miles per hour).

The force and destructive effects of tsunamis should not be underestimated. At some locations, the advancing turbulent wave front will be the most destructive part of the wave. In other situations, the greatest damage will be caused by the outflow of water back to the sea between crests, sweeping all before it and undermining roads, buildings, bulkheads, and other structures. This outflow action can carry enormous amounts of highly damaging debris with it, resulting in further destruction. Ships and boats, unless moved away from shore, may be dashed against breakwaters, wharves, and other craft, or be washed ashore and left grounded after the withdrawal of the seawater.

18.3 HAZARD PROFILE

18.3.1 Past Events

California is at risk from both local and distant tsunamis. Eighty-two possible or confirmed tsunamis in California have been observed or recorded. Table 18-1 summarizes the major events among these. Most of these events were small and only detected by tide gages. Eleven were large enough to cause damage and four events caused deaths. At least three of these events had direct measurable impacts on Humboldt County. Two tsunami events caused major damage. The 1960 Chilean earthquake produced a great tsunami that impacted the entire Pacific basin. Damage was reported in California ports and harbors from San Diego to Crescent City and losses exceeded $1 million. The worst event was the 1964 tsunami generated by the magnitude-9.2 Alaska earthquake, which killed 12 in Northern California and caused over $15 million in damage. The peak wave height was 21 feet in Crescent City and 29 city blocks were inundated. Wave oscillations in San Francisco Bay lasted more than 12 hours, causing nearly $200,000 in damage to boats and harbor structures.

18.3.2 Location

The earth’s surface is made up of a number of crustal plates that contain large sections of the continents and ocean basins. These plates may pull apart from, slide past, override, or under-ride (i.e., “subduct”) one another. Plate boundaries coincide with faults that produce earthquakes as stress accumulated from the relative movement of the plates is relieved. The earthquakes, in turn, may produce displacements of the sea floor that can set the overlying column of water in motion, initiating a tsunami. However, all submarine earthquakes do not produce tsunamis. It depends on the magnitude of the earthquake and type of faulting that has occurred.

The most active plate boundaries rim the Pacific Ocean and the Caribbean Sea. Consequently, this is where most tsunami activity is expected. Most tsunamis originate in the Pacific “Ring of Fire,”(Figure 18-1), which is the most active seismic feature on earth. An estimated 489 cities in Alaska, California, Hawaii, Oregon, and Washington are susceptible to tsunamis. As many as 900,000 residents of these cities could be inundated by a 50-foot tsunami. In addition, millions of tourist that visit these regions each year could be impacted by tsunami events along the pacific coast.

TABLE 18-1.
TSUNAMIS THAT HAVE AFFECTED NORTH COAST CALIFORNIA

Date	Origin of Tsunami	Impacted Areas	Runup (meters)	Observations/comments
3/19/1855	N. California	Humboldt Bay	Observed	Water in the bay agitated for 1 hour
4/6/1943	N. Central Chili	Crescent City	Trace	
4/1/1946	E. Aleutian Islands	Crescent City	1.0	Three foot amplitude and a twelve minute period were recorded for this event.
12/20/1946	Nankaido, Japan	Crescent City	0.2	
3/4/1952	SE Hokkaido, Japan	Crescent City	0.2	
11/4/1952	Kamchatka Peninsula, Russia	Crescent City	1.0	In Crescent City, 4 boats were overturned and concrete buoys were moved.
3/91957	Central Aleutian Is.	Crescent City	0.7	
5/22/1960	South/Central Chili	Crescent City	1.7	$30,000 in damages. Two ships were destroyed, others were damaged.
10/13/1963	Kuril Islands, Russia	Crescent City	0.5	
3/28/1964	Gulf of Alaska	Crescent City	6.3	Ten people killed, 35 injured, 52 homes and 172 businesses damaged or destroyed. $15 million in damages
		Klamath River		One person killed $4,000 damages to dock and boats at Requa. Damage reported least 2.6 km from mouth of Klamath River.
		Trinidad		Observed runup was 5.4 meters above MLLW.
2/4/1965	W. Aleutian Islands	Crescent City	0.1	
10/17/1966	Peru	Crescent City	0.1	
5/16/1968	Honshu, Japan	Crescent City	0.6	
7/26/1971	New Ireland	Crescent City	<0.1	
10/3/1974	Peru	Crescent City	<0.1	
5/7/1986	W. Aleutian Islands	Crescent City	0.1	
4/25/1992	Northern CA Cape Mendocino	Humboldt Bay	0.3 Observed	Waves arrived at Humboldt Bay about 20 minutes after ground shaking.
		Clam Beach	0.6	Water level changed several feet
		Crescent City	0.9	Oscillations in harbor, the 4th wave were the highest recorded.
		Trinidad		Cars were struck on the beach.
9/1/1994	Northern CA Cape Mendocino	Crescent City	0.14	Recorded on Crescent City tide gauge 45 minutes after earthquake.
11/15/2006	Kuril Islands	Crescent City	1.76	Recorded on Marigram
		Arena Cove	1.18	
		Pt. Reyes	0.62	
01/13/2007	Kuril Islands	Crescent City	0.23	Recorded on Marigram
		Arena Cove	0.25	
		Pt. Reyes	0.12	

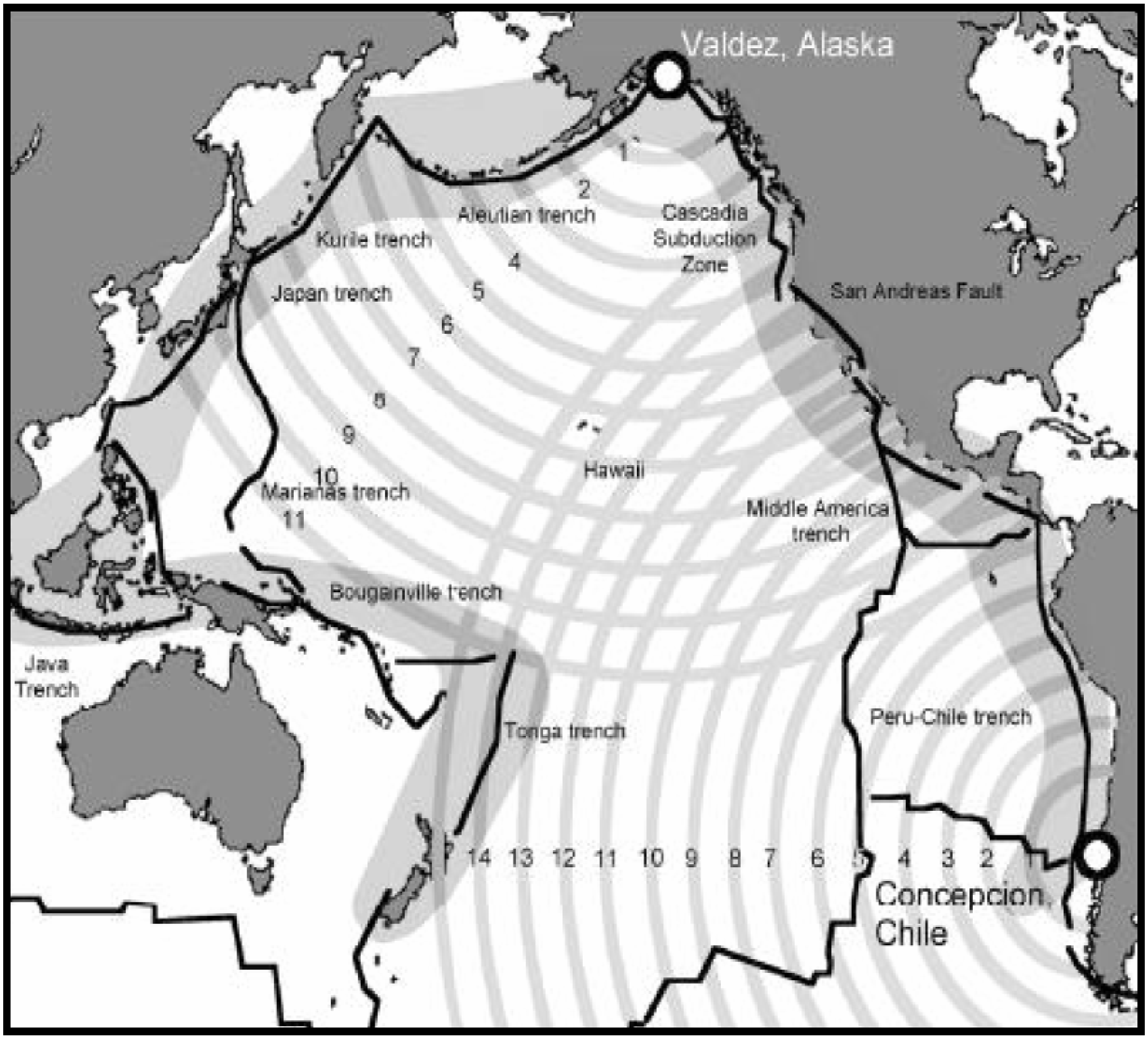

Figure 18-1: The Pacific "Ring of Fire".

History has demonstrated that most tsunamis affecting the Pacific Northwest (Northern California, Oregon, and Washington) have originated in the Gulf of Alaska (Aleutian Subduction Zone). There is also geological evidence of significant impacts from tsunamis originating along the Cascadia subduction zone. The Cascadia subduction zone extends from Cape Mendocino in California to the Queen Charlotte Islands, British Columbia, and its surface trace is only a short distance off the coast. Historically, the Washington and Oregon coasts have received comparatively minor damage from Alaskan tsunamis. However, Crescent City, in Northern California, has experienced damaging tsunamis from Alaska and noticeable effects from a tsunami originating near Chile. A tsunami generated along the nearby Cascadia subduction zone would probably also be very damaging to that community.

Tsunamis that damaged California's coast have come from all around the Pacific basin, including South America and Alaska. Nearly two-thirds of California's tsunami events and all but one damaging event were generated by distant sources. Local tsunamis have the potential to cause locally greater wave heights and pose a threat to the state. The largest historical local-source tsunami on the west coast was caused by the 1927 Point Arguello, California, earthquake (magnitude 7.1), which produced 7-foot waves in the nearby coastal area.

Figure 18-2 illustrates the estimated extent and location of the highest and moderate tsunami hazard zones for the planning area. These zones correspond approximately to a 500-year and 100-year event, respectively. This mapping is based on the best available historical and observed data and technical interpretation of tsunami risk for the planning area, not on probabilistic tsunami modeling.

18.3.3 Frequency

The frequency of tsunamis is related to the frequency of the events that cause them, so it is similar to the frequency of seismic or volcanic activities or landslides. Generally four or five tsunamis occur every year in the Pacific Basin, and those that are most damaging are generated in the Pacific waters off South America rather than in the northern Pacific.

The Cascadia subduction zone threatens California, Oregon and Washington with potentially devastating tsunamis that could strike the coast within minutes. There is increasing geological and seismological evidence that: earthquakes of magnitude 8 or higher have occurred in this region; at least one segment of the subduction zone may be approaching the end of a seismic cycle culminating in such an earthquake; and these earthquakes have generated tsunamis that have caused extensive flooding along the coastlines of California, Oregon and Washington. Tsunami experts estimate that the probability of a Cascadia earthquake occurring is comparable to that of large earthquakes in Southern California (i.e., 35-percent probability of magnitude 8 or higher between 1995 and 2045).

18.3.4 Severity

Tsunamis are a threat to life and property to anyone living near the ocean. From 1950 to 2007, 478 tsunamis have been recorded globally. Fifty-one of these events caused fatalities to over 308,000 coastal residents. The overwhelming majority of these events occurred in the Pacific basin. Recent tsunamis have struck Nicaragua, Indonesia, and Japan, killing several thousand people. Property damage due to these waves was nearly $1 billion. Historically, tsunamis originating in the northern Pacific and along the west coast of South America have caused more damage on the west coast of the United States than tsunamis originating in Japan and the Southwest Pacific.

The Cascadia subduction zone will produce the state’s largest tsunami. The Cascadia subduction zone is similar to the Alaska-Aleutian trench that generated the magnitude 9.2 1964 Alaska earthquake and the Sunda trench in Indonesia that produced the magnitude 9.3 December 2004 Sumatra earthquake. Native American accounts of past Cascadia earthquakes suggest tsunami wave heights on the order of 60 feet, comparable to water levels in Aceh Province Indonesia. Water heights in Japan produced by the 1700 Cascadia earthquake were over 15 feet, comparable to tsunami heights observed on the African coast after the Sumatra earthquake. The Cascadia subduction zone last ruptured January 26, 1700, creating a tsunami that left markers in the geologic record from Humboldt County, California to Vancouver Island, Canada and is noted in written records in Japan. At least seven ruptures of the Cascadia subduction zone have been observed in the geologic record.

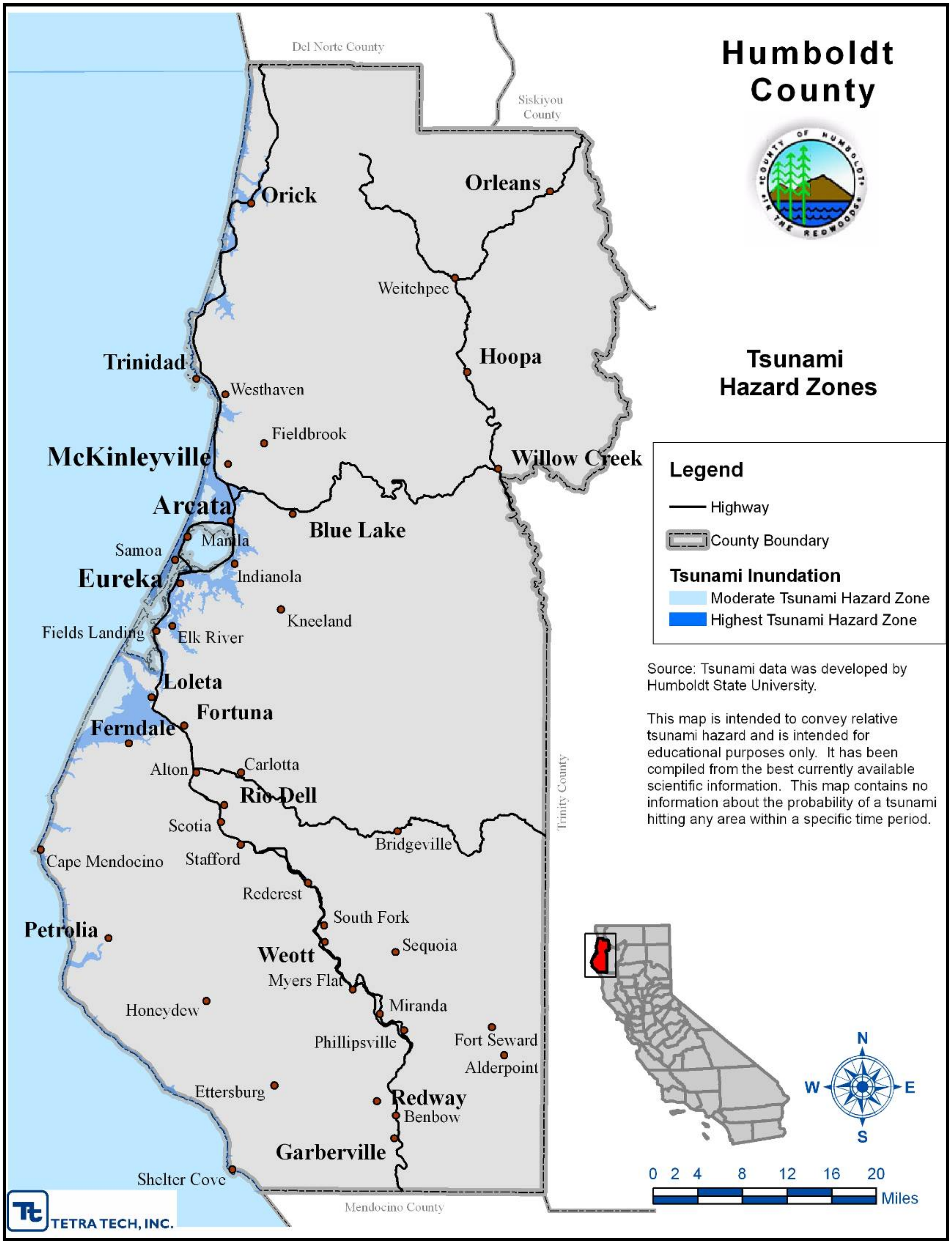

Figure 18- 2: Extent and location of the moderate (100 year) and the highest (500 year) Tsunami Hazard Zones

18.3.5 Warning Time

Typical signs of a tsunami hazard are earthquakes or a sudden and unexpected rise or fall in coastal water levels. The large waves are often preceded by coastal flooding and followed by a quick recession of the water. Tsunamis are difficult to detect in the open ocean, with waves only 1 or 2 feet high. The tsunami's size and speed, as well as the coastal area's form and depth, affect the impact of a tsunami; wave heights of 50 feet are not uncommon. In general, scientists believe it requires an earthquake of at least a magnitude 7 to produce a tsunami. Earthquake shock waves close to the epicenter consist of high-frequency vibrations, while those at much greater distances are of lower frequency, which can enhance the rhythmic movement in a body of water. Figure 18-3 shows estimated arrival times for a Pacific tsunami.

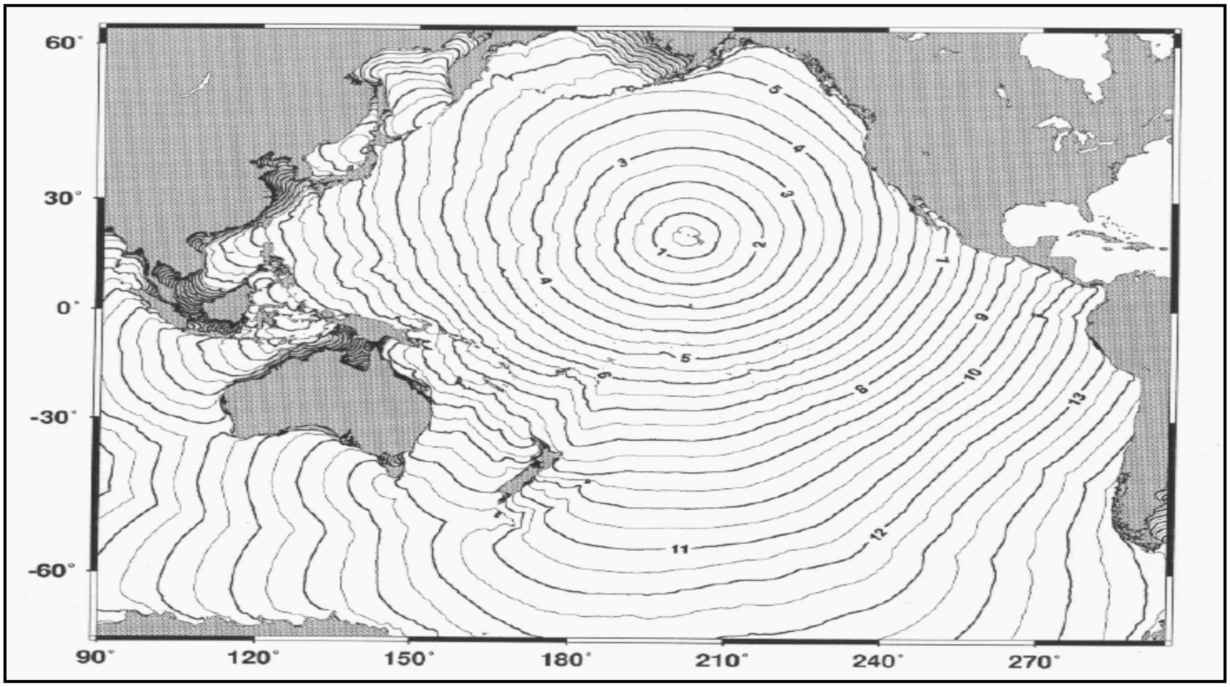

Figure 18-3: Arrival Times of Pacific-Based Tsunami

The present Pacific tsunami warning system evolved from a program initiated in 1946. It is a cooperative effort involving 26 countries along with numerous seismic stations, water level stations and information distribution centers. The National Weather Service operates two regional information distribution centers. One is located in Ewa Beach, Hawaii, and the other is in Palmer, Alaska. The Ewa Beach center also serves as an administrative hub for the Pacific warning system. The system only begins to function when a Pacific basin earthquake of magnitude 6.5 or greater triggers an earthquake alarm. When this occurs, the following sequence of actions occurs:

- Data is interpolated to determine epicenter and magnitude of the event.
- If the event is magnitude 7.5 or greater and located at sea, a TSUNAMI WATCH is issued.
- Participating tide stations in the earthquake area are requested to monitor their gages. If unusual tide levels are noted, the tsunami watch is upgraded to a TSUNAMI WARNING.
- Tsunami travel times are calculated, and the warning is transmitted to the disseminating agencies and thus relayed to the public.

- The Ewa Beach center will cancel the watch or warning if reports from the stations indicate that no tsunami was generated or that the tsunami was inconsequential.

This system is not considered to be effective for communities located close to the tsunami source (e.g.' The Cascadia subduction zone) because the first wave would arrive before the data were processed and analyzed. In this case, strong ground shaking would provide the first warning of a potential tsunami.

18.4 SECONDARY HAZARDS

Aside from the tremendous hydraulic force of the tsunami waves themselves, floating debris carried by a tsunami can endanger human lives and batter inland structures. Ships moored at piers and in harbors often are swamped and sunk or are left battered and stranded high on the shore. Breakwaters and piers collapse, sometimes because of scouring actions that sweep away their foundation material and sometimes because of the sheer impact of the waves. Railroad yards and oil tanks situated near the waterfront are particularly vulnerable. Oil fires frequently result and are spread by the waves.

Port facilities, naval facilities, fishing fleets, and public utilities are frequently the backbone of the economy of the affected areas, and these are the very resources that generally receive the most severe damage. Until debris can be cleared, wharves and piers rebuilt, utilities restored, and the fishing fleets reconstituted, communities may find themselves without fuel, food, and employment. Wherever water transport is a vital means of supply, disruption of coastal systems caused by tsunamis can have far reaching economic effects.

18.5 ASSESSING TSUNAMI RISK

The Level 2 HAZUS-MH protocol was used to assess the risk and vulnerability to tsunami in the planning area. HAZUS-MH uses census data at the block level that was augmented with assessor's data provided by Humboldt County. Although HAZUS-MH does not directly model tsunami damage out of the box, the inputs including damage functions may be changed to help better assess the hazard. To model the tsunami hazard, a tsunami hazard zone was created after reviewing historical events and creating a probable scenario. For Humboldt County, Humboldt State University developed the tsunami hazard areas for a highest hazard and moderate hazard event near the coast. A tsunami occurring near the coast is a worse case scenario since the public will have little to no evacuation time. Humboldt State University created a model which shows the possible depth of flooding and the water velocity as it strikes the coastline. It should be noted that this data is not considered to be the probabilistic area for tsunami "inundation" based on detailed modeling. This information is based on historical observed data and was developed primarily for emergency response planning and public education. At the time of this analysis, this is considered to be the best available information.

Two procedures were used to analyze and model the potential damage due to tsunami. The first procedure involved identifying the exposure to the tsunami hazard. The second procedure involved altering the HAZUS-MH coastal flood model to develop loss estimates.

To first analyze what is at risk, the tsunami hazard zones were overlaid with the HAZUS-MH inventory. The buildings that fell in the hazard zones were then added. This is not a true loss estimate since it shows all buildings in the tsunami hazard zone.

FEMA Headquarters and Region IV have developed a methodology to model storm surge during a hurricane using HAZUS-MH. This methodology involves setting up a coastal flood probabilistic scenario using the surge height(s) as the 100-year stillwater elevation. After running the analysis, the 100-year results show damage due to the storm surge. A similar methodology was used to model the tsunami loss. The tsunami heights were input into the model as the incremental still water elevations. These heights were taken from the hazard zones created by Humboldt State University. The tsunami damage functions are different from those of a typical coastal storm, but damage functions may be edited in HAZUS-MH. To edit the damage functions, the tsunami damage components were compared to those of a coastal flood. The components of a tsunami damage function include the following:

- Breaking wave forces—Breaking wave forces typically take place offshore with the exception of very steep slope beaches. Due to the beaches' physical characteristics derived from the elevation data, these forces were removed from consideration.
- Hydrostatic forces—Hydrostatic forces act on buildings during a tsunami. This component is captured in the HAZUS-MH V-Zone damage function.
- Buoyant forces—Buoyant forces act vertically through the center of mass of the displaced volume and are a major concern for wood frame buildings. This component needs to be captured for certain structures.
- Hydrodynamic forces—Hydrodynamic forces occur when steady water flows around a building. These forces are captured in the V-Zone damage function but they need to be modified slightly. In the V-Zone damage function, water deeper than 3 feet causes substantially more damage than water less than 3 feet. In a tsunami, there may be substantial damage below 3 feet, so this component was modified accordingly.
- Surge forces—Surge forces are caused by the leading edge of a surge of water. This component is not captured in the V-Zone damage functions.
- Impact forces—Impact forces are caused by debris impacting the structures. This component is not captured in the V-Zone depth damage curves, but may be significant near piers and ports, where boats may be used as missile-like debris. HAZUS was used to identify the pier and port locations. A separate damage function was developed for census tracts near these locations.

18.6 EXPOSURE

The exposure to the tsunami hazard was evaluated in terms of the population exposed, property exposed, critical facilities/infrastructure exposed and environmental exposure. For this section, exposure refers to the population and/or property within an area that has been identified as being susceptible to a moderate hazard or highest hazard tsunami event.

18.6.1 Population

Population counts of those living in possible tsunami hazard zones within the planning area were generated analyzing the census blocks that intersect with the moderate hazard and highest hazard tsunami hazard zones. Census tract and blocks groups do not follow the same boundaries as the tsunami hazard zones. The populations that would be most exposed to this type of hazard are those along beaches, low lying coastal areas, tidal flats and river deltas that empty into ocean going waters. Therefore the census blocks within this geographical region were analyzed.

The methodology used identified census tract groups whose centers are along the coastline of the planning area. HAZUS-MH estimated the number of buildings in each block that are in the tsunami hazard zone, and then estimated the total population by multiplying the average Humboldt County household size of 2.39 persons per household by the number of structures. Using this approach, it is estimated that the highest tsunami hazard zone exposed population is 42,428 (33.5 percent of the County total) and the moderate tsunami hazard zone exposed population is 3,094 (2.4 percent of the County total).

Development of more detailed spatial analysis can assist in identification of the most vulnerable among residents living in the tsunami hazard zone and can be used to focus public education and outreach efforts on these communities.

18.6.2 Property

The value of exposed buildings in the moderate hazard and highest tsunami hazard zones in the planning area was generated using HAZUS-MH at the census block level and is summarized in Table 18-2. The estimates include the value of both the buildings and their contents.

TABLE 18-2.
VALUE OF EXPOSED BUILDINGS WITHIN TSUNAMI HAZARD AREAS IN HUMBOLDT COUNTY

	Moderate Tsunami Hazard Zone				Highest Tsunami Hazard Zone			
Jurisdiction	Building Exposure Value	Contents Exposure Value	Total Exposure Value	% of Total Assessed Value	Building Exposure Value	Contents Exposure Value	Total Exposure Value	% of Total Assessed Value
Arcata	$27,087,629	$20,788,010	$47,565,639	3.65	$551,785,134	$357,188,470	$901,132,604	69.1
Blue Lake	0	0	0	0	0	0	0	0
Eureka	$122,578,414	$102,659,090	$224,757,504	6.95	$793,986,702	$524,148,700	$1,307,765,402	58.6
Ferndale	0	0	0	0	$20,271,730	$10,683,670	$30,649,700	25.8
Fortuna	0	0	0	0	0	0	0	0
Rio Dell	0	0	0	0	0	0	0	0
Trinidad	$1,003,800	$511,900	$1,495,700	4.1	$4,284,200	$2,177,100	$6,391,300	17.4
Tribes	$225,200	$112,800	$338,000	0.18	$1,949,500	$981,100	$2,930,600	1.6
Unincorporated County	$73,927,231	$46,452,326	$119,127,557	2.4	$596,765,669	$726,297,675	$1,313,365,044	26.5
Total	**$224,822,274**	**$170,524,126**	**$393,284,400**	**4.1**	**$1,969,042,935**	**$1,621,476,715**	**$3,562,234,650**	**36.9**

This methodology estimates that that there is $393.3 million worth of building/contents exposure to the moderate hazard tsunami within the planning area. This represents approximately 4.1 percent of the total assessed value of the planning area, based on Humboldt County Assessor values as of March 1, 2007. It is also estimated that there is $3.56 billion of building/contents exposure to the highest hazard tsunami within the planning area. This represents 36.9 percent of the total assessed value for the area.

Structures in the Tsunami Hazard Zones

The number and type of structures exposed to the tsunami hazard areas was estimated from the Level 2 HAZUS-MH analysis and is illustrated in Table 18-3. For planning purposes, these estimates represent a fair gauge of vulnerability.

18.6.3 Critical Facilities/Infrastructure

Critical Facilities

Tables 18-4 and 18-5 summarize the identified critical facilities in the moderate and highest tsunami hazard zones, respectively.

TABLE 18-3.
STRUCTURES WITHIN / TSUNAMI HAZARD ZONES HUMBOLDT COUNTY

Jurisdiction	Moderate Tsunami Hazard Zone			Highest Tsunami Hazard Zone		
	Residential	Other	Total	Residential	Other	Total
Arcata	83	8	91	3156	90	3246
Blue Lake	0	0	0	0	0	0
Eureka	177	65	242	3802	167	3969
Ferndale	0	0	0	185	1	186
Fortuna	0	0	0	0	0	0
Rio Dell	0	0	0	0	0	0
Trinidad	12	0	12	51	1	52
Tribes	2	0	2	16	0	16
Unincorporated County	768	9	777	5437	57	5494
Total	**1,042**	**82**	**1124**	**12,647**	**316**	**12,963**

TABLE 18-4.
CRITICAL FACILITIES IN THE MODERATE HAZARD TSUNAMI HAZARD ZONE

Jurisdiction	Medical and Health Services	Government Function	Hazardous Materials	Schools	Other	**Total**
Arcata	0	0	1	0	4	**5**
Blue Lake	0	0	0	0	0	**0**
Eureka	0	0	8	0	16	**24**
Ferndale	0	0	0	0	0	**0**
Fortuna	0	0	0	0	0	**0**
Rio Dell	0	0	0	0	0	**0**
Trinidad	0	0	0	0	0	**0**
Tribes	0	0	0	0	0	**0**
Unincorporated County	0	1	4	0	8	**13**
Total	**0**	**1**	**13**	**0**	**28**	**42**

**TABLE 18-5.
CRITICAL FACILITIES IN THE HIGHEST HAZARD TSUNAMI HAZARD ZONE**

Jurisdiction	Medical and Health Services	Government Function	Hazardous Materials	Schools	Other	**Total**
Arcata	2	3	10	8	21	**44**
Blue Lake	0	0	0	0	0	**0**
Eureka	1	6	22	2	73	**104**
Ferndale	0	0	0	1	1	**2**
Fortuna	0	0	0	0	0	**0**
Rio Dell	0	0	0	0	0	**0**
Trinidad	0	0	0	1	0	**1**
Tribes	0	0	0	0	0	**0**
Unincorporated County	0	2	13	9	22	**46**
Total	**3**	**11**	**45**	**21**	**117**	**197**

Infrastructure

Roads or railroads that are blocked or damaged can prevent access throughout the County and can isolate residents and emergency services providers needing to get to vulnerable populations or to make repairs. Bridges washed out or blocked by tsunami inundation or debris from flood flows also can cause isolation. Water and sewer systems can be flooded or backed up, causing further health problems. Underground utilities can also be damaged during flood events.

Roads

Roads are an important component in the management of tsunami related emergencies in that they act is the primary resource for evacuation to higher ground before and during the course of a tsunami event. Roads often act as flood control facilities in low depth, low velocity flood events by acting as levees or berms and diverting or containing flood flows. Using HAZUS-MH, the planning team identified the following major road facilities that may be impacted by tsunami events by analyzing the bridge inventory exposed to the tsunami hazard areas: US Highway 101, Highway 255, Highway 211, Highway 299, Highway 1, King Salmon Avenue.

This list of roads should not be misinterpreted as possible evacuation routes for tsunami events. Evacuation routes are identified in emergency response plans in effect within the planning area. This is simply a list of major roads that may be impacted by a tsunami based solely on exposure.

Bridges

Bridges exposed to tsunami events can be extremely vulnerable due to the forces transmitted by the wave runup and by the impact of debris carried by the wave action. HAZUS-MH identified 19 bridges that would be exposed to a moderate hazard event and an additional 37 bridges that would exposed to a highest hazard event.

Water/Sewer/utilities

Water and sewer systems can be affected by the flooding associated with tsunami events. Floodwaters can back up drainage systems, causing localized flooding. Culverts can be blocked by debris from flood events, also causing localized urban flooding. Floodwaters can get into drinking water supplies, causing contamination. Sewer systems can also be backed up, causing wastes to spill into homes, neighborhoods, rivers and streams. The forces of tsunami waves can impact above ground utilities by knocking down power lines and radio/cellular communication towers. Power generation facilities can be severely impacted by both the velocity impact of the wave action and the inundation of floodwaters. HAZUS identified 9 utilities that would be exposed to a moderate hazard event and an additional 19 utilities that would exposed to a highest hazard event.

18.6.4 Environment

All waterways would be exposed to the effects of a tsunami; inundation of water and introduction of foreign debris could be hazardous to the environment. This would also expose all wildlife inhabiting the area. There are 13 hazardous material sites located in the moderate hazard tsunami hazard zone and 45 sites located in the highest hazard zone.

18.7 VULNERABILITY

18.7.1 Population

The populations most vulnerable to the tsunami hazard are the elderly, disabled and very young who reside near beaches, low lying coastal areas, tidal flats and river deltas that empty into ocean going waters. In the event of a local tsunami sourced in or near the planning area, there would be little warning time, so more of the population would be vulnerable. The degree of vulnerability of the population exposed to the tsunami hazard event is based on a number of factors:

- Is there a warning system?
- What is the lead time of the warning?
- What is the method of warning dissemination?
- Will the people evacuate when warned?

For this assessment, the population vulnerable to possible tsunami inundation is considered to be the same as the exposed population.

18.7.2 Property

All structures along beaches, low lying coastal areas, tidal flats and river deltas would be vulnerable to a tsunami, especially in an event with little or no warning time. The impact of the waves and the scouring associated with debris that may be carried in the water could be very damaging to structures located in the tsunami's path. Those that would be most vulnerable are those located in the front line of tsunami impact and those that are structurally unsound.

HAZUS-MH generated loss estimates for the moderate hazard and highest hazard tsunami hazard areas, as reflected in Table 18-6. It is estimated that there would be up to $148.9 million of loss potential from a moderate hazard tsunami event within the planning area. This represents 1.5 percent of the total assessed valuation for the planning area. It is also estimated that there would be $2.2 billion of loss potential from a highest hazard tsunami event within the planning area. This represents 22.9 percent of the total assessed valuation for the planning area.

TABLE 18-6.
ESTIMATED LOSS FOR TSUNAMI EVENTS IN HUMBOLDT COUNTY

	Moderate Tsunami Hazard Zone				Highest Tsunami Hazard Zone			
Jurisdiction	Building Exposure Value	Contents Exposure Value	Total Exposure Value	% of Total Assessed Value	Building Exposure Value	Contents Exposure Value	Total Exposure Value	% of Total Assessed Value
Arcata	$6,900,905	$5859,950	$12,760,855	0.98	$294,640,854	$345,794,800	$640,435,654	49.1
Blue Lake	0	0	0	0	0	0	0	0
Eureka	$44,805,390	$40,023,310	$84,828,700	3.8	$411,317,710	$271,234,390	$682,552,100	30.6
Ferndale	0	0	0	0	$7,238,880	$3,849,120	$11,088,000	9.3
Fortuna	0	0	0	0	0	0	0	0
Rio Dell	0	0	0	0	0	0	0	0
Trinidad	$120,000	$32,000	$157,000	0.43	$1,042,000	$520,000	$1,562,000	4.2
Tribes	$23,500	$12,300	$35,800	0.02	$569,500	$296,700	$866,200	0.50
Unincorporated County	$28,879,724	$22,250,680	$51,130,404	1.03	$558,743,656	$315,912,890	$874,656,546	17.7
Total	**$80,729,519**	**$68,178,240**	**$148,912,759**	**1.5**	**$1,273,552,600**	**$937,607,900**	**$2,211,160,500**	**22.9**

18.7.3 Critical Facilities/Infrastructure

HAZUS-MH was used to estimate the tsunami loss potential to critical facilities in the planning area. Using depth/damage function curves to estimate the percent of damage to buildings and their contents, HAZUS-MH correlates these estimates to estimated functional down-time. Functional down-time is the time it will take to restore a facility to 100 percent of its functionality. This is an important factor when assessing vulnerability for critical facilities, because it gauges how long the planning area could have limited use of facilities deemed critical to disaster response and recovery. HAZUS estimated that on the average, critical facilities would receive 16 percent damage to structures and 44 percent damage to contents during a moderate tsunami event. The functional down-time to restore these facilities to 100 percent of their functionality would be approximately 480 days. A highest hazard tsunami event would cause 100 percent damage to both the buildings and contents of critical facilities exposed to the event. The functional down-time to restore these facilities to 100 percent of their functionality after a highest hazard event was not determined, due to the severity of the estimated damages.

18.7.4 Environment

Environmental impacts would be most significant in areas closest to the point of impact. Local waterways and wildlife would be most vulnerable at these points. Areas near gas stations, industrial areas and Tier II facilities would be most vulnerable due to potential contaminations from hazardous materials. The vulnerability of aquatic habit and associated ecosystems in low-lying areas close to the coastline would be highest. Tsunami waves can carry destructive debris and numerous pollutants that can have devastating impacts on all facets of the environment, as evidenced in the Indian Ocean in 2004. Millions of dollars have been spent on habitat restoration and conservation within the planning area that could all be wiped out by one significant tsunami. There are currently no tools available to measure these impacts.

Projects that deal solely with environmental restoration or mitigation are not eligible for funding under FEMA hazard mitigation programs, so environmental assessment tools have not been developed to support their programs. However, it is conceivable that the potential financial impact of a tsunami event on the environment could equal or exceed the impact on property. Community planners and emergency managers should take this into account when preparing for the tsunami hazard.

18.8 FUTURE TRENDS IN DEVELOPMENT

The Humboldt County planning area has experienced a relatively low rate of growth in past years (less than 1 percent per year). Considering these historical trends and future population projections produced by the state, anticipated development trends for the planning area are considered low, consisting primarily of residential development with the exception of the Eureka and Fortuna areas. It is assumed that development trends in Humboldt County are not such that there is major concern about development in identified tsunami hazard areas.

Humboldt County is subject to state general planning laws and the California Coastal Act. The County and its cities have adopted critical areas and resources lands regulations pursuant to these laws. Maintaining the agricultural heritage of Humboldt County is a high priority for its land use programs and managers. It has been Humboldt County's policy in the past to not allow for an increase in exposure within its floodplains. The information in this plan provides Humboldt County and its planning partners a tool to ensure that there is no increase in exposure within the floodplains of the planning area.

18.9 SCENARIO

The worst case scenario for the planning area is a local tsunami event triggered by a seismic event along the Cascadia subduction zone. Historical records suggest that tsunami wave heights on the order of 15 to 60 feet could be generated by a Cascadia subduction event. The Humboldt County planning area possesses some geographical features that may help absorb some of the impacts of tsunami events. However, a major tsunami event in the region would have devastating impacts on the people, property and economy of Humboldt County

18.10 ISSUES

The planning team has identified the following issues related to the tsunami hazard for the planning area:

- Hazard Identification: To truly measure and evaluate the probable impacts of tsunamis on planning, new hazard mapping based on probabilistic scenarios likely to occur for Humboldt County need to be created. The science and technology in this field are emerging. For tsunami hazard mitigation programs to be truly effective, probabilistic tsunami mapping will need to be a key component.
- Present building codes and guidelines do not adequately address the impacts of tsunamis on structures and current tsunami hazard mapping is not appropriate for code enforcement.
- Resources in the planning area such as the Redwood Coast Tsunami Work Group and Humboldt State University that have done excellent work in implementing and supporting public information and awareness programs. These programs need to be continued, supported and enhanced to promote the concepts of mitigation and preparedness for the impacts of tsunamis and all hazards addressed by this plan.
- As tsunami warning technologies evolve, the tsunami warning capability within the planning area will need to be enhanced to provide the highest degree of warning to planning partners with tsunami risk exposure.
- With the possibility of climate change, the issue of sea level rise may become an important consideration as probable tsunami inundation areas are identified through future studies.

- Special attention will need to be focused on the vulnerable communities in the tsunami zone and on hazard mitigation through public education and outreach.