Tsunami Hazard Mitigation Implementation Plan

A Report to the Senate Appropriations Committee

Prepared by

Tsunami Hazard Mitigation Federal/State Working Group

April 1996

Tsunami Hazard Mitigation Implementation Plan

A Report to the Senate Appropriations Committee

Prepared by

The Tsunami Hazard Mitigation Federal/State Working Group

Alaska
Wayne Rush, Alaska Division of Emergency Services
Roger Hansen, University of Alaska

California
Richard Eisner, Office of Emergency Services
Lori Dengler, Humboldt State University

Hawaii
Brian Yanagi, State Civil Defense Division
Gus Furumoto, University of Hawaii

Oregon
Dennis Sigrist, Oregon Emergency Management
Don Hull, Department of Geology and Mineral Industries

Washington
Eric Paige, Office of Emergency Management
Timothy Walsh, Division of Geology and Earth Resources

NOAA
Eddie Bernard, Pacific Marine Environmental Laboratory
Richard Hagemeyer, NWS Pacific Region
Richard Hutcheon, NWS Alaska Region

FEMA
Frank Tsai, Hazard Identification and Risk Assessment Division
Chris Jonientz-Trisler, Earthquake Program Manager, Region X

USGS
Craig Weaver, USGS Pacific Northwest Regional Coordinator for NEHRP (National Earthquake Hazards Reduction Program)

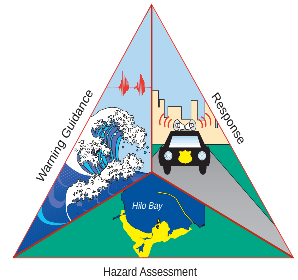
NSF
Clifford Astill, Program Director, Civil and Mechanical Systems Division

April 1996

EXECUTIVE SUMMARY

Senate Charge to NOAA: Form federal/state working group to

1. Review 12 recommendations from 1995 NOAA Report
2. Develop an action plan and budget



Primary Issues of Concern to States:
Alaska, California, Hawaii, Oregon, Washington

- Quickly confirm potentially destructive tsunamis and reduce false alarms
- Address local tsunami mitigation and the needs of coastal residents
- Improve coordination and exchange of information to better utilize existing resources
- Sustain support at state and local level for long-term tsunami hazard mitigation

ACTION PLAN

Objective – Develop state/federal partnership to reduce the impact of tsunamis through the implementation of five recommendations

Goals
- Raise awareness of affected populations (Recommendations 1, 4)
- Supply tsunami evacuation maps (Recommendation 3)
- Improve tsunami warning systems (Recommendations 2, 5)
- Incorporate tsunami planning into state and federal all-hazards mitigation programs (Recommendations 1, 4)

Time Line
- 4-year intensive development period – guided by steering committee
- Continued sustained effort

BUDGET ($000)*

Year	1	2	3	4	5 and beyond
Distant Tsunami					
Recommendation 1 – Develop State/NOAA Coordination and Technical Support					
Five States	(500)	(500)	(500)	(500)	(500)
NOAA	(500)	(500)	(500)	(500)	(500)
Recommendation 2 – Deploy Tsunami Detection Buoys					
NOAA	800	800	800	800	600
Local Tsunami					
Recommendation 3 – Produce Inundation Maps					
Five States	(200)	(200)	(100)	0	0
FEMA	200	200	100	0	0
NOAA	200	200	125	125	125
Recommendation 4 – Develop Hazard Mitigation Programs					
Five States	(100)	(150)	(25)	(65)	(25)
FEMA	175	1,050	100	300	100
Recommendation 5 – Improve Seismic Networks					
Five States	(1,000)	(1,000)	(1,000)	(1,000)	(1,000)
USGS	1,000	1,000	1,000	1,000	600
TOTALS					
Five States	(1,800)	(1,850)	(1,625)	(1,565)	(1,525)
NOAA	(500)	(500)	(500)	(500)	(500)
Federal New Money	2,375	3,250	2,125	2,225	1,425

* Numbers in parentheses represent in kind contribution as match

Contents

I. Background

In July 1994 the Senate Appropriations Committee directed NOAA to formulate a plan for reducing the tsunami risks to coastal residents:

> "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)

NOAA hosted three workshops involving over 50 scientists, emergency planners, and emergency operators from all levels of governments and universities and produced a plan (see Appendix A) in March 1995. In July 1995 the Committee reacted to the NOAA report by stating:

> "The Committee appreciates the timely NOAA report on tsunami hazard mitigation in response to concerns raised by the Committee about tsunami preparedness for the United States. The Committee is in agreement with the primary recommendation of the report that a federal/state working group be formed to discuss the 12 NOAA recommendations and write a plan of action. The Committee directs NOAA to serve as lead agency by forming the group by November 1, 1995, and submitting the action plan by March 31, 1996. NOAA should spend no more than $50,000 for group meetings and preparation of the action plan. The Committee directs the federal/state working group to formulate a budget to implement the tsunami hazard mitigation action plan." (Report on FY96 Budget, July 1995)

NOAA invited representatives from the five affected states—Alaska, California, Hawaii, Oregon, and Washington, along with the Federal Emergency Management Agency, the United States Geological Survey, and the National Science Foundation, to meetings on February 13–14 and March 21 to develop the action plan and budget contained in this report. The report preparation was delayed due to the unanticipated federal furlough. The cost to produce this plan was $15,000 for participant travel expenses and report preparation, reproduction, and distribution.

The Working Group developed a Mitigation Plan to address the concerns of west coast states posed by the Cascadia subduction zone. In developing this Plan, the Group considered the potential impact on this area caused by both a locally generated event and a tsunami generated elsewhere, such as Alaska. The Plan, therefore, while focusing on the West Coast impacts of a catastrophic rupture of the Cascadia subduction zone, has significant benefits for other areas. The improved seismic network will also benefit Alaska and Hawaii by providing critical earthquake information on a Cascadia event much faster than can be determined from the current warning network. Similarly, the data from the proposed tsunami detection buoys will provide tsunami warning centers with much earlier and more accurate information on the expected effects of a tsunami than can be determined from the present system. The buoys will confirm real events and reduce false tsunami alarms both on the West Coast and in Alaska and Hawaii.

An integral part of this Plan is the development of hazard mitigation tools and strategies to reduce the damage and losses from future tsunamis. These tools will fill a gap in knowledge and practice at the state and local government level that will have a direct impact on reducing future losses.

The technology for rapidly determining tsunami potential and the mitigation methods to improve preparedness proposed in this Plan have application beyond the boundaries of the five states directly considered here. They are of value to other U.S. interests in the Pacific such as Guam and Midway, and to the Caribbean and states bordering the Gulf of Mexico, where there is a growing awareness of a potential tsunami threat.

II. The Issues

The following four issues were identified by state representatives to provide a context for discussion of the 12 recommendations developed in the 1995 NOAA Tsunami Hazard Mitigation Plan (See Appendix 1).

A. Quickly Confirm Potentially Destructive Tsunamis and Reduce False Alarms

Destructive tsunamis need to be quickly detected and warnings issued as soon as possible because orderly evacuation of many coastal communities requires several hours. Rapid confirmation that damaging tsunami waves have not been generated is equally important, eliminating the need for unnecessary, disruptive evacuations. “False alarms,” when damaging tsunamis do not occur after warnings have been issued, are expensive and erode credibility and must be greatly reduced or eliminated.

Since the creation of the Tsunami Warning System in the Pacific in 1948, Hawaii has experienced 20 warnings that have resulted in evacuations of coastal areas. Of these 20 warnings, 15 have been considered “false” because no damaging tsunami ensued. A study conducted by the State of Hawaii after the May 1986 false alarm estimated the cost of lost business productivity to be between $30,000,000 and $40,000,000. Not only are false alarm evacuations costly, they also erode the credibility of the emergency management/tsunami warning system. The cost of failing to evacuate for a real event or incorrectly estimating the duration risk can be much greater. On April 1, 1946, 159 people died in Hawaii from a tsunami that originated in Alaska. The City of Crescent City was successfully evacuated before the first waves produced by the 1964 Alaska earthquake arrived. However, some people reentered the evacuated area after it receded and 11 were killed by subsequent waves.

B. Address Local Tsunami Mitigation and the Needs of Coastal Residents

The recent revelations about the potential for a great earthquake off the Washington, Oregon, and northern California coastlines have led to several studies about the effect of a local tsunami generated by this earthquake zone. Local tsunami waves may reach nearby coastal communities within minutes of the earthquake with little or no time to issue formal warnings. The states feel that they do not have the support or the proper tools to educate coastal residents or alert them for this hazard and need a comprehensive mitigation program to fill the void. FEMA estimates that a Cascadia type earthquake/tsunami would cost $25–125 billion in losses to the region. If we assume that the tsunami would cause 5% of these losses, then the tsunami losses would total between $1.25 and 6.25 billion. The population directly at risk from a Cascadia tsunami is significant. About 300,000 people live or work in coastal regions that could be affected and at least as many tourists travel through these areas each year. Some tourism and financial corporations already plan for and educate employees about tsunamis. Others are interested but do not know where to begin and are unaware of the potential losses in terms of lives, operations, and clients.

A local tsunami in the Aleutians could also have devastating impacts on Alaska. If a large earthquake in the Shumagin Islands area generated a destructive local tsunami, thousands of lives would be at risk in Sand Point, King Cove, Akutan City, and Dutch Harbor. Since these communities are some of the largest fishing ports in the U.S., hundreds of millions of dollars of fishing industry infrastructure would be damaged or destroyed.

C. Improve Coordination and Exchange of Information to Better Utilize Existing Resources

Significant investments in technology and other resource expenditures have been made as part of tsunami and seismic detection systems and programs to mitigate the seismic risk. The Group felt that at a small additional cost, these existing systems could be used more effectively. The USGS and the states presently spend about $8 million each year to maintain an extensive network of seismometers along the west coast, in Alaska, and in Hawaii. A $23 million capital investment was required over the past decade to build these sophisticated networks. All networks are trying to reduce the time required to evaluate earthquake effects. In Southern California, earthquake information is distributed as the earthquake is rupturing (about 15 seconds). The group recommends that the NOAA tsunami warning centers aggressively work towards incorporating real-time seismic technology for all regions where potential tsunami generating earthquakes may occur.

Tsunami educational material, evacuation signs, and numerous other mitigation-related products have been developed by different organizations at the federal, state and local level. Much of this material is not widely accessible nor has it been examined for consistency of message or effectiveness. Several communities have launched comprehensive tsunami mitigation programs. Following the April 1992 earthquake in northern California, the State of California, with FEMA funding, prepared an earthquake planning scenario showing the likely effects of a major Cascadia earthquake and tsunami. This document has initiated a number of mitigation efforts in the area, including emergency response planning, workshops with many affected user groups, video public service announcements, and both printed and electronic educational materials. Similar efforts are being made in coastal Oregon communities. However, many of these local community projects are not well known outside their immediate region and there is no central archive of either products or programs readily accessible to all communities exposed to tsunami hazards. The Group felt it essential to inventory existing products and programs, evaluate their accuracy and effectiveness, and make this information widely available to all potential users. Equally important, such an inventory will identify gaps in the existing inventory so that future resource expenditures will be used for needed new products and not duplicate existing efforts.

D. Sustain Support at State and Local Level for Long-Term Tsunami Hazard Mitigation

The states are convinced that effective tsunami hazard mitigation requires a long-term, sustained effort. The tsunami risk is a permanent fixture of life along the Pacific coast and will not be solved by a few years of intensive effort. Tsunami mitigation needs to become an institutionalized part of public education, emergency planning and responsible planning decisions in coastal communities. Some efforts have already been made in this direction. Hawaii routinely publishes tsunami evacuation maps in public telephone books. Oregon has passed two state laws pertaining to tsunamis: a law concerning the siting of critical, essential facilities in potential inundation zones, and a law requiring tsunami drills and education programs for coastal public schools. To foster sustained mitigation programs, the Group felt that tsunami inundation/evacuation maps must be available to all at-risk communities and that successful mitigation efforts need to incorporate them into the permanent, all-hazard mitigation framework at both the state and local level.

It was recognized that local and distant tsunamis will generally require different approaches to hazard mitigation. Thus, the 12 original recommendations were modified to five recommendations—two for the distant tsunami problem and three for the local tsunami problem. The following discussions describe the formulation of these five recommendations and the budgets required to implement them.

III. Distant Tsunami Problem

Distant tsunamis are those generated far enough from a coastal community that sufficient time is available—more than several hours—for risk assessment and reasoned decisions regarding public evacuation and other hazard mitigation actions.

A. Major Needs

Based in large part on their experiences during recent distant tsunami events, state representatives were in clear agreement that two issues were paramount:

1. Information exchange and coordination must be improved. Confusion and uncertainty appear to dominate the situation in the critical decision-making hours after a warning is issued. A survey conducted in 14 west coast communities after the false alarm of 4 October 1994 found that more than 30% felt that tsunami warning information was unclear or unusable and 71% felt that information was updated too slowly. Furthermore, communities frequently received conflicting information or guidance from multiple sources. A major cause of this problem was identified by participants as the lack of adequate state personnel and infrastructure to receive information, make informed decisions, then organize an appropriate and coherent response at the state level.

2. False alarms must be reduced. A false alarm rate of 75% is unacceptably high. But this is, in fact, the present rate, based on the 20 tsunami warnings that have been issued in the 48 years since the establishment of the existing warning system. This high false alarm rate seriously undermines the credibility of warnings and, to the extent that future warnings are unheeded, could contribute to loss of life and property. Furthermore, the economic cost of such false alarms is unacceptably high. The cost to Hawaii alone of the 7 May 1986 false alarm which triggered the evacuation of Honolulu has been estimated to be more that $30M in terms of lost salaries and business revenues. Finally, the fear and disruption of a false alarm can itself put a population at physical risk; fatalities and injuries have occurred during an evacuation due to such things as heart attacks and accidents.

B. Recommendations

To address these issues, two major recommendations were endorsed by the participants:

1. Develop state/NOAA coordination and technical support. The states will organize tsunami activities within their respective states through state-wide tsunami coordinators. These coordinators will serve as the focal point for tsunami-related activities during tsunami events by communicating with NOAA's Tsunami Warning Centers and other states, and by serving as a source of tsunami information and guidance for the state during tsunami events. NOAA will provide technical support for these coordinators through Warning Coordination Meteorologists in Alaska, California, Hawaii, Oregon, and Washington, the Tsunami Warning Centers, and the International Tsunami Information Center in Honolulu, Hawaii.

2. NOAA must establish a real-time reporting network of deep ocean tsunami detection buoys. The rationale for this is straightforward. With existing technology, warning centers are forced to make a warn/no-warn decision based on indirect and insufficient information, such as earthquake magnitude and location, past history of regional tsunamis, and a sparse network of tide gauges, which provide data only after the waves have passed and do not provide information that can directly predict wave heights at other locations. Thus, false alarms are issued because there is no direct verification that a destructive tsunami is propagating across the deep ocean toward a distant coastline. Additionally, there is an understandable tendency for warning centers to “err on the safe side.” Detection systems strategically located seaward of known tsunami source regions will provide the needed verification within minutes of an earthquake through direct open ocean wave measurements. If no tsunami is detected, a false alarm evacuation will be averted. Conversely, if a tsunami is detected, the detection system will provide warning centers with the single most important piece of information required for decision making—the deep ocean tsunami amplitude. Consequently, this system will not only decrease false alarms, but will also quickly confirm a real tsunami and improve the speed and accuracy of true alarms. Existing technology can provide this tsunami detection network; NOAA has already designed and fabricated a prototype tsunami buoy system and successfully deployed it for several months off the Washington-Oregon coast (Figure 1).

C. Implementation Plan

1. State/NOAA coordination and technical support – NOAA: $500,000/year; states: $500,000/year. Each state will establish and support state tsunami coordinators, who will act as the focal point for tsunami-related activities within their respective state. These individuals will interact with state/federal agencies on tsunami warning procedures, seismic information, tsunami inundation map usage, and educational programs. The state tsunami coordinators will organize activities within the state with the other tsunami hazard states in writing proposals and plans for emergency planning and educational programs. Coordination among the five states is essential to public safety. Since U.S. citizens are constantly traveling among these states, signs and warning procedures must be compatible and consistent. Some coordinators will serve on the Tsunami Hazard Mitigation Implementation Group during the first 4 years of activity. Following the initial implementation of the Plan, these coordinators will continue to serve as the focal point for that state’s tsunami hazard mitigation program and coordinate with FEMA, NOAA, and the USGS, as well as the other four states as required.

NOAA will provide technical support for these state coordinators through its Warning Coordination Meteorologist (WCM). The WCM serves as the principal interface between the users of forecasts, watches, warnings, and other NOAA information. The WCM plans and carries out public awareness programs designed to educate the public to ensure the mitigation of death, injury, and property damage or loss caused by natural events for which NOAA has the warning responsibility. These include severe meteorological events, hydrologic events, and tsunamis.

Ten WCMs are located at NOAA offices with coastal warning responsibility and are responsible for awareness and outreach activities for the entire Pacific U.S. coastline. WCMs are located at Anchorage and Juneau, Alaska; Seattle, Washington; Portland and Medford, Oregon;

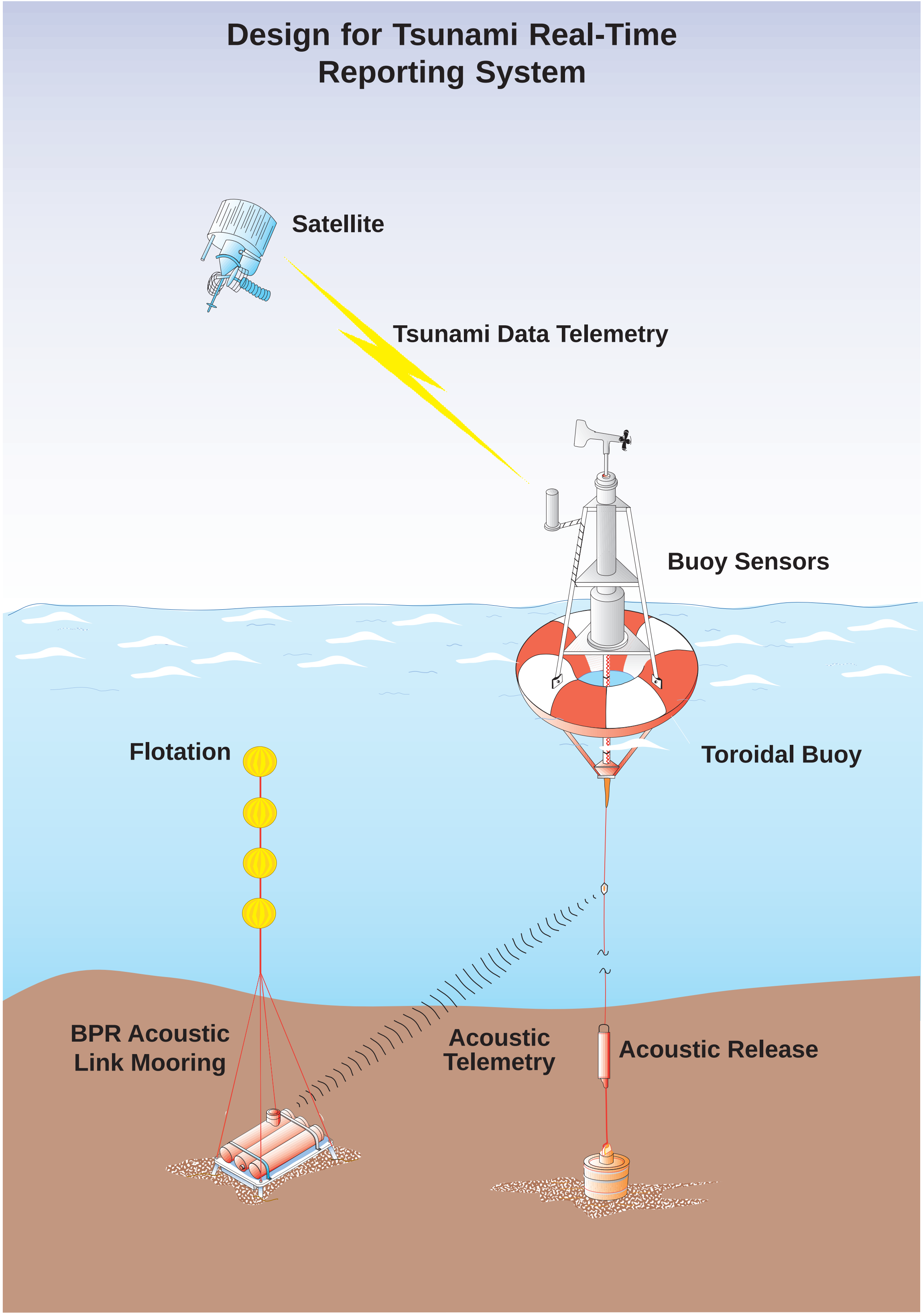


Figure 1. Design for tsunami real-time reporting system.

Eureka, San Francisco Bay Area, Los Angeles and San Diego, California; and Honolulu, Hawaii. NOAA also supports the International Tsunami Information Center in Honolulu, which can provide technical and educational material to the states.

2. Establish real-time tsunami detection network – NOAA: $800,000/year; out years: $600,000/year. Historical and paleoseismic data show that earthquakes capable of producing significant Pacific-wide tsunamis are identified in the shaded coastal regions on Figure 2. The proposed siting of buoys will ensure the detection of any tsunami within these regions within 30 minutes of the generating earthquake. NOAA has built and tested a prototype deep ocean tsunami detection buoy that measures the tsunami in the open ocean and transmits these data to shore in near real time. To protect U.S. coastlines, a six-buoy array is proposed to quickly detect the propagation of a tsunami from areas where earthquakes generate destructive tsunamis and relay tsunami data to the warning centers and the states (Figure 2).

To establish the array over 4 years, NOAA proposes the following schedule:

Year 1	Engineering and software developments will advance the prototype buoy to operational robustness. Procurement and fabrication of two buoy systems will be completed.	Cost – $800,000
Year 2	First two systems will be deployed in Alaska and materials and supplies will be purchased to build two more systems. Engineering and software development will continue.	Cost – $800,000
Year 3	Next two systems will be deployed off the West Coast. Materials and supplies will be purchased to build two more systems. Improvements in engineering and software will continue.	Cost – $800,000
Year 4	Two more systems will be deployed near Kuril Islands and the equatorial Pacific. Materials and supplies will be purchased to build one system. Maintenance visits will be made to two Alaska sites and continued on a 2-year cycle.	Cost – $800,000
Out years	Each year three sites will be visited for maintenance and replacement parts for the equivalent of one system will be purchased. Engineering and software support will be provided to maintain the six-site array.	Cost – $600,000/year

IV. Local Tsunami Problem

Local tsunamis are those generated so close to coastal communities that insufficient time is available for local officials to accurately assess the risk, make reasoned decisions regarding evacuation, disseminate warnings to the public, and carry out an orderly evacuation. The most probable source of local tsunamis is very large earthquakes which complicate response by producing significant damage to structures, roads, communication networks, and other vital lifelines.

NOAA Proposed Siting of Real-Time Tsunami Detectors

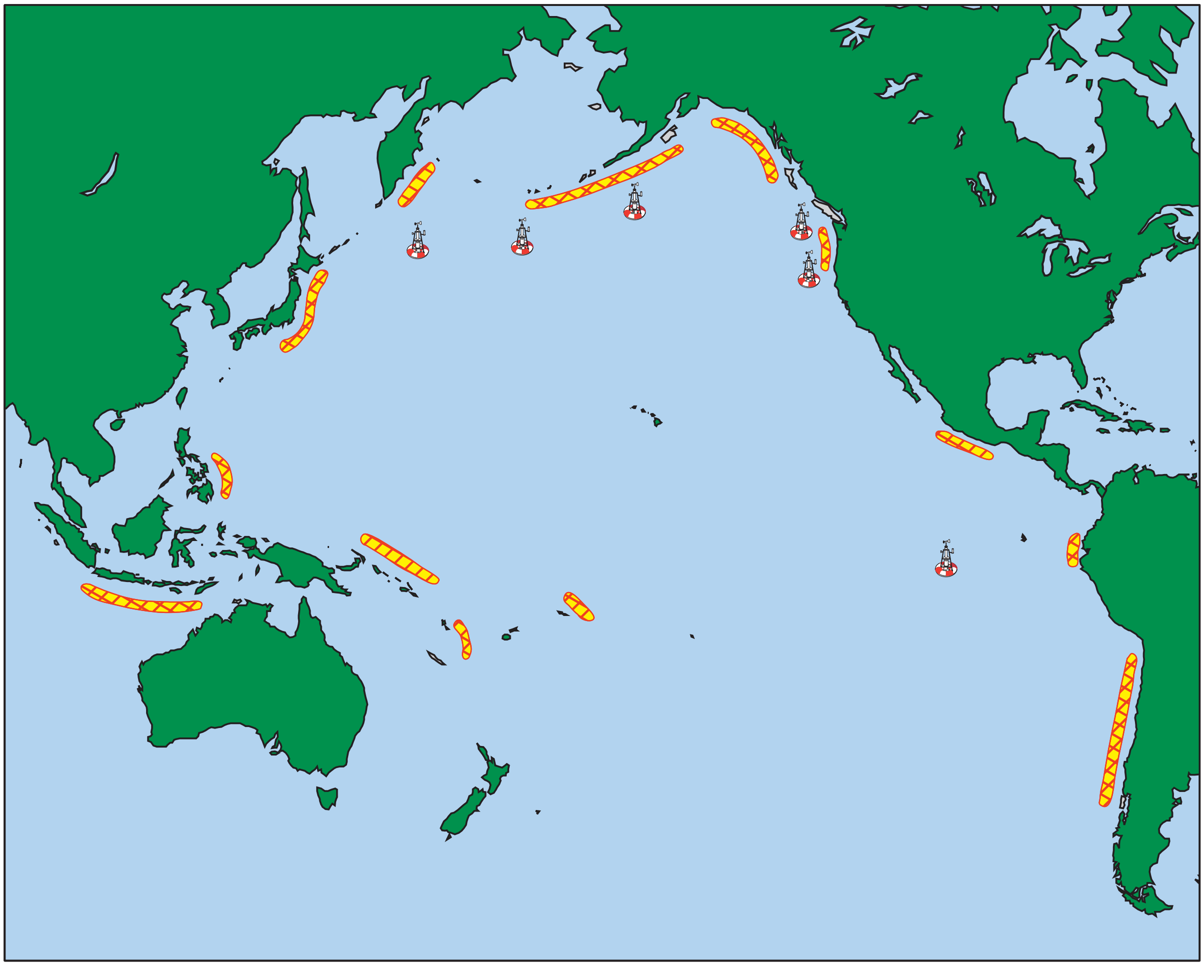


Figure 2. NOAA proposed siting of real-time tsunami detectors.

A. Major Needs

There is universal agreement within the tsunami and emergency response community that technology alone cannot protect coastal inhabitants located in the immediate area of a near-source tsunami. When a large subduction zone earthquake occurs nearby, the first tsunami waves may reach coastal communities within minutes to tens of minutes of the event. Local populations at risk must be able to recognize the signs of impending tsunami hazard such as strong, prolonged ground shaking, and seek higher ground immediately. Communities need to know what areas are likely to be flooded through inundation maps that define the evacuation area and designate evacuation routes and safe regions in which to assemble evacuees. Planners, emergency responders, and residents need to understand the multi-hazard ramifications of a very large local earthquake that will disrupt much of the community infrastructure. At-risk regions need near-real time determination of earthquake source information to assess the nature of the hazard in order to optimize emergency response. Local decision makers need to understand the nature of the risk and be provided with mitigation tools in order to make reasoned long-term planning decisions. A sustained public outreach program is needed to gain the long-term grass-root support of coastal populations and to institutionalize tsunami mitigation in an all-hazard approach to risk reduction. Such a program should encourage consistent informational content among the states and communities at risk and encourage innovative approaches at many different levels.

The local tsunami problem is of particular concern to coastal communities along the Pacific coast of Alaska and in the Pacific Northwest from northern California to Washington State. The major tsunami produced by the 1964 Alaska earthquake was generated by a broad 700-km-long zone of sea-floor warping along the Alaska-Aleutian subduction zone. Tsunami waves arrived at Kodiak Island about 30 minutes after the earthquake. Secondary slump-related tsunamis produced by submarine slides in Prince William Sound arrived at Valdez only minutes after the earthquake. Over 90 percent of the deaths from the 1964 earthquake were a result of these local tsunami waves.

The Cascadia subduction zone along the Pacific northwest coast occupies a similar geologic setting to Alaska. Although no great earthquakes have ruptured this zone in recent historical times, there is increasing geological and seismological evidence that a number of earthquakes in the magnitude 8.5 to 9 range have occurred within the past 2000 years, generating tsunamis which have caused extensive flooding along the coastlines of Washington, Oregon, and California. The proximity of the southern portion of the Cascadia subduction zone to the coastline makes it likely that tsunami waves will arrive along Humboldt and Del Norte counties, California, and Curry County, Oregon, coasts only a few minutes after such an earthquake. Along the central and northern parts of the Cascadia subduction zone, waves might arrive in as little as 20 to 40 minutes after a large earthquake. In the United States, a substantial population is at risk from such a tsunami; on the order of a half million people live, work, and travel each year through potential inundation areas in the three-state region along the Cascadia subduction zone.

Coastlines bordering subduction zones are at the greatest risk of significant local tsunamis; however, all communities along the Pacific ocean need to consider the local tsunami hazard. Large strike-slip earthquakes may trigger local submarine landslides and potentially damaging tsunamis. There are several poorly documented local tsunamis that caused some damage to southern California communities in the 1800's, three of which produced flooding in the Santa Barbara area. A magnitude 5.2 earthquake in 1930 reportedly generated a 20 ft. wave at Santa Monica. Hawaii has been affected by at least 6 local tsunamis since the mid 1800's. In 1975, a magnitude 7.2 earthquake near the southeast coast of Hawaii produced a local tsunami with wave heights of at least 20 feet and in one area nearly 45 feet. $1.5 million in property damages and two deaths were attributed to this local Hawaiian tsunami.

B. Recommendations

To address these issues, three major recommendations were endorsed by the participants:

1. Compilation and distribution of inundation/evacuation maps. Maps showing the areas of likely tsunami inundation for at-risk communities will be constructed using one-dimensional models similar to those presently used in Hawaii for distant tsunami evacuation maps. For some communities more sophisticated models of inundation may be required. There was unanimous agreement among participants that inundation/evacuation maps are the basis of local tsunami hazard planning. Without a clear understanding of what areas are at risk and which areas are unlikely to be flooded, it is impossible to develop effective emergency response plans and education programs. If this Plan is funded, all communities will have an inundation map as a basic planning tool.

2. Develop state and local tsunami mitigation programs. A comprehensive program to address and meet the needs of local at-risk communities will be established. The program will inventory and assess existing mitigation programs and materials which have been developed at federal, state, and local levels and by other countries and define gaps that need to be addressed. It will define the audiences that need to be reached, such as emergency response personnel, the private sector, government decision makers, visitors and tourists, and local residents. The program will develop needed mitigation tools for states and communities based on the inventory and needs assessment and train local user groups through a series of workshops. The program will institutionalize tsunami hazard mitigation by incorporating it into existing state and local all-hazards risk abatement efforts.

3. Improve seismic networks. The current tsunami warning systems are triggered by information from earthquake seismic networks. Typically, earthquake magnitudes above certain levels cause tsunami warnings to be issued. Despite the use of earthquakes as a trigger, the earthquake and tsunami warning systems have remained separate.

Because of increased capabilities in seismic network technology and tsunami warning systems, these two systems will be merged under this Plan. Indeed, as concerns have heightened along the west coast of the United States about consequences of a Cascadia earthquake producing both very strong ground shaking and a tsunami, combining the capabilities of the two systems becomes a necessary requirement for producing better warnings.

This Plan is designed to provide a virtually seamless, integrated tsunami warning system that delivers notification of a major earthquake within 2 minutes of the initial rupture. This initial notification will be followed within 3 minutes by detailed seismic parameters that provide an understanding of the likelihood of a tsunami and an estimate of the pattern of strong ground shaking. Because the rupture speed of a great earthquake is much slower than the initial seismic waves, this capability means that some portions of the west coast will be alerted before the shaking actually arrives. Reporting of a potential tsunamigenic earthquake in Alaska, Hawaii, or Cascadia, proposed under this Plan, would be complete in 5 minutes; currently the same level of detail not available until at least 1 hour after the event. That delay of notification is unacceptable given the lives and property at risk.

Currently, there are over 900 seismometers operating in northern California, Oregon, Washington, and British Columbia, Alaska, and Hawaii. These existing seismometers are telemetered in real time to seismic data centers in Menlo Park, California, Seattle, Washington, Sidney, British Columbia, Fairbanks, Alaska, and the Hawaiian Volcano Observatory (HVO). There, computers analyze the signals, look for earthquake signals, and run location routines. Typically, earthquake locations are now available in 2 to 6 minutes; however, limitations of existing instrumentation make it impossible to offer additional information such as detailed strength of shaking or faulting parameters.

C. Implementation Plans

1. Tsunami inundation/evacuation maps – Costs: Year 1: $600,000; Year 2: $600,000; Year 3: $325,000; Year 4 and beyond: $125,000. The Group felt that the production of tsunami inundation maps was essential to the development of effective hazard planning. In order to produce these maps within 3 years of implementation of this Plan, the Group recommended the Hawaii approach to evacuation map production. Hawaii updated its tsunami evacuation maps in 1990 using a one-dimensional modeling technique developed at the University of Hawaii. The Group recommends that this technique be taught to city and/or county engineers (or state representatives) through a workshop format for each state that lacks inundation maps. The workshops will provide basic training on the application of the one-dimensional model and provide personal computer software with user manuals to aid in the calculations. The instructor will train the engineers at an initial 5-day workshop, be available for assisting the workshop participants for the next month while maps are being produced, and will conduct a concluding 3-day workshop to review the work and finalize the maps. This training process will yield inundation maps and trained local engineers for each coastal community or state representatives to map all communities. As physical changes to the community occur, the trained engineer or state representative can modify the maps to reflect the changes. The trained engineer or state representative can also answer questions about the basis for the maps.

It is estimated that each training program will cost $50,000, funded by FEMA. The first year, training would be conducted for Washington and Oregon, while Alaska and California would be completed in year two and Hawaii would be completed in year three. The combined value of all the city/county engineers' time is estimated to be $100,000 and would be contributed by each community.

The Group also recognized that the one-dimensional models should be supplemented by two-dimensional models for certain communities. NOAA would continue its development of two-dimensional models through the formation of a tsunami inundation mapping center. The mapping center would consist of one contract employee plus supporting funds for a total of $200,000 for the first 2 years and $125,000/year thereafter.

In the first 2 years the mapping center would develop the necessary digitized data bases, adapting the two-dimensional model to run on supercomputers and the one-dimensional models to run on personal computers, and provide data and support for running the models. Support for the generation of inundation maps for appropriate communities would consist of providing required bathymetric and topographic data from the center's data bases and overseeing the running of the two-dimensional model. Support to other communities which wish to run the one-dimensional model would include providing a personal computer version of the one-dimensional model, the required data from the center's data bases, and instructions on how to apply the model.

After the tsunami flooding maps are completed, the Group recommends that a maintenance effort be established to keep the maps updated due to coastal developments and improved mapping technology. The cost would be $125,000/year for one full-time NOAA employee plus support.

2. State and local tsunami mitigation program implementation – Costs: Year 1: $275,000, Year 2: $1,200,000, Year 3: $125,000, Year 4: $365,000, $125,000/year thereafter.

YEAR 1

Task 1: Inventory and Needs Assessment of Existing Materials – Cost $150,000 (State $75,000; FEMA $75,000)

Conduct an inventory, needs assessment and gap analysis of existing educational programs, public information materials, warning and mitigation programs. This initial evaluation of capability will establish a baseline against which products resulting from this Plan can be assessed. This analysis is to include both domestic efforts on federal, state and local levels and foreign programs developed in other tsunami-prone regions. Develop a work program to develop needed materials and disseminate both existing and new programs and products.

Responsibility: FEMA and states

Products:
- Needs analysis
- Resource library
- Work program and network identification

Task 2: Strategic Implementation Plan – Cost $125,000 (State $25,000; FEMA $100,000)

Develop a Strategic Implementation and Utilization Plan for promoting, implementing and supporting tsunami mitigation utilizing existing federal, state and local networks and institutions.

Responsibility: FEMA and states

Product:
- Strategic Implementation Plan

YEAR 2

Task 1: Incorporation of Tsunami Mitigation Into All-Hazards Planning – Cost $250,000 (State $125,000; FEMA $125,000)

Integrate tsunami risk analysis into FEMA all-hazards mitigation planning for coastal states.

Responsibility: FEMA and states

Product:
- Integrated analysis by states

Task 2: Tsunami Mitigation Tools – Cost $800,000 (FEMA $800,000)

Develop tools to support local government risk reduction, including land use guidelines, construction guides and model codes, tsunami abatement techniques (barriers, vegetation, etc.), model awareness and preparedness programs, media materials, and education programs. Utilize existing products where available and crossover information from other hazard mitigation efforts.

Responsibility: FEMA and states

Products:
- Model land use guide
- Model building code provisions
- Model abatement projects
- Model construction guide
- Prototype education and training materials

Task 3: Training Workshops – Cost $150,000 (State $25,000; FEMA $125,000)

Convene five regional training workshops for land use planners, building officials, elected officials, private sector interests, educators, and emergency managers to promote utilization of risk-reduction approaches. Evaluation and modification of workshop content and format.

Responsibility: FEMA, NOAA, states

Product: • Knowledge and risk communication

YEAR 3

Task 1: Continued Training Workshops and Technical Support – Cost $125,000 (State $25,000; FEMA $100,000)

Convene an additional five regional training workshops and provide continuing technical support to local governments and communities.

Responsibility: FEMA, NOAA, states

Products:
- Knowledge and risk communication
- Implementation of risk reduction

YEAR 4

Task 1: Continued Training Workshops and Technical Support – Cost $125,000 (State $25,000; FEMA $100,000)

Convene an additional five regional training workshops and provide continuing technical support to local governments and communities..

Responsibility: FEMA, NOAA, states

Products:
- Knowledge and risk communication
- Implementation of risk reduction

Task 2: Evaluation and Assessment – Cost $240,000 (State $40,000; FEMA $200,000)

Develop and implement evaluation instruments to assess program effectiveness. Integrate results into program.

Responsibility: FEMA, NOAA, NSF, and states

Product: • Program evaluation and adjustment

YEAR 5 and beyond

Task 1: Continued Training Workshops and Technical Support – Cost $125,000 (State $25,000; FEMA $100,000)

Convene an additional five regional training workshops and provide continuing technical support to local governments and communities.

Responsibility: FEMA, NOAA, states

Products:
- Knowledge and risk communication
- Implementation of risk reduction

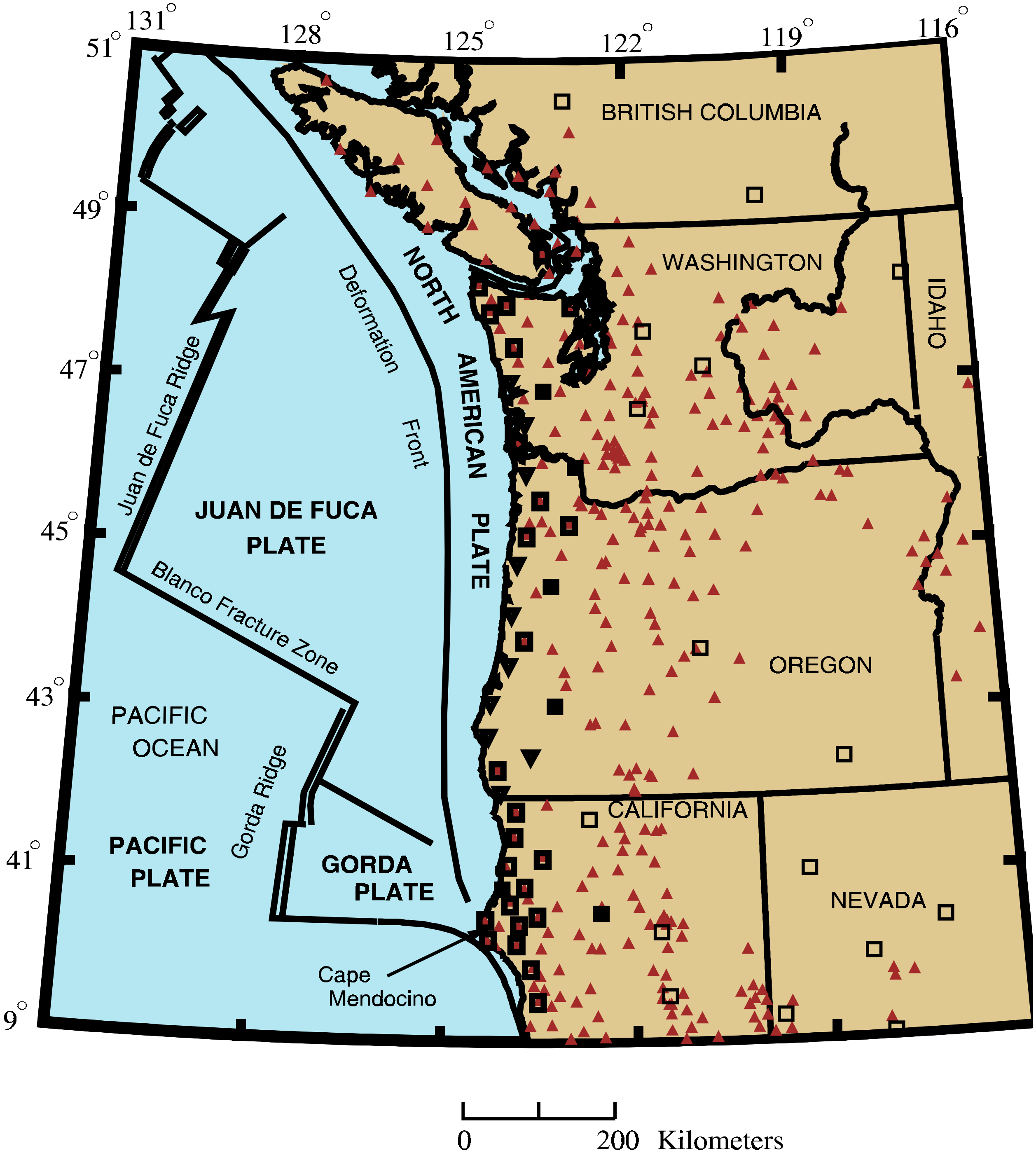
3. Seismic network implementation plan – Costs: Years 1–4: $2,000,000/year; Year 5 and beyond: $1,600,000. Under this Plan it is recommended that 36 existing seismic stations be upgraded and 16 new sites installed along the west coast, Alaska, and Hawaii (Figures 3–5). The proposed instruments, coupled with improvements to communication links and existing data processing centers, will provide state-of-the art warning capability. The 36 sites slated for upgrading are of two types. There are currently a few modern, digital, instrument sites (open squares in Figure 3) operating along the west coast. These broad-band sites are designed to provide detailed recording of earthquakes; for all but the largest local events these stations provide high-quality data in real time. However, a Cascadia event will produce ground motions that will saturate these stations. Therefore, we propose to install digital, strong ground-motion sensors at six sites (filled squares in Figure 3).

The second group of stations to be upgraded consists of 30 existing, short-period sites (small triangle in a square in Figure 3–5). At these sites the seismic instrumentation is typically 25 years old and the entire instrumentation package would be replaced with digital equipment. Some of these sites would be converted into six component stations, with both broad-band and strong-motion sensors. Other sites would be converted to modern short-period stations with strong-motion seismometers. New stations would be concentrated along the Oregon and Washington coast, southern Alaska, and at sites in the Aleutians (inverted triangles in Figures 3 and 4) to fill gaps in existing seismic coverage. These new stations will be a mixture of six component sites and short-period sites with strong-motion instruments.

The network upgrade to digital instrumentation will require upgrading and replacing existing telemetry links in northern California and an increase in telemetry capacity in Oregon, Washington, Alaska, and Hawaii. We expect that the rapid changes in the communications field will result in reduced long-term operating costs of the expanded new system compared to the existing system.

At the earthquake data centers, no major hardware upgrades are required, but new computer algorithms will be necessary to stream the new data into existing data flows. In addition, we are proposing an open architecture, in that all seismic data will be available to all data centers in near real time. This builds an important redundancy into the analysis. As part of the software development, the seismic data centers would work with the Tsunami Warning Centers to design and build the appropriate interface.

The proposed improvements to the existing seismic networks will allow formal, post-earthquake response to begin within 2 minutes of a major event, with very complete details available within 5 minutes. The accuracy of the improved seismic data will allow decisions to be made immediately concerning emergency response. The quicker response allows more time for rescue and evacuation (between the earthquake alert broadcast and arrival of the tsunami) and translates into the ability to save lives. Specific tsunami information (from detection buoys), as



▲ existing short-period stations to remain
□ existing broad-band stations to remain
⧈ existing short-period stations to be upgraded under Tsunami Plan
■ existing broad-band stations to be upgraded under Tsunami Plan
▽ new stations to be installed under Tsunami Plan

Figure 3. Proposed West Coast seismic network upgrade.

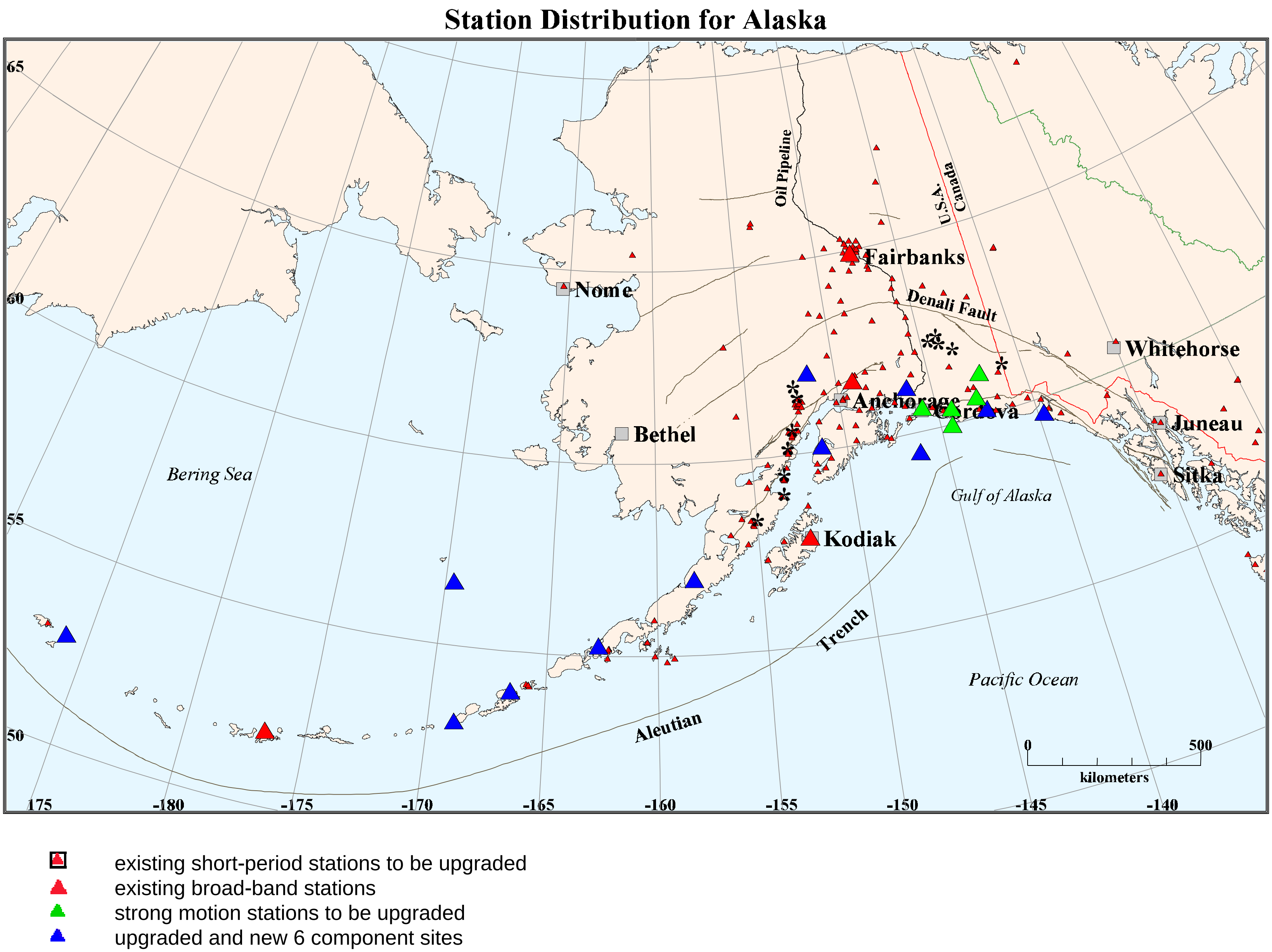


Figure 4. Proposed Alaska seismic network upgrade

existing short-period stations
proposed upgrade of existing short-period stations
volcano summits
Hilo, Hawaii

Figure 5. Proposed Hawaii seismic network upgrade.

well as the progress of aftershocks, will continue to be broadcast after the initial earthquake information.

The proposed upgrades will require an initial 4-year investment of $4,000,000 and long-term maintenance and replacement costs of $600K per year. These upgrades represent a 17% increase in the capital investment of the $23M existing networks and a 7% increase in maintenance costs. Currently, the operation of these networks requires about $8M per year, with an annual contribution of $1,000,000/year by the States of California, Alaska, Hawaii, and Washington. Contract employees will install the new stations and develop software systems. No permanent new staff is required, and no contract employees are needed once the system is fully deployed.

To establish the increased seismic network warning capacity, the USGS proposes the following schedule:

Year 1	Determine and select telemetry upgrade options in northern California, Oregon, and Washington. Design prototype seismic display interfaces for Tsunami Warning Centers. Select and permit new seismic station sites. Cost – $1,000,000
Year 2	Install/purchase upgraded telemetry links. Begin and complete upgrading of existing broad band stations. Begin installation of new sites. Complete design testing of seismic display interfaces at Tsunami Warning Centers. Cost – $1,000,000
Year 3	Install final seismic display interfaces. Continue installation of new seismic stations. Complete extensive testing of links between seismic networks for redundancy. Initiate annual workshops for emergency response officials on the uses and capabilities of the seismic information. Cost – $1,000,000
Year 4	Complete installation of new seismic stations. Run complete test of detection system, including links to NOAA buoys, local emergency response groups. Cost – $1,000,000
Out Years	The cost of operating the new seismic systems includes telemetry costs and annual maintenance visits to most sites. Engineering and software development will be provided to continue to improve the performance of the seismic detection system. Annual workshops for emergency response officials on the uses and capabilities of the seismic information provided by the system. Cost – $600,000

V. Budget Summary

The Group has identified state needs, reviewed the 12 NOAA recommendations in the context of these needs, developed five recommendations, and formulated a plan of action and budget to implement these five recommendations.

BUDGET ($000)*

Year	1	2	3	4	5 and beyond
Distant Tsunami					
Recommendation 1 – Develop State/NOAA Coordination and Technical Support					
Five States	(500)	(500)	(500)	(500)	(500)
NOAA	(500)	(500)	(500)	(500)	(500)
Recommendation 2 – Deploy Tsunami Detection Buoys					
NOAA	800	800	800	800	600
Local Tsunami					
Recommendation 3 – Produce Inundation Maps					
Five States	(200)	(200)	(100)	0	0
FEMA	200	200	100	0	0
NOAA	200	200	125	125	125
Recommendation 4 – Develop Hazard Mitigation Programs					
Five States	(100)	(150)	(25)	(65)	(25)
FEMA	175	1,050	100	300	100
Recommendation 5 – Improve Seismic Networks					
Five States	(1,000)	(1,000)	(1,000)	(1,000)	(1,000)
USGS	1,000	1,000	1,000	1,000	600
TOTALS					
Five States	(1,800)	(1,850)	(1,625)	(1,565)	(1,525)
NOAA	(500)	(500)	(500)	(500)	(500)
Federal New Money	2,375	3,250	2,125	2,225	1,425

* Numbers in parentheses represent in kind contribution as match

The Group estimates that it will cost the five states $6,840,000 and the federal agencies $11,975,000/year for the first 4 years and the states $1,525,000/year and the federal agencies $1,925,000/year thereafter to implement this action plan. These budgets included a 57% match by the states in the first 4 years and a 79% match in the out years. Of the federal agencies, the USGS would contribute $4,000,000 (or 33%), NOAA would contribute $5,850,000 (or 48%), and FEMA would contribute $2,225,000 (or 18%) of the federal contribution for the first 4 years. For the out year federal contributions, USGS would contribute $600,000/year (31%), NOAA would contribute $1,225,000/year (64%), and FEMA would contribute $100,000/year (5%).

The five recommendations of the Plan address each of the state issues:

A. Quickly Confirm Potentially Destructive Tsunamis and Reduce False Alarms—Recommendations 1 and 2

B. Address Local Tsunami Mitigation and the Needs of Coastal Residents—Recommendations 3, 4 and 5

C. Improve Coordination and Exchange of Information to Better Utilize Existing Resources— Recommendations 1, 2, 3, 4, and 5

D. Sustain Support at State and Local Level for Long-Term Tsunami Hazard Mitigation—Recommendations 1, 2, 3, 4, and 5

The recommendations address two types of tsunami threats—local and distant sources. The Group recognizes that all five recommendations address both types of tsunamis, but for simplicity, elected to describe these recommendations in the context of two types of tsunamis.

The Group recommends that a steering group, composed of representatives from the five states, NOAA, USGS, FEMA, and NSF, be formed to oversee implementation of the Tsunami Hazard Mitigation Plan and coordinate efforts between federal agencies and state jurisdictions.

Letters of Support from all states for this Plan are provided in Appendix II.

Appendix I

Tsunami Hazard Mitigation

(March 1995 Report to the Senate Appropriations Committee)

Appendix II

Letters of Support

Alaska – Robert E. Heavilin

California – Richard Andrews

Hawaii – Edward V. Richardson

Oregon – Donald A. Hull

Washington – Linda Burton-Ramsey

Washington – Raymond Lasmanis