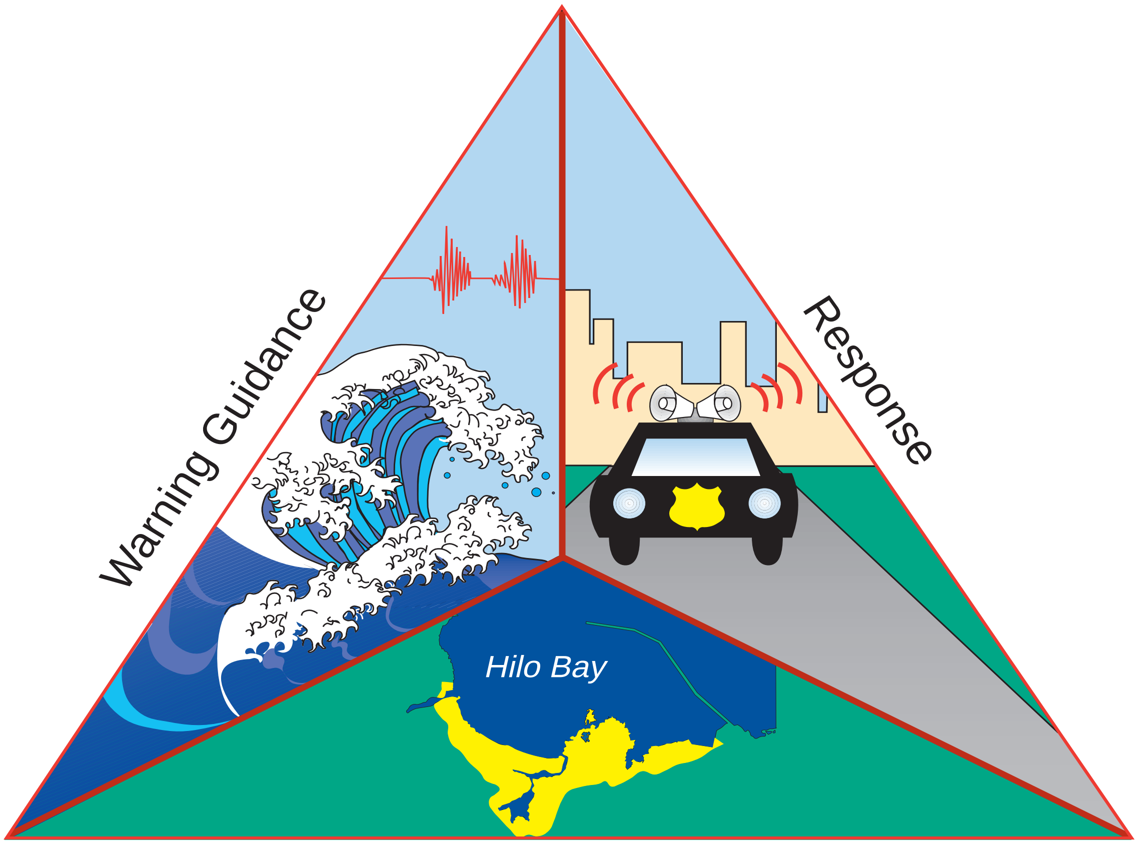
Tsunami Hazard Mitigation

A Report to the Senate Appropriations Committee



Prepared by

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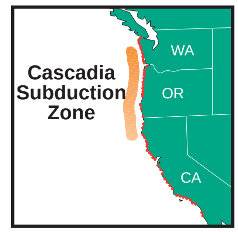
March 31, 1995

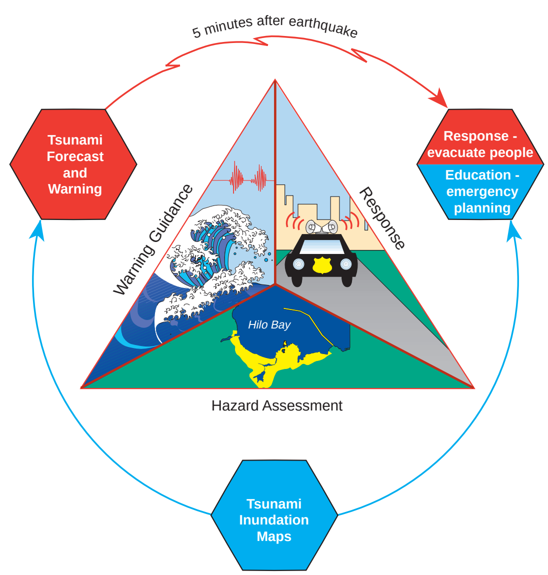
Executive Summary

- **Senate Concern.** The threat to West Coast communities from destructive tsunamis generated by earthquakes in the Cascadia Subduction Zone.



- **NOAA Response.** Lead the first coordinated, comprehensive effort by Federal and State agencies, academia, and local communities to
    - identify needs of at-risk communities
    - inventory existing national resources
    - review recent technological advances
    - develop specific, practical recommendations

- **Tsunami Hazard Mitigation Plan.** Modernize and integrate existing national capabilities by exploiting recent technological advances. Focus on at-risk coastal communities. Provide each with effective
    - Tsunami Hazard Assessment
    - Tsunami Warning
    - Tsunami Educated Response



- **First Step.** Create necessary Federal/State partnership to examine each recommendation and oversee implementation of the agreed plan. Broad-based membership should include Federal, State, local and academic participation.

I. Background

The Senate Committee on Appropriations has expressed its concern about the destructive potential of a major tsunami to U.S. coastal communities and has issued the following directive to the National Oceanic and Atmospheric Administration (NOAA):

> "The Committee directs NOAA to prepare a plan for a tsunami warning system that could reduce risk to coastal residents. The plan should evaluate sites for a tsunami warning system that would assist States in the mapping of possible tsunami inundation. The Committee expects such a report no later than March 31, 1995." (Report on FY95 Budget, July 1994)

In response to this directive, NOAA has developed a plan to reduce the risk of tsunamis to coastal residents on U.S. coastlines. The strategy involves the use of new technologies along with better coordination of existing activities to reduce tsunami risk through an integrated program that focuses on:

A. Hazard assessment (identify and map tsunami flooding potential)
B. Real-time tsunami monitoring and warning systems (alert the people)
C. Public education (population awareness and community response)

Intensive workshops to develop each component have been held with broad-based participation that included tsunami scientists, Federal, State, and local emergency planners and emergency operators. Workshop participants focussed on evaluation of new hazard assessment and mitigation technology. NOAA technical reports were published on each workshop. This document summarizes and synthesizes these workshop recommendations into a coherent plan.

II. The Problem

U.S. coastal communities are threatened by tsunamis that are generated by both **local** earthquakes and **distant** earthquakes. Local tsunamis give residents only a few minutes to seek safety. Tsunamis of distant origins give residents more time to evacuate threatened coastal areas but increase the need for timely and accurate assessment of the tsunami hazard to avoid costly false alarms. Thus, U.S. residents in Alaska can experience a local earthquake and tsunami while residents of Hawaii and the west coast may experience this disaster as a distant tsunami. Similarly, west coast residents can experience a local tsunami that may also have an impact on the distant states of Alaska and Hawaii. Of the two, local tsunamis are more devastating. The challenge is to design a tsunami hazard mitigation program to protect life and property from two very different types of tsunami events.

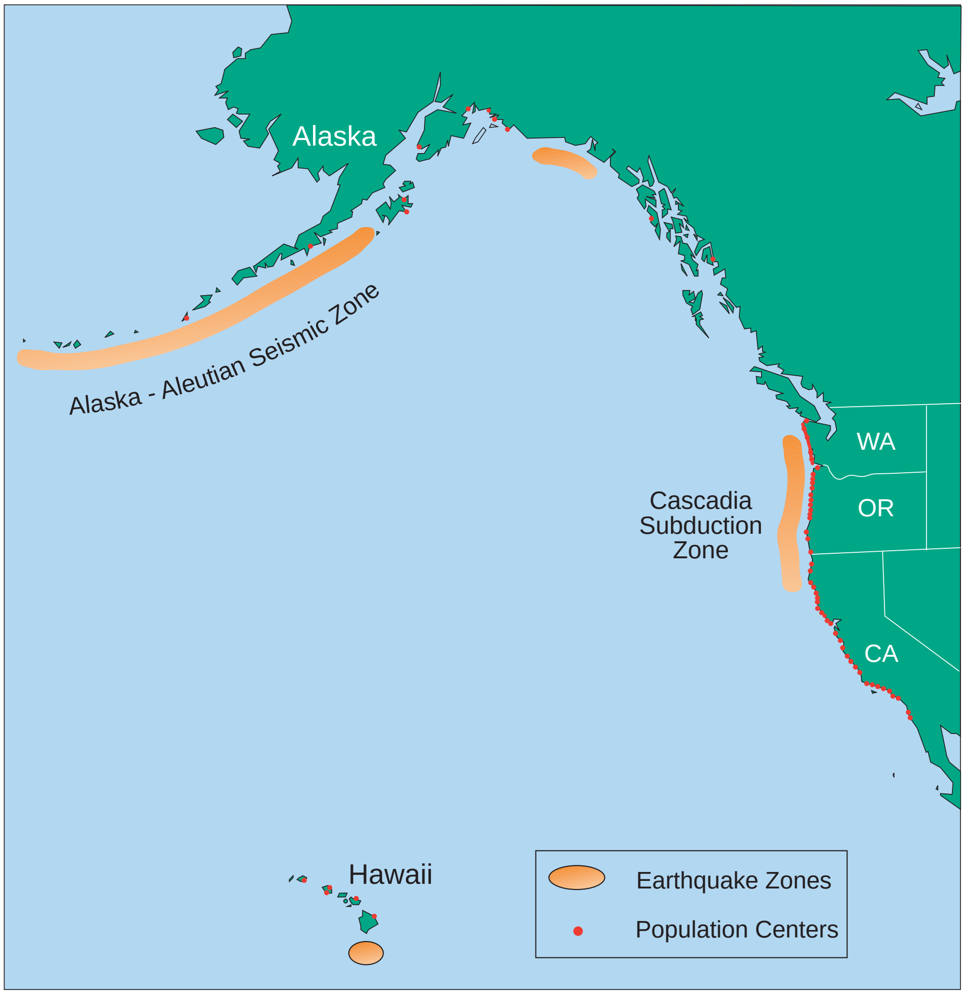


Figure 1. Tsunami hazard for the United States is defined by the earthquake zones capable of generating tsunamis in the Alaska-Aleutian Seismic Zone, the Cascadia Subduction Zone, and Hawaii. The populations at risk from tsunami are identified as population centers.

1. The Greatest Threat—Local Tsunamis Generated Off the U.S. Coast

The Cascadia Subduction Zone threatens California, Oregon, and Washington with devastating local tsunamis (Figure 1) that could strike the coast within minutes. There is increasing geological and seismological evidence that: earthquakes of Richter scale magnitude 8 and more have previously 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 Washington, Oregon, and California (Heaton and Hartzell, 1987; Weaver and Shedlock, 1992). Recent articles (Waethrich, 1994) indicate that the probability of a Cascadia earthquake occurring is comparable to that of large earthquakes in southern California (i.e., 35% probability of magnitude of 8 or above between 1995–2045). The Alaska and Aleutian Seismic Zone also has been recognized as a region with very high seismic potential. Respected U.S. seismologists have predicted the occurrence (84% probability between 1988–2008) of a major earthquake with magnitude greater than 7.4 in Alaska (Nishenko and Jacob, 1990). When this earthquake occurs, Alaska's coastlines can be expected to flood within 15 minutes.

A reminder of this threat occurred in April 1992 when a small tsunami was generated at the southern end of the Cascadia Subduction Zone by a large (7.1 M_s) earthquake near Cape Mendocino, California (González and Bernard, 1992). This tsunami arrived at Eureka, California only 15 minutes after the earthquake origin time. No tsunami warning was issued because the instruments used to determine earthquake magnitude were outdated. During a post-earthquake scientific meeting on the Cape Mendocino earthquake/tsunami, sponsored by the Federal Emergency Management Agency (FEMA), one of the two most urgent recommendations suggested was the production of local tsunami inundation maps for Northern California coastal communities at risk. Tsunami preparedness was deemed to be of such high importance and urgency that the project was funded by FEMA and NOAA to produce tsunami inundation maps for Eureka and Crescent City, California. FEMA also funded an earthquake scenario study of Northern California. The combined study

Eureka, California

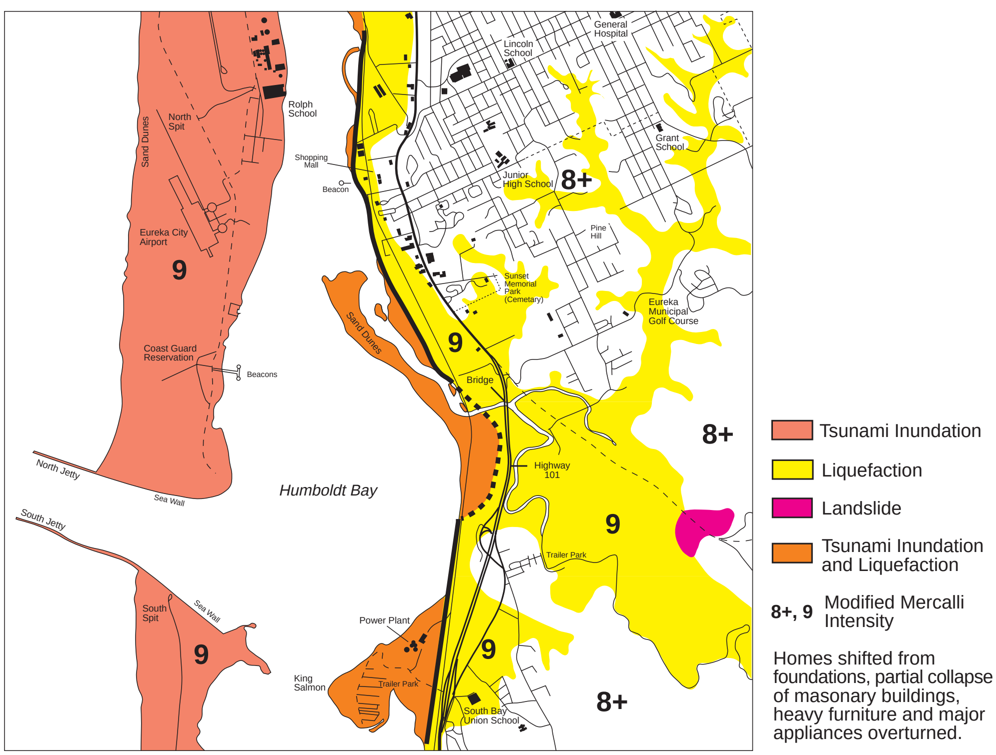


Figure 2. This map identifies areas of tsunami flooding, areas of liquefaction, landslides, and intense ground shaking. If the tsunami is generated by a local, major earthquake near Eureka, then highway 101 probably will be damaged by the liquefied soils to the south. Evacuation then would be feasible only to the north on highway 101. It is important to evacuate to safe areas.

produced the first comprehensive assessment of the nearby earthquake and local tsunami risk to a coastal community (Bernard *et al.*, 1994, and Toppozada *et al.*, 1995). The first-of-a-kind map is illustrated in Figure 2, which clearly shows areas susceptible to tsunami flooding, earthquake shaking intensity, earthquake-induced liquifaction, and earthquake-triggered landslides.

The Eureka tsunami study can be considered the prototype and model for the application of existing technology to local tsunami hazard assessment. These local tsunami hazard maps will be incorporated into the emergency plans of Eureka, California. This process, which starts in March 1995, will provide an opportunity for NOAA, FEMA, the State of California, and local Eureka emergency planners to set the standard for emergency procedures for other coastal communities threatened by local tsunamis.

2. The Silent Threat—Tsunamis Generated at a Distance

The U.S. has suffered major damage from tsunamis originating in Chile, Japan, Russia, and Alaska. If an earthquake in Alaska generated a major tsunami, Alaskan shores would be flooded within 15 minutes, while the coasts of Hawaii, Washington, Oregon, and California would be hit within 5 hours after the event. Under present conditions, the Alaskan and Pacific Tsunami Warning Centers (ATWC and PTWC) would issue warnings, based on seismic data alone, covering a limited area as soon as the earthquake is detected, located, and sized. It then would take about an hour for the Centers to receive confirmation from Alaskan coastal tide gauges that a major tsunami had been generated. With confirmation, the ATWC would expand its warning area to include the entire west coast of the United States, and the PTWC might issue a Pacific Basin-wide warning. Even at this time, the Centers would have only a rough idea of the potential size of the tsunami. They would receive no further information until the tsunami reached Midway Island (about 3 hours after the earthquake) or the west coast of the United States (4 to 5 hours after the earthquake). At that point, it would be too late for Washington and Oregon emergency managers to change their plans of operation, and Hawaii emergency managers would have only about an hour and a half to adjust their plans. Recently, the development of a method to detect, in real time, the passage of a tsunami in the open ocean could provide additional lead time to evacuate coastal residents.

For the Alaska earthquake/tsunami scenario, it is important to recognize that only Hawaii possesses a set of evacuation maps for the distant tsunami scenario. These maps were derived from tsunami inundation models and are published in local telephone directories. Once a warning is received in Hawaii, residents are evacuated from potential tsunami inundation areas. The other affected states have no similar maps. Lack of evacuation maps and timely tsunami wave information gives rise to confusion on how to respond to a NOAA tsunami warning. Lack of evacuation maps and timely tsunami wave information certainly contributed to the confusion caused by the October 4, 1994 distant tsunami warning. (See the Tsunami Education Workshop report (Good *et al.*, 1995).)

3. Conclusions

Local tsunamis are the greatest threat to U.S. coastlines, but distant tsunamis are also a constant threat. Technologies now exist to identify areas at risk from both types of tsunamis and to detect the passage of a tsunami in the deep ocean in real time.

III. Tsunami Hazard Mitigation Plan

Eventually, tsunamis will strike all U.S. Pacific Ocean coastlines. To mitigate any rapid onset natural disaster, it is critical to accurately assess the nature of the hazard, design an alerting technique, and prepare the at-risk area for appropriate reaction to reduce the impact of the hazard. Applying the conceptual model—hazard assessment, warning, and educated response—to the tsunami hazard is a way to reduce the inevitable impact of tsunamis. One way to think about the application of this model to the tsunami hazard is illustrated in Figure 3. The three interdependent pieces of the conceptual model are shown as a triangle.

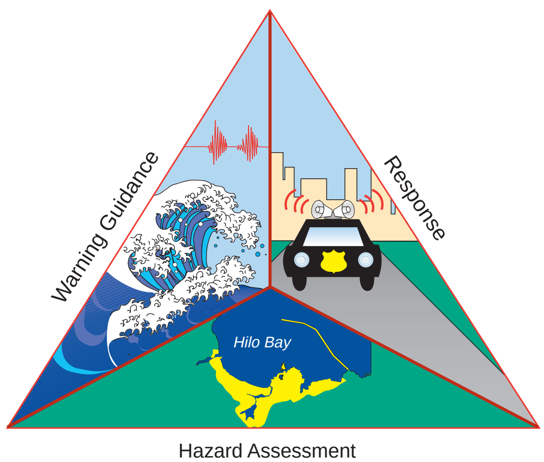


Figure 3. Tsunami Hazard Mitigation Model.

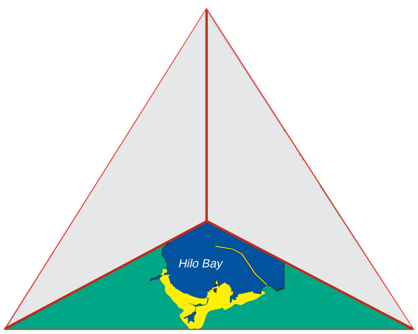
NOAA conducted the first comprehensive evaluation of existing tsunami hazard mitigation technology and user needs through a series of three workshops (hazard assessment, warning, educated response) held from November 1993 to October 1994. (For details about the workshops see Appendix A.) The process of involving Federal, State, and local representatives yielded a rich diversity of ideas and suggestions. The main theme that emerged was that the hazard affects local populations, so the solutions should be developed with input from these people. Below is a summary of the major findings and recommendations from each workshop. These major recommendations form the basis of the NOAA plan to mitigate the U.S. tsunami hazard. Agencies involved in the mitigation plan at the Federal level include NOAA, United States Geological Survey (USGS), FEMA, and the Army Corps of Engineers. At the State and local level, emergency planning and operations are involved as well as universities.

A. Tsunami Hazard Assessment

The base of the triangle in Figure 3 and the first element for designing appropriate warning and education systems is **hazard assessment**. For each coastal community, an assessment of the tsunami hazard must be carried out to identify at-risk populations and areas. For some communities, data from earlier tsunamis provide an empirical method for identifying hazardous areas. For most communities, however, little or no data exist. For these areas, tsunami inundation numerical models can provide estimates of areas that could be flooded in the event of a local or distant earthquake. The accuracy of this technology is appropriate to design the other two elements of the model—warning and educated response systems. Our first workshop found that existing technologies are adequate to produce tsunami inundation maps for emergency preparedness and documented several technical methods (Bernard and González, 1994). Participants were of the strong opinion that the production of these maps should be guided by local experts who had detailed knowledge of that geographical area. The participants also wanted these maps to be as accurate as possible, so they felt that the models should be tested and validated with observed data.

Major Finding:

- Technology exists to produce tsunami inundation maps for emergency preparedness.



Hazard Assessment

Major Recommendations:

1. Establish a group of scientists to produce tsunami inundation maps for coastal towns in Alaska, California, Hawaii, Oregon, and Washington.
2. Tsunami inundation map production should be guided and implemented by State and local users.
3. Test and validate models with observed data.

B. *Tsunami Warning*

The second element of the conceptual model (Figure 3) is the appropriate warning system to alert coastal communities that danger is imminent. Three types of tsunami warning systems exist to alert populations of the occurrence of an earthquake that has high potential to generate a tsunami. The Pacific-wide system warns populations in about 1 hour (>750 km from the source); regional systems warn in about 10 minutes (100–750 km from the source); local systems warn in about 5 minutes (<100 km from the source). Three warning systems exist today. There is one Pacific-wide system—the Pacific Tsunami Warning Center; five well-established regional systems (U.S.–2, Japan, Russia, French Polynesia), and local systems exist in Chile and Japan (Bernard *et al.*, 1986). All three systems use earthquake magnitude as the trigger for warnings and use coastal tide stations as verification that a tsunami exists and as a guide to announce that the danger has passed. Because these systems are activated by earthquake magnitudes, and because not all earthquakes generate tsunamis, there are false alarms.

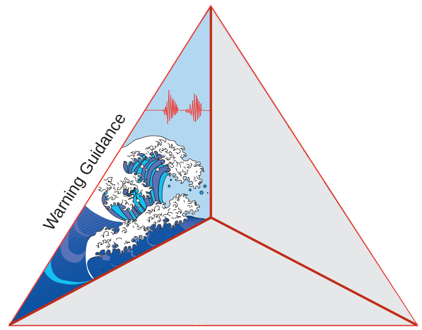
In the tsunami hazard mitigation model, warning systems are designed according to the local hazard assessment. For the U.S., the earthquake areas shown in Figure 1 subject California, Oregon, Washington, Alaska, and Hawaii to the local tsunami hazard and all coastal areas are exposed to the distant tsunami hazard. The tsunami warning system for the U.S. should provide local and distant tsunami warnings for coastal communities. Our second workshop found that the national effort to detect earthquakes in the states of California, Oregon, Washington, Alaska, and Hawaii consists of seven seismic networks with about 1000 real-time reporting seismometers at a capital cost of $23 million and annual operating costs of over $9 million. The participants of the workshop found that this extensive network could be utilized, with some modifications, to provide tsunami warnings within five minutes for any earthquake occurring along U.S. coastlines. Those modifications include 1) the inclusion of more real-time seismometers which can be used to quickly determine the magnitude of a large earthquake (broad-band seismometers); 2) the agreement that these data plus other real-time seismic data should be exchanged among the existing networks; and 3) the implementation of 24-hr/day in-office operations at the two existing tsunami warning centers.

Participants felt that making better use of existing networks was preferred over the siting of a new tsunami warning center. If their recommendations are implemented, there is no need to create another traditional tsunami warning center on the West Coast.

They also found that the existing water level network of 12 real-time tide gauges in Alaska and Hawaii was inadequate to detect local tsunamis for forecasting local tsunami impacts. Participants recommended the modification of coastal gauges to detect large tsunamis. They recognized that the new technology to detect tsunamis near the source offers an improved approach to early detection and forecasting of tsunamis. With this realization, they recommended the installation of deep water tsunami gauges and the use of the resulting data for forecasting tsunami wave heights. Details of the discussions and recommendations can be found in the tsunami warning workshop report (Kanamori and Blackford, 1995).

Major Findings:

- Technology exists to issue local tsunami warnings within five minutes for earthquakes occurring along U. S. coastlines.
- Existing water level system is inadequate to track large tsunamis in a timely manner.



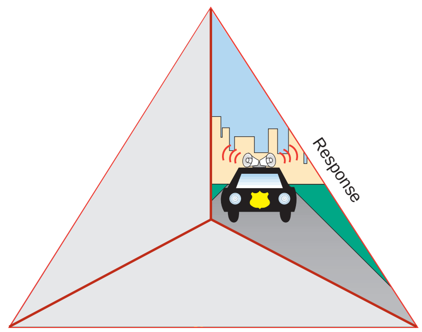
Major Recommendations:

4. Upgrade existing seismic networks to include real-time instruments that provide more accurate earthquake magnitudes.
5. Implement a plan to coordinate the exchange of data among existing seismic networks.
6. Implement 24 hr/day in-office operations at two tsunami warning centers.
7. Install network of deep water tsunami gauges and modify existing coastal network to survive large tsunamis.
8. Develop procedures that incorporate water level data for forecasting local tsunami impacts.

C. Tsunami Response/Education

The third element of the tsunami mitigation model (Figure 3) is the educated response which is based on hazard assessment and warning systems. The appropriate response to impending danger from a tsunami requires knowledge of areas that could be flooded (tsunami inundation maps) **and** knowledge of the warning system to know when to evacuate and when it is safe to return. Without both pieces of information the response could be inappropriate and fail to mitigate the impact of the tsunami. Our third workshop found that the residents of Oregon, Washington, and California were unaware of hazard assessment and warning procedures. A FEMA survey of 14 coastal communities' response to the October 4, 1994 NOAA tsunami warning found the information unusable by 30 percent of the communities surveyed and not timely for 71 percent of the affected communities.

Workshop participants recommended the formation of an educational network to exchange existing information and keep abreast of new educational material being developed. Participants, recognizing that lack of tsunami inundation maps was a major obstacle in education of local residents, recommended the production of tsunami inundation maps as soon as possible. Workshop participants were concerned that each state may create different signs for guiding people out of tsunami hazard areas, so they recommended that standardized signs for tsunami hazard zone and evacuation be used in all affected states. They were also concerned that too many "experts" were being used by the media during tsunami warnings, which led to public confusion. Participants recommended that each state establish a tsunami advisor to provide expert guidance to the media, decision makers, and emergency planners. A summary of this workshop can be found in the tsunami education workshop report (Good *et al.*, 1995).



Major Finding:

- Tsunami education for local and distant tsunami is deficient for West Coast decision makers and residents.

Major Recommendations:

9. Establish an educational network among local, State, and Federal agencies to promote communication and coordinate the exchange of existing and new information and assist in improving tsunami warning messages.
10. Produce preliminary tsunami inundation maps to aid in local educational process.
11. Develop standardized tsunami hazard zone and evacuation signs for use in Alaska, California, Hawaii, Oregon, and Washington.
12. Establish each state's single-point tsunami expert contact for media, decision makers, and emergency planners.

D. The Plan

By combining the three elements—hazard assessment, warnings, and response—we have a context for implementing the workshop recommendations. A schematic summary of the plan is illustrated in Figure 4.

The tsunami hazard mitigation plan (Figure 3) uses hazard assessment to design appropriate warning systems and appropriate response by affected populations to reduce the impact of the tsunami. These three components must be highly interactive and well coordinated to mitigate the effects of a tsunami. Thus, a coordinating body of appropriate scientists, emergency managers, emergency planners, and warning center operators, with representations from each affected state, should be created to ensure this coordination.

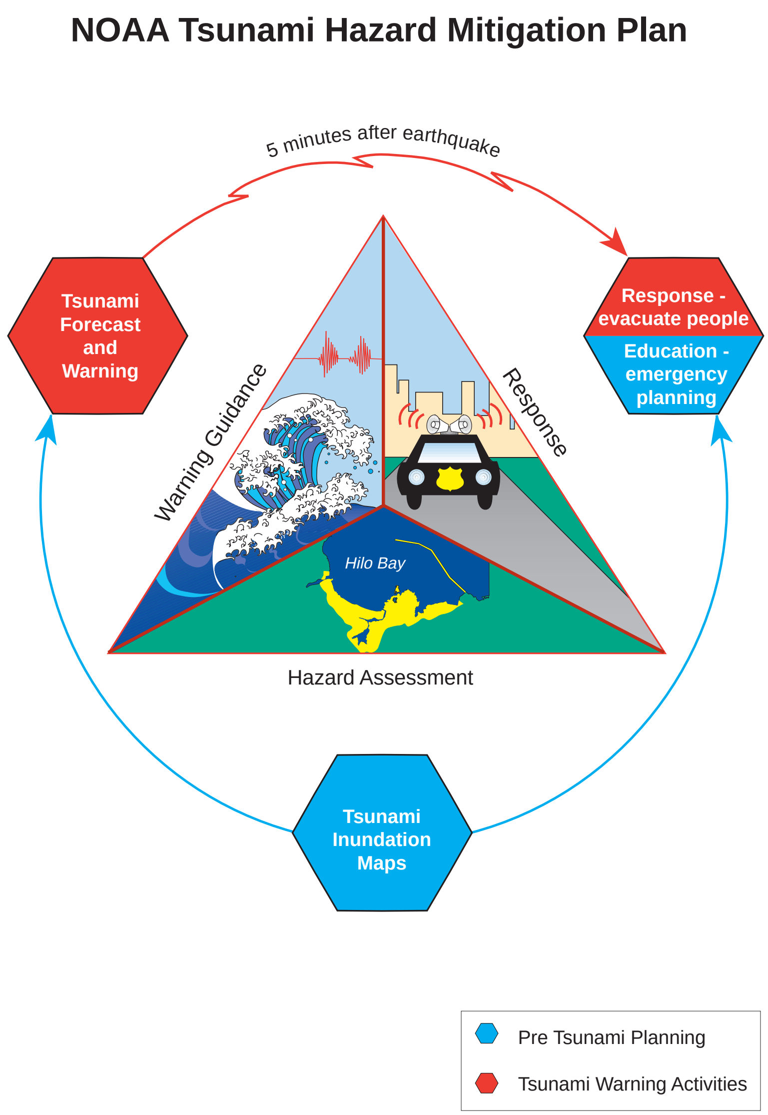


Figure. 4. NOAA Tsunami Hazard Mitigation Plan. Each element requires the participation of NOAA, USGS, FEMA, and the states' emergency agencies and universities.

IV. The First Step—A Federal/State Partnership

To implement the plan requires three phases:

1. Coordination
2. Planning
3. Implementation

The coordination phase is essential to form a coherent plan of action with time milestones. The three workshops provide a technical basis for identifying techniques and needs, but they represent only the first step in coordination. The next step is to form a Federal/State partnership to convert these recommendations into an action plan. The Federal side of the partnership should include NOAA, USGS, FEMA, and the Army Corps of Engineers. Since NOAA has Federal responsibility for tsunami warnings, NOAA should be the lead agency. The State side of the partnership should include Alaska, California, Hawaii, Oregon, and Washington. Each state should have a representative that could become the expert for that state (Recommendation #12). Through this process, a plan can evolve in which the Federal role to protect life and property is appropriately applied at the local level. The plan should outline what recommendations can be implemented at various resource levels. We must recognize that each state has a different emergency planning/operational structure and that the Federal government is downsizing. These two facts force us to use our existing resources as wisely and productively as possible.

The planning phase should emerge as soon as possible. The present document contains 12 recommendations that could be the essential elements of the plan. Coordination is required to establish a process to rank the recommendations. Once the ranking of recommendations is agreed upon, then the implementation phase can begin. The process of implementation will be controlled by resources available from all sources—the Federal sector, the State sector, and the private sector.

V. Conclusions

The three workshops on tsunami hazard assessment, warning guidance, and educated response have provided a set of recommendations that can reduce the impact of local tsunamis on West Coast residents. The next step is to rank these recommendations through a coordinating group composed of Federal/State partners and formulate a plan of action. The recommendations do not call for the siting of a new warning center, but rather the use of existing seismic networks through focused upgrades of instrumentation, telemetry, and processing. The recommendations provide for inundation mapping for all Pacific coastal communities through a process that involves local governments, including affected coastal residents.

References

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Appendix A

Tsunami Mitigation Workshops

Three workshops were held during a one-year period (November 1993–October 1994) to capture a snapshot of the "state-of-the-art" technology and to identify the needs of users of NOAA's tsunami warning products. Fifty-six specialists in tsunami science, emergency planning and operations, and educators represented 41 different organizations of local, State, and Federal Governments and Universities. The five affected states of Alaska, California, Hawaii, Oregon, and Washington were represented. The list of participants is given below.

TSUNAMI INUNDATION WORKSHOP ATTENDEES

Name	Affiliation
Frank Tsai	FEMA
Karla Heerman	FEMA-Pacific Area Office
Eddie Bernard	NOAA/PMEL
Frank González	NOAA/PMEL
Stephen Hammond	NOAA/PMEL
Dennis Sigrist	ITIC/NOAA-NWS
Chip Mccreery	NOAA/NWS/PTWC
Bill Mass	NOAA/NWS/PTWC
Michael Blackford	NOAA/NWS/PTWC
Mel Nishihara	State of Hawaii Civil Defense
Brian Yanagi	Hawaii State Civil Defense
Gus Furumoto	Tsunami Advisor, State of Hawaii
Richard Mccarthy	California Seismic Safety Comm.
Vasily Titov	University of Southern California
Don Hull	Oregon Department Of Geology
Jim Good	Oregon State University Sea Grant
Philip Liu	Cornell University
George Carrier	Harvard University
George Curtis	JIMAR/University of Hawaii
Dennis Moore	JIMAR/University of Hawaii
Zygmunt Kowalik	University of Alaska, Fairbanks

TSUNAMI WARNING WORKSHOP ATTENDEES

Name	Affiliation
Michael Blackford	NOAA/NWS/PTWC
Eddie Bernard	NOAA/PMEL
Frank González	NOAA/PMEL
Hugh Milburn	NOAA/PMEL
Thomas Sokolowski	Alaska Tsunami Warning Center

David Mcgehee	U.S. Army Corps of Engineers
John Filson	USGS
Thomas Heaton	USGS
David Oppenheimer	USGS
Hiroo Kanamori	California Institute of Technology
Stephen Malone	University of Washington
Reinhard Flick	University of California, San Diego
Emile Okal	Northwestern University
Kenji Satake	University of Michigan
Costas Synolakis	University of Southern California

TSUNAMI EDUCATION WORKSHOP ATTENDEES

Name	Affiliation
Connie Manson	WA Department of Natural Resources
Susan Larson	WA Emergency Management Division
Lloyd Rayment	B.C. Provincial Emergency Program
George Priest	DOGAMI
Beverly Vogt	DOGAMI
Susan Mcbride	Humboldt County Coop Extension
Jeri Allemand	Curry City Emergency Services
Dave Mayer	OR Emergency Management
Leslie Ewing	CA Coastal Commission
Sarah Nathe	CA Office of Emergency Services
Emily Toby	DLCD
Frank Tsai	FEMA
Eddie Bernard	NOAA/PMEL
Frank González	NOAA/PMEL
Thomas Ainsworth	NOAA/NWS Western Region
William Sites	NOAA/NWS
Dennis Sigrist	International Tsunami Information Center
Thomas Sokolowski	AK Tsunami Warning Center
Michael Blackford	NOAA/NWS/PTWC
Bob Goodwin	University of Washington
Bill Steele	University of Washington
Jim Good	Oregon State University
Curt Peterson	Portland State University
Antonio Baptista	Oregon Graduate Institute
Lori Dengler	Humboldt Earthquake Education Center
Vicki Osis	Extension Sea Grant
Robert Malouf	Oregon Sea Grant
Pat Ainsworth	American Red Cross Field Service Office
Sherry Patterson	American Red Cross
Teresa Atwill	Newport, OR
Al Aya	Cannon Beach, OR