Oregon Department of Geology and Mineral Industries
Special Paper 35

Tsunami Warning Systems and Procedures

Guidance for Local Officials

Oregon Emergency Management
and the
Oregon Department of Geology and Mineral Industries

2001

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Special Paper 35

Tsunami Warning Systems and Procedures: Guidance for Local Officials

Prepared for the
National Tsunami Hazard Mitigation Program
by
Oregon Emergency Management
and
Oregon Department of Geology and Mineral Industries

2001

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
John D. Beaulieu, State Geologist

“The greatest enemy

of communication

is the illusion

that it has taken place.”

Pierre Martineau

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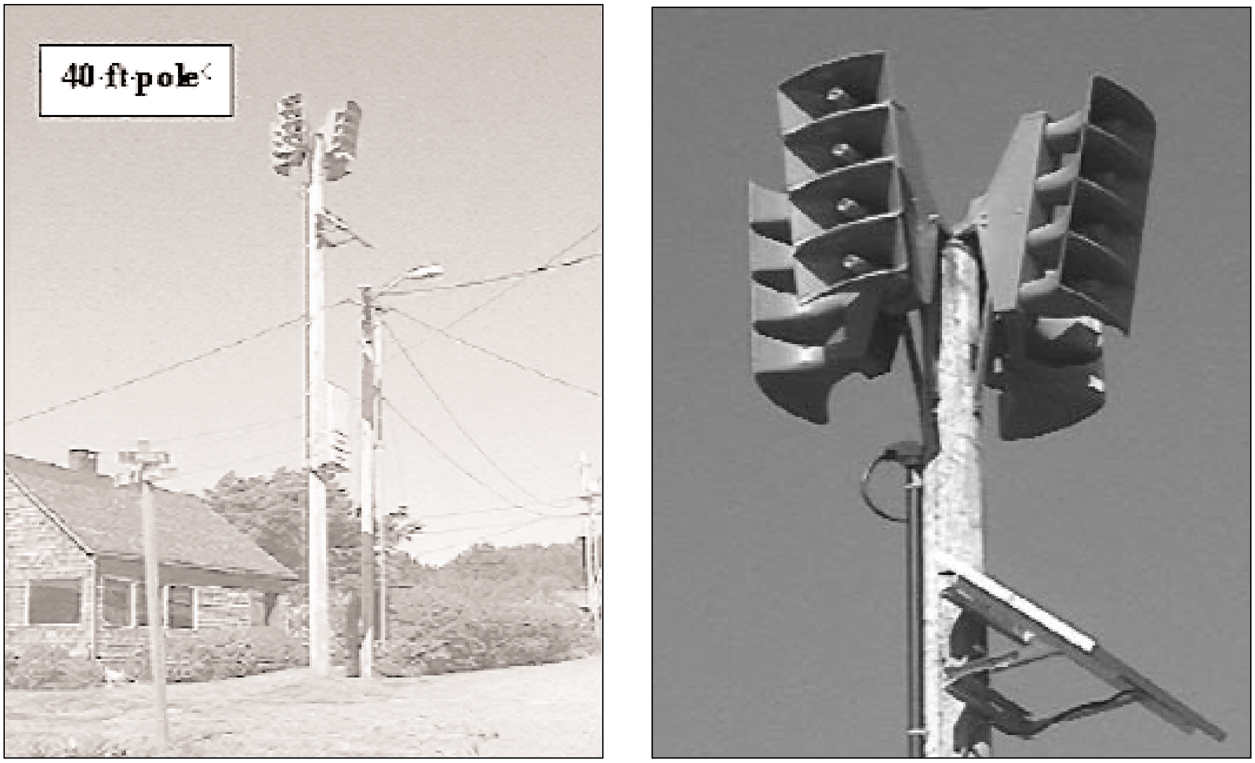

Pictured is an electronic siren station of the Cannon Beach Rural Fire Protection District Community Warning System. This unit is a Whelen WS2000-16 with Public Address feature. The unit is comprised of sixteen re-entrant speakers, four speakers aiming at each compass quadrant. The effective range is approximately 2,400 feet in each direction. Each station operates on 24 VDC supplied by four 6 VDC deep cycle storage batteries maintained by a solar charger entirely independent of commercial power. Station operation is radio-controlled from the district's main fire station using pre-recorded announcements (Sony MiniDisc format). The system operator can also make special announcements by microphone through all the stations simultaneously or any single station. Controls at the main fire station have automatic auxiliary power if commercial power fails.

Executive Summary

Tsunamis are one of the most destructive forces in nature and can cause much loss of life, injury, and property damage. Tsunamis are usually produced by the uplift of the sea floor from a large magnitude subduction zone earthquake. Most tsunamis are created in the Pacific Ocean, because the largest number of subduction zones is found there. The effects of a tsunami can be local or distant. The last destructive tsunami to significantly affect the United States was caused by the 1964 Alaskan earthquake. There was damage and loss of life locally in Alaska, and distantly in Hawaii, California, Oregon, and Washington.

Injury and loss of life can be minimized if coastal populations are warned that a tsunami is approaching. Coastal populations can be notified of a distant tsunami by a combination of: Tsunami warnings from the Tsunami Warning Centers in Hawaii and Alaska; and evacuation notifications from local systems, such as sirens and NOAA Weather Radio. In the case of a local tsunami, the warning is usually the earthquake. However, notification by local systems is also needed to reinforce evacuation orders, provided the systems are functional after the earthquake.

There are a variety of local evacuation notification systems. They include sirens, NOAA weather radio, the Emergency Alert System, telephones, the Emergency Managers Weather Information Network, and others. Each system has benefits and drawbacks, which are discussed in detail in this document.

The system that an area uses depends on several factors, including the nature of the population (residents vs. non-residents), budget, and geographic location. There should be complete coverage, redundancy, and seamless meshing of new and existing systems. Regardless of the system, it is critical that there be consistency in its application and message, as well as consistent and continuous education about the alerts.

Preface and Acknowledgments

These guidelines were prepared by Oregon Emergency Management for the National Tsunami Hazard Mitigation Program under a contract awarded to the Oregon Department of Geology and Mineral Industries. The National Tsunami Hazard Mitigation Program (NTHMP) is funded by the National Oceanographic and Atmospheric Administration (NOAA). It is steered by a group made up of representatives from NOAA, the United States Geological Survey (USGS), the Federal Emergency Management Agency (FEMA), the National Science Foundation (NSF), and the five Pacific coastal states (Alaska, California, Hawaii, Oregon, and Washington).

The National Tsunami Hazard Mitigation Program was created to reduce the impact of tsunamis through:

1. Warning guidance - deploy tsunami detection buoys and improve seismic systems
2. Mitigation – develop tsunami hazard mitigation programs and projects
3. Hazard assessment – produce tsunami inundation maps.

For more information on the program, visit the web site at www.pmel.noaa.gov/tsunami-hazard.

This document is the result of the efforts of many individuals representing several organizations. Special thanks to the following for their review, comments, and contributions:

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Washington

John Vollmer, George Crawford, and Sheryl Jardine, Washington State Emergency Management Division

Introduction

The main purpose of this document is to provide state and local officials with information on various local tsunami warning systems and procedures, and to assist coastal jurisdictions with planning and developing warning systems and procedures for their own areas. This document was the basis for discussion of tsunami warning systems at a Tsunami Warning Workshop on May 14 and 15, 2001 in Portland and should be considered a work in progress. The workshop summary, which includes five consensus recommendations, is found in Appendix III.

Systems are the hardware to alert people to evacuate to high ground. These systems can also be used for other hazards, prompting people to turn on the radio or television for information on whether to evacuate or take other protective action. Tsunami alerts should be incorporated into a jurisdiction's all-hazards warning system.

Procedures are the protocols followed to activate the systems. There are two types of warning systems and procedures described in this document: One is the warning from the Tsunami Warning Centers in Hawaii and Alaska that a tsunami has been generated; the other is the warning that evacuation from low-lying areas is necessary. To avoid confusion between the two, a *warning* will refer to the message from the Tsunami Warning Centers in Hawaii and Alaska and a *notification* will refer to the call for evacuation. For example, coastal counties can receive a tsunami warning from the West Coast/Alaska Tsunami Warning Center (WC/ATWC) then activate a tsunami evacuation notification system, such as sirens.

There is no one tsunami evacuation notification system that is best for all coastal areas. All systems have their pros and cons, which are addressed at length in this document. Different communities have distinct characteristics and needs. Each coastal jurisdiction must decide what system to use, ideally with assistance from the state and federal governments.

Several factors must be taken into consideration when making decisions about what system is best for an area:

1. The size and layout of the area.
    - A. Is it compact or spread out?
    - B. Is it located adjacent to a beach or adjacent to a harbor?
2. The make up and activities of the population to be served.
    - A. Is the town mostly retirees?
    - B. Is there a large transient population?
    - C. Are they mainly on the beach or in/near the bay?
3. The financial resources of the community.
4. The existing notification systems in each jurisdiction as well as in adjacent cities, counties, boroughs and states. Is there a need for system consistency within a jurisdiction and between boroughs, counties, and states?

This document provides you with information to make these decisions. It consists of four major sections.

Section 1 provides a brief overview of tsunamis causes and characteristics.

Section 2 describes the Pacific, West Coast/Alaska, and Chile Tsunami Warning Centers and their roles in the tsunami detection, warning and local notification process.

Section 3 describes briefly existing notification systems from different countries and states: Japan, Hawaii, Alaska, California, Oregon, and Washington.

Section 4 describes in detail various evacuation notification systems and their associated procedures.

Section 1: General Tsunami Information

Causes and geographic locations of tsunamis

A tsunami is a series of ocean waves generated by the sudden displacement of large volumes of water due to:

1. The vertical movement of the sea floor as a result of large thrust-type submarine earthquakes (called subduction zone earthquakes),
2. Submarine volcanic eruptions,
3. Meteor impacts, or
4. Coastal (land-based or submarine) landslides.

Tsunamis usually occur in zones of strong seismic activity. The most active tsunami zone is the Pacific Ocean, surrounded by the Ring of Fire (Figure 1). The Ring of Fire features active volcanoes, rugged coastal terrain, and submarine subduction zones, such as the Alaskan/Aleutian off Alaska and the Cascadia off the Pacific Northwest United States. Tsunamis are usually associated with subduction zone earthquakes in the Pacific Ocean, although rare, destructive tsunamis have also occurred in the Atlantic Ocean and Caribbean Sea. In 1929 a submarine landslide in the Grand Banks off Canada sent destructive waves into the eastern seaboard.

Characteristics of tsunamis

Tsunamis travel outward in all directions from the source area (Figure 2). The tsunami can strike coastal areas with devastating effect even in areas far removed from the source. Their speed depends on the depth of water. In the deep and open ocean, waves can reach speeds of 800 kilometers per hour (approximately 480 mph or as fast a commercial jetliner). The waves slow down in shallow water.

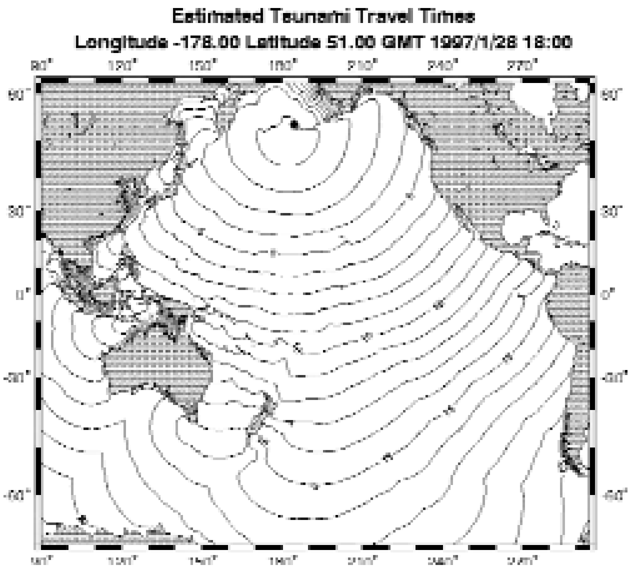

Figure 2. Tsunami arrival chronograph (Pacific Disaster Center) (contours in hours).

The height of the waves in deep water may range from 30 to 60 centimeters (1-2 feet), producing only a gentle rise and fall of the sea surface, and are usually unnoticed. As a tsunami wave enters the shallow waters of a coastline, its speed decreases rapidly. This causes the front of the wave to slow down relative to the back, producing a greater height as the water piles up onto the coastline. The configuration of the coastline, shape of the ocean floor, and characteristics of the advancing waves play an important role in the destructiveness of the wave. A wave may be of negligible size at one point on a coast and of much larger size at other points. Narrow bays and inlets may cause funneling effects that magnify the initial and subsequent waves. Upon striking a coast, the wave reflects (bounces seaward) and then turns back toward the coast as a series of waves. Thus, every tsunami creates numerous waves, which may continue to arrive for hours after the first wave.

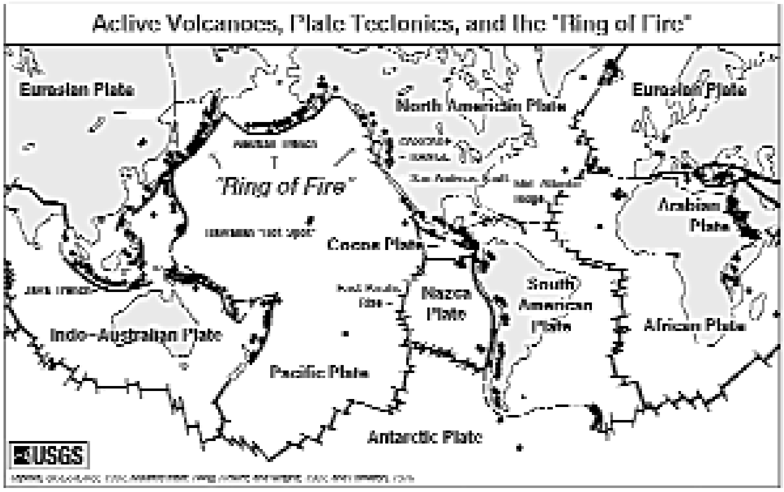

Figure 1. The Pacific Ring of Fire.

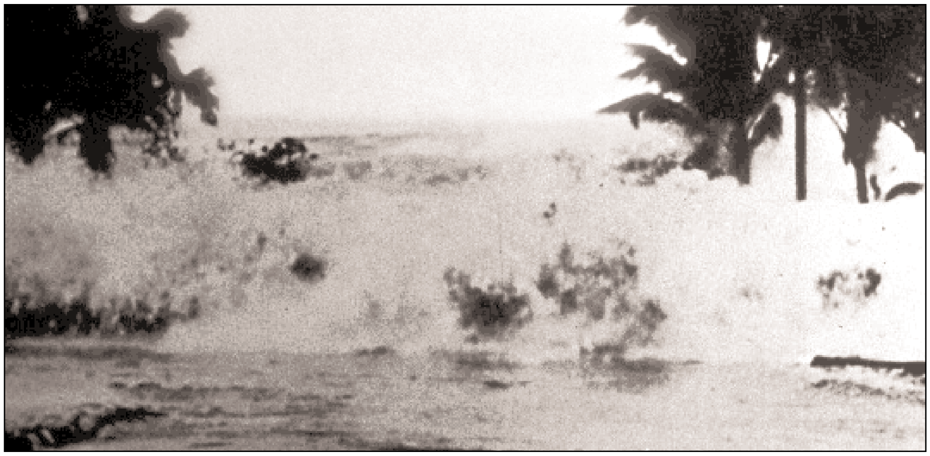

Figure 3. Cresting wave entering Hilo in 1946.

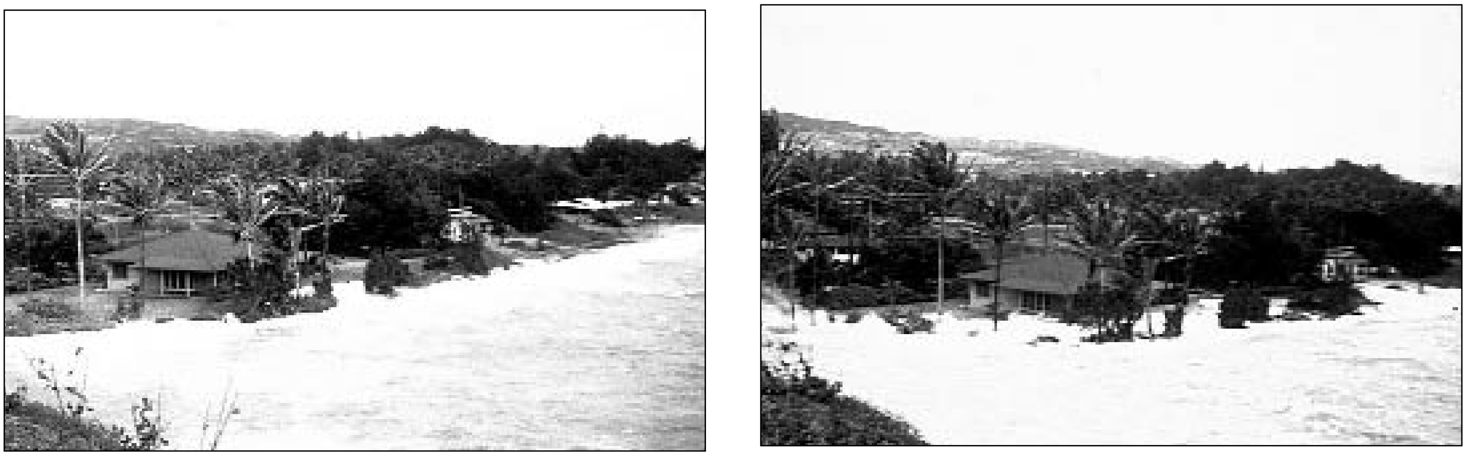

Figure 4. Fast rising tide in Hawaii (1957).

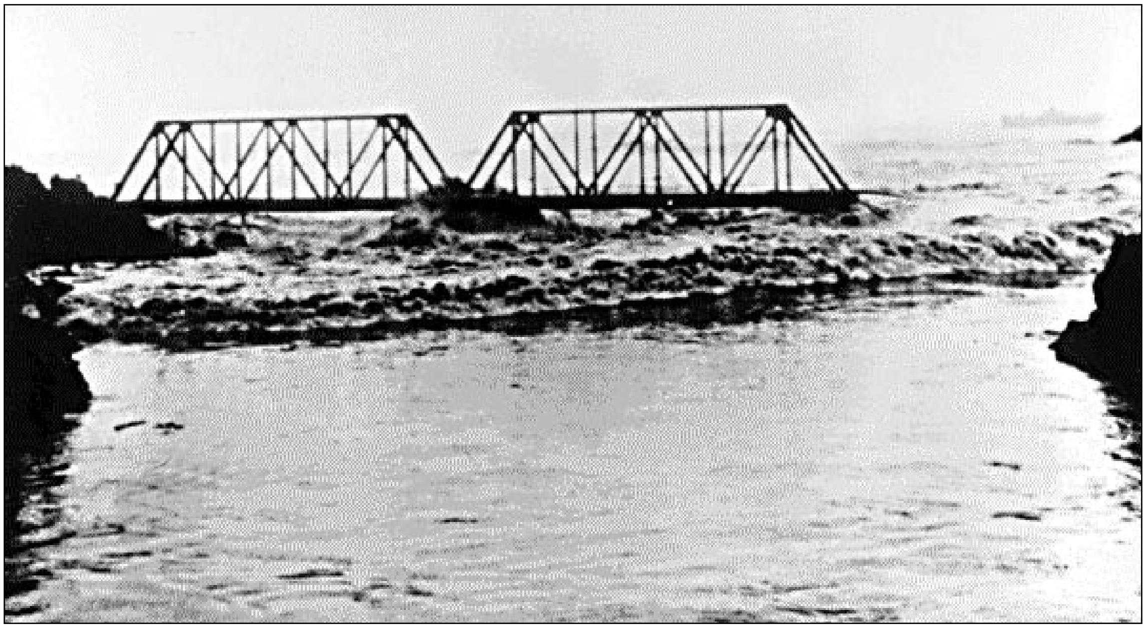

Figure 5. Tsunami bore heading up a river in Hawaii.

The first visible indication of an approaching tsunami may be the rapid retreat of the ocean. In some instances, particularly with local tsunamis, the water may initially rise. The force and destructive effects of tsunamis should not be underestimated.

Tsunamis attack the coast either as a cresting wave, a fast rising tide, or bore (Figures 3-5). At some locations, the advancing turbulent 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 tsunami surges, sweeping all before it and undermining roads, buildings and other works. Ships, 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. A significant additional problem occurs when boats that are on moorings can not refloat fast enough when the water returns over their sterns.

Local versus distant tsunamis

For notification system purposes, tsunamis are categorized as local or distant, depending on how long it takes the tsunami to arrive at the area of concern. A local tsunami can arrive at the coast in minutes, while a distant tsunami may arrive several hours after it was generated. A local tsunami could be produced by a very local event affecting only a very limited area of the coast. An example is the July 9, 1958 Lituya Bay, Alaska tsunami which was caused by a local landslide and created wave run-ups as high as 525 meters (approximately 1,700 feet). Areas affected by regional events are generally smaller than those affecting the entire Pacific. Because of either a lower level of energy released or the geographical configuration of the region, the tsunami's spread is inhibited. An example of a regional tsunami is the one that originated off the coast of the Philippines, August 16, 1976, in which approximately 8,000 people were killed.

A local tsunami could also be produced by a major event that would have regional or Pacific-wide effects, and thus be considered both a local and distant tsunami. For example, a tsunami generated off the coast of Chile is local to Chile but distant to the United States and Japan. Loss of life and property is most severe closest to the source in an event that generates a Pacific-wide tsunami.

Pacific-wide tsunamis are much less frequent but have greater destructive potential, because the initial waves are larger and more area is affected. For example, a tsunami generated by a M_w 9.5 subduction zone earthquake off southern Chile on May 22, 1960 caused death and destruction from Chile, to Hawaii, Japan and the Philippines. The Pacific Northwest was also affected by the Chile tsunami, but suffered more damage from a similar tsunami produced by a subduction zone earthquake off Alaska on March 27, 1964. Since Pacific-wide tsunamis strike multiple areas, most areas of the Pacific basin experience many more distant tsunamis than locally derived ones.

Tsunamis that affect the United States and Canada

Zones that can cause local and distant tsunamis that would affect the United States and Canada include:

1. The Cascadia Subduction Zone and Alaskan-Aleutian Subduction Zone
2. Other zones that could produce a potentially damaging tsunami are Chile, Peru, Kamchatka, Japan, and the Kuril Islands. There are also minor zones off the coast of Hawaii and California that could produce potentially destructive but localized tsunamis. The Hawaiian Islands consist of active, inactive, and dormant volcanoes. Offshore eruptions and landslides off Hawaii and tectonic activity and landslides off southern California can cause tsunamis that arrive on their shorelines within minutes.

Cascadia Subduction Zone (CSZ)

The Cascadia Subduction Zone (CSZ) lies to the west of the California, Oregon, Washington, and British Columbia coasts (Figure 6). CSZ earthquakes have the potential to generate large tsunamis that can affect the entire Pacific Ocean. Local arrival times for these events can be from 5 to 30 minutes.

Alaskan-Aleutian Subduction Zone

The Alaskan-Aleutian Subduction Zone extends from southeastern Alaska to the westernmost tip of the Aleutian Islands (Figure 7). The 1946 earthquake and tsunami, which resulted in the founding of the Tsunami Warning Center, occurred just off Unimak Island in the Aleutians. The first wave arrived in less than one hour and totally destroyed the Coast Guard lighthouse at Scotch Cap with a loss of all hands.

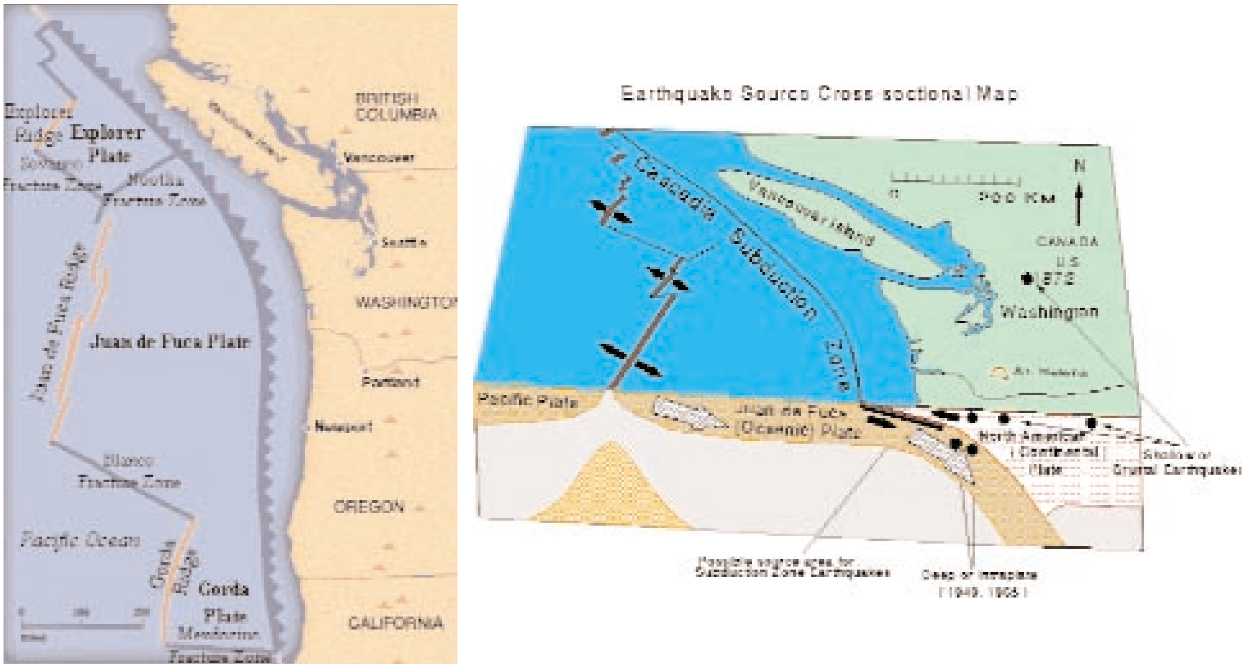

Figure 6. Cascadia Subduction Zone in map view and cross section.

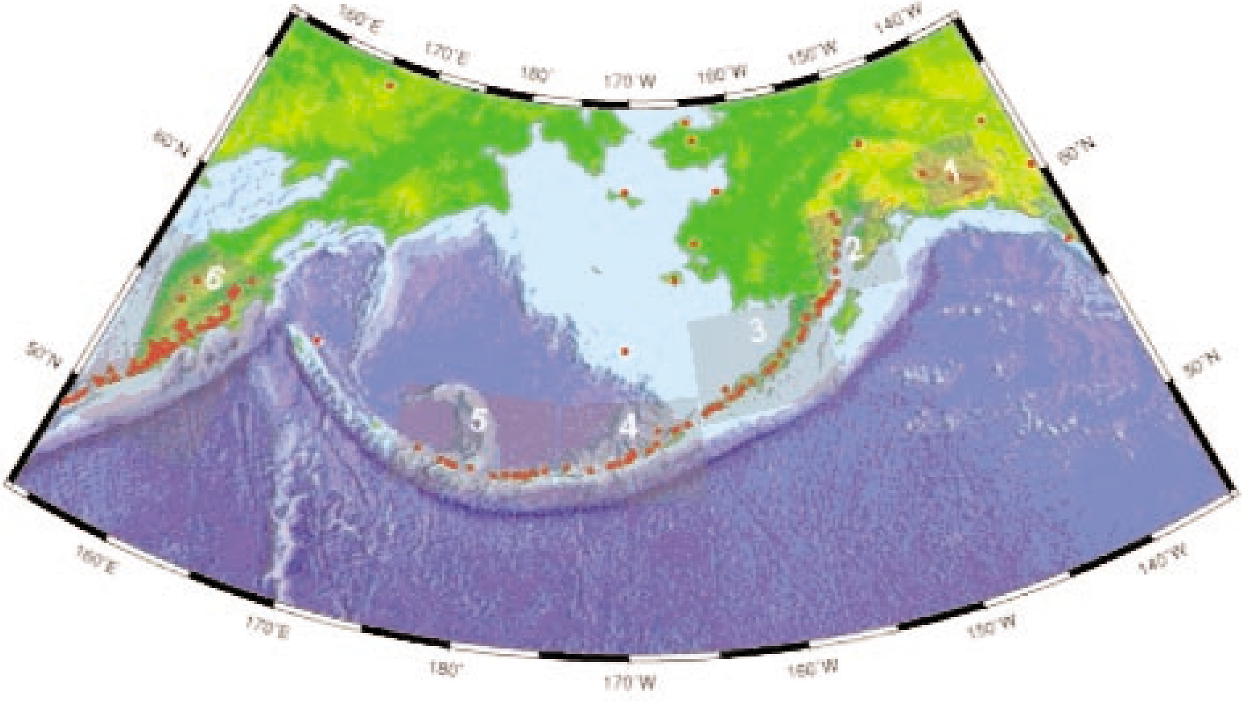

Figure 7. Alaskan-Aleutian Subduction Zone (numbers refer to potential rupture segments).

Section 2:
Tsunami Warning Centers

The Tsunami Warning Centers, operated by the National Oceanic and Atmospheric Administration (NOAA), have the primary responsibility to issue tsunami notices within their areas of responsibility, especially through emergency officials. Coordinating and managing evacuations (evacuation notification) is the responsibility of local emergency personnel. In other words, the Warning Centers warn emergency officials; local emergency officials notify and direct the local evacuation efforts.

There are currently two Tsunami Warning Centers for the United States and Canada (figure 8):

1. West Coast/Alaska Tsunami Warning Center (WC/ATWC)
2. Pacific Tsunami Warning Center (PTWC)

The Chile Warning System will also be discussed. The Chile system has similarities to the WC/ATWC and PTWC, but also a few major differences.

West Coast/Alaskan Tsunami Warning Center (WC/ATWC)

The WC/ATWC, located in Palmer, Alaska, has the sole responsibility for issuing tsunami warnings to coastal locations of California, Oregon, Washington, British Columbia, and Alaska. Tsunami warnings, watches, advisories, information bulletins, and messages are issued based on earthquake location and magnitude. Bulletins issued by the WC/ATWC are defined below:

Warning: *Indicates a tsunami is imminent and coastal locations in the warned area should prepare for flooding.* The initial warning is typically based on seismic information alone. Earthquakes within the WC/ATWC area of responsibility (AOR) over Magnitude (M)7.0 trigger a warning covering the coastal regions within 2 hours tsunami travel time from the epicenter. When the magnitude is over 7.5, the warned area is increased to 3 hours tsunami travel time. For earthquakes outside the WC/ATWC AOR, warnings are only issued for earthquakes greater than M7.5 and for those locations within 3 hours tsunami travel time of the leading edge of the wave. As tidal gage data showing the tsunami is recorded, the warning will be cancelled, expanded incrementally, or expanded to cover the entire WC/ATWC AOR in the event of a major tsunami.

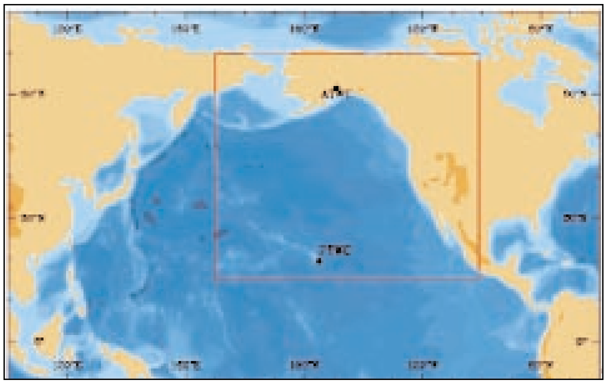

Figure 8. Warning center locations.

Watch: *An alert issued to areas outside the warned area.* The area included in the watch is based on the magnitude of the earthquake. For earthquakes over M7.0, the watch area is 1 hour tsunami travel time from the warning zone. For earthquakes over M7.5, the watch area is 3 hours tsunami travel time from the warning zone. The watch will either be upgraded to a warning in subsequent bulletins or will be cancelled, depending on the severity of the tsunami.

Advisory: *A message issued when a major quake has occurred outside the AOR prompting PTWC to issue a tsunami warning, and the event is either far enough away so that no AOR region is within a watch/warning OR the tsunami poses no threat to the AOR.* Advisories are updated hourly as PTWC issues bulletins and can be upgraded to a watch or warning if necessary.

Information Bulletin: *Bulletins issued for earthquakes less than warning threshold, but greater than M6.5 which are not likely to trigger a destructive tsunami.* Unless further information is gathered on tsunami generation, only one Information Bulletin is issued for an event.

Information Message: *A message issued for earthquakes below M6.5 strongly felt along coastal areas of the AOR.* Its purpose is to rapidly inform residents that there is no tsunami danger.

All initial messages are based solely on seismic data. The WC/ATWC has developed a state-of-the-art earthquake processing system (EarlyBird) which automatically locates and sizes potentially tsunami-producing events worldwide. Geophysicists can easily interact with the automatic results so that reviewed information is issued in tsunami messages. Epicenter locations are normally computed within 2 minutes of the origin time for earthquakes within the AOR. Magnitudes for earthquakes less than M6 are computed at the same time as the location, while for larger earthquakes it takes a few more minutes to compute an accurate magnitude. Earthquakes outside the AOR are located within seconds after enough P-wave arrivals have been recorded to accurately locate the event. This time varies from about 6 minutes for Kamchatka quakes to 12 minutes for southwest Pacific quakes.

After a tsunami bulletin is issued, tide gage data is monitored to determine whether or not a tsunami has occurred. The tsunami severity as recorded on the gages indicates to the WC/ATWC whether to continue and expand the warning or cancel. If no tsunami has reached a gage within an hour of the first message, a second message will be issued as a precaution which expands the warning area.

There is no way to accurately predict wave heights for a local tsunami generated near the source zone of an earthquake. Difficulties in determining the exact source mechanism, secondary tsunami generation sources, and the lack of time between tsunami generation and impact at the nearest coastal locations make an accurate prediction impossible. However, the WC/ATWC has made great improvements in estimating tsunami heights outside the source zone. Based on pre-computed tsunami models and observed tsunami heights, an estimate of tsunami height can be made for locations along the North American coast outside the source region.

Tsunami bulletins are issued over several different communication systems. Primary paths are: verbal warnings over the National Warning System network (NAWAS), hard-copy over the NOAA Weather Wire, and hard-copy over the FAA NADIN2 communication system. These systems activate the National Weather Service (NWS) Emergency Management Weather Information Network (EMWIN) and the NOAA Weather Radio. Also, the Emergency Alert System (EAS) is activated through the NWS forecast offices and/or the state departments of emergency services. However, locals often determine which messages and associated message type headers will activate the local EAS Decoders. So not all tsunami messages will activate the local EAS system, even though they are generated by the NWS. Primary sites to receive tsunami bulletins are the state emergency service offices, FEMA, military contacts, US Coast Guard, and NWS offices. Secondary methods of message dissemination are direct phone contacts, e-mail messages, home page updates (wcatwc.gov), and an experimental pager notification system.

Since 1980, the average time it has taken WC/ATWC to issue a tsunami warning has been 11 minutes. With the recent installation of new data communication systems, instruments, and processing techniques, this time should decrease. For example, after the December 6, 1999 M6.9 Kodiak Island earthquake, a tsunami information bulletin was issued 3 minutes after the earthquake's origin time.

What will the warning centers tell us?

The warning centers provide the following information when there is a potentially tsunami-generating earthquake within their AOR:

1. Warning or no warning
2. Limits of areas in warning and watch
3. Location, size, and time of event
4. Evaluation of event; has the tsunami been verified or not
5. Recorded wave heights if there were any
6. Estimated times of tsunami arrival
7. What action has the other center taken
8. When to expect the next message

All warning message sequences will have a final bulletin. This could be a cancellation when it is apparent the danger is minimal. It could be a final supplement, issued when there is a danger to a centers' entire area of responsibility (AOR). This supplement states a potentially damaging tsunami has been generated. It also states that the *all clear* determination must be made by local officials since there is such a great difference in how a tsunami can affect different locations.

What won't the warning centers tell us?

The warning centers do not provide the following information:

1. When to evacuate
2. How to evacuate
3. Where to evacuate
4. Expected wave heights
5. All clear determination after a large tsunami has occurred

Pacific Tsunami Warning Center (PTWC)

The PTWC, located in Ewa Beach, Hawaii, is responsible for Hawaii and the rest of the Pacific Rim nations, including Mexico and South America. The PTWC is responsible for monitoring seismic events throughout the Pacific Ocean. It works with regional and national centers to monitor seismological and tidal stations to evaluate earthquakes for their potential to generate tsunamis. When there is a regional or Pacific-wide event, the PTWC works closely with the West Coast/Alaska Tsunami Warning Center to ensure warnings are consistent.

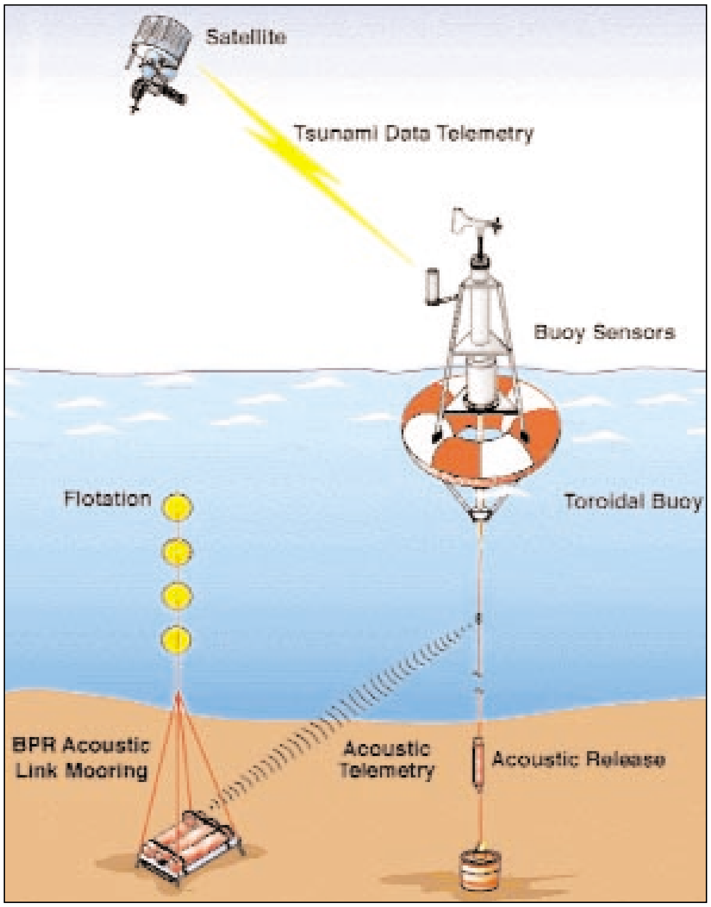

Figure 9. Tsunami warning buoy configuration.

The PTWC also works closely with the International Tsunami Information Center (ITIC), which is responsible for monitoring warning activities in the Pacific, recommending improvements in them, assisting member states in establishing warning systems, and fostering research.

The general criteria the PTWC uses to determine the tsunami producing potential of an earthquake and the types of messages sent (warning, watches, advisory bulletins) are essentially the same as the ATWC, although the text of the messages and the protocol for local tsunamis may be slightly different. The major difference is their areas of responsibility.

Chile Warning Center

THRUST (Tsunami Hazards Reduction Utilizing Systems Technology) is a satellite-based tsunami warning system that was developed by the NOAA Pacific Marine Laboratory and tested in Chile in the late 1980s. It is designed to rapidly evaluate local offshore earthquakes for tsunami generating potential and transmit the warning to local officials. Locally produced tsunamis could arrive on shore in 5 to 30 minutes. Therefore, a very rapid assessment and warning is required to trigger evacuation notification systems to supplement evacuation activity triggered by the ground shaking.

After nine months of testing, the average response time was two minutes. With reliable notification systems in place, evacuation notification based on the rapid warning would be timely and save lives. To withstand strong ground shaking, the equipment is durable and self-powered by uninterruptable sources. Hardware costs for the most basic THRUST system were $15,000 in 1986 US dollars.

Improvements in tsunami warning

Tsunami warning technology is continually improving, reflecting changes in technology, growing awareness that accurate tsunami prediction requires international teamwork, and increased local interest in improving tsunami prediction. Following are examples of recent developments.

Deep Ocean Assessment and Reporting of Tsunamis (DART)

DART is a real time distant tsunami detector system developed by NOAA's Pacific Marine Environmental Laboratory (PMEL). PMEL is installing the systems (buoys and bottom sensors, see Figure 9) in the open ocean off Alaska, Oregon, and Washington. The system uses sensitive water-depth detection equipment, underwater modems, satellite telemetry, and advanced sig-

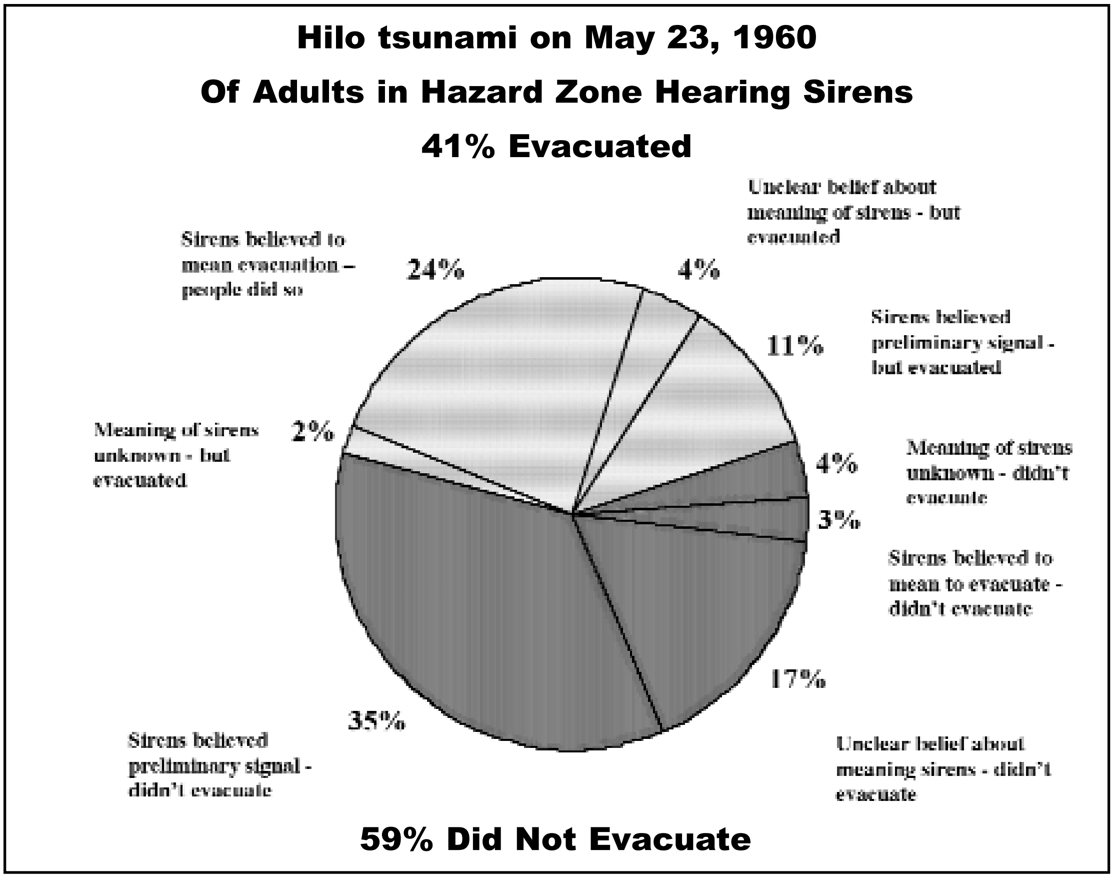

Figure 10. Actual figures from Hilo, Hawaii tsunami on Monday, May 23, 1960.

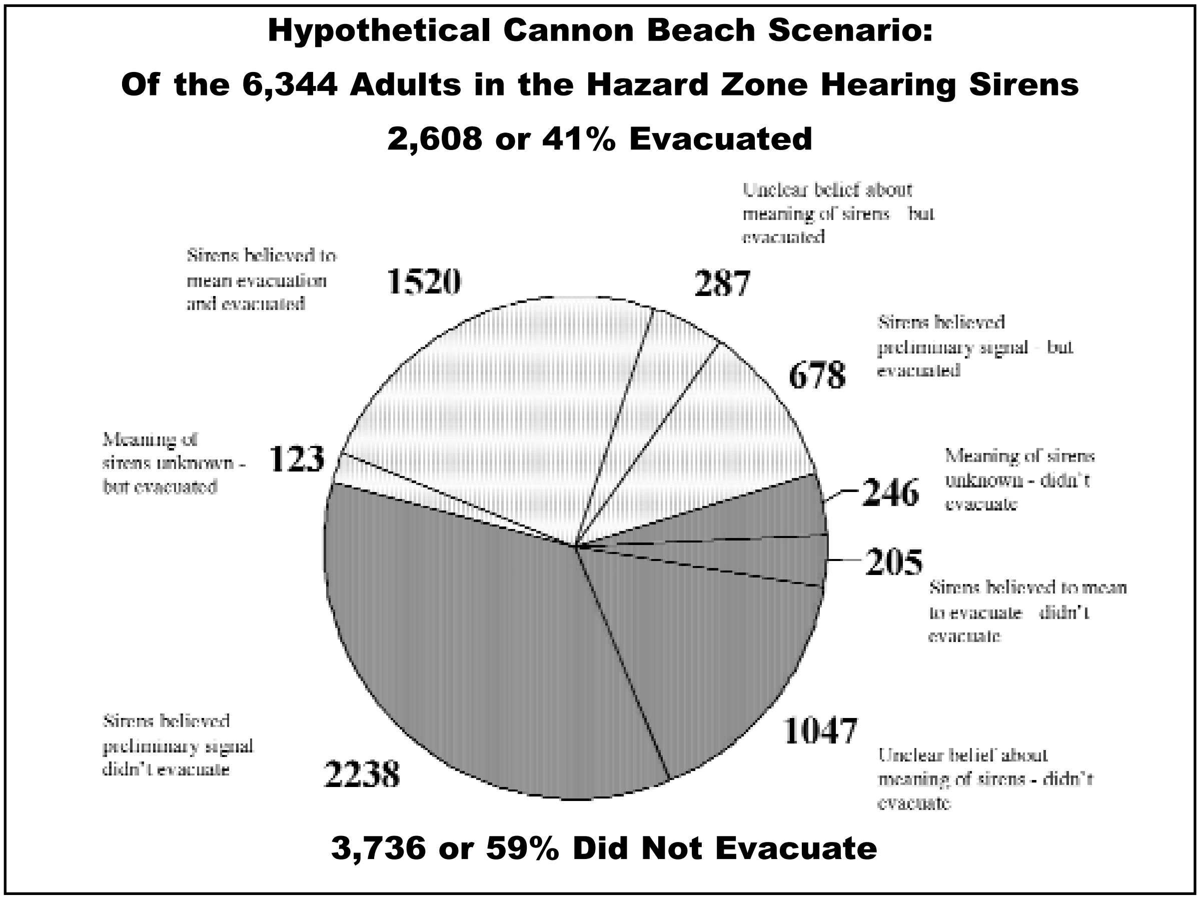

Figure 11. Applying Hilo May, 1960 experience to a hypothetical at-risk peak population in Cannon Beach, Oregon.

nal processing to detect and measure tsunami waves in the open ocean. Its purpose is to confirm that a potentially destructive tsunami has been produced. The ultimate goal is to reduce the number of false alarms in the Pacific Northwest and Hawaii.

False alarms, if numerous, may cause people to ignore an actual evacuation notification. Even in areas like Hawaii, which has a long history of destructive tsunamis, sirens have been ignored. A study (Lachman and others, 1961) showed that during the May, 1960 tsunami, only 42% of the people who heard the alarm evacuated (Figure 10). Many Hilo residents knew about the oncoming Chilean tsunami at least 10 hours ahead of time. More than 4 hours ahead of the first wave, Civil Defense sirens, meant as evacuation notification, sounded for twenty minutes. Of an estimated 1,000-1,200 adults in the hazard area, 61 were killed and several hundred severely injured. Figure 11 applies the Hilo experience to a peak population in Cannon Beach. The Cannon Beach Fire District community warning system in this scenario would be generic sirens instead of the actual system in use. The actual system includes electronic sirens that alert people in hazard areas and public address instructions that say what the emergency is, what to do about it, and when to do it.

It is estimated that in a significant tsunami, more than half the people remaining in the hazard zone will be buried in wreckage and one quarter injured or killed. Using the Hilo estimate of significant casualties in a tsunami hazard zone for Cannon Beach, more than half (>1,869) of the people remaining in the Cannon Beach Fire District hazard zone would be buried in wreckage and one quarter (934) injured or killed.

Consolidated Reporting of Earthquakes and Tsunamis (CREST)

CREST is a project funded through the National Tsunami Hazard Mitigation Program. Its purpose is to upgrade regional seismic networks in Alaska, Washington, Oregon, California, and Hawaii and provide near real-time seismic information (location, magnitude, and continuous seismic waveforms) from these networks to the tsunami warning centers. CREST facilities are linked by real time communication, including dedicated circuits with routers and satellite transceivers, to quickly and reliably exchange information between the various components. The transfer of information is becoming increasingly rapid and continuous through technologies which include the Internet, telephones, modems, radios, local-area networks (LANs) and wide-area networks (WANs).

Real time Earthquake Notification Systems

Rapid earthquake notification systems are located in California, Oregon, and Washington: CUBE (Caltech USGS Broadcast of Earthquakes), REDI (Rapid Earthquake Data Integration), and RACE (Rapid Alert Cascadia Earthquake). These systems provide preliminary earthquake epicenters and magnitudes (above a defined threshold) within minutes of the earthquake’s occurrence. Knowledge of the location and magnitude could be used by emergency managers to halt evacuation that was initiated by inland ground shaking. For example, the 1999 M5.9 Satsop earthquake was centered approximately 30 miles inland from the coast in Washington. It was strongly felt in coastal areas and caused 50-100 people to evacuate to high ground.

Later Wave Forecast Methodology (LWFM)

LWFM is a statistical model that uses coastal tide gage observations to forecast the extreme heights of later waves in Pacific-wide tsunamis for locations in the vicinity of real-time reporting tide gages. The forecast method is based on a study of six observed Pacific-wide tsunamis, including the 1960 Chile and 1964 Alaska. It was developed by NOAA’s Tsunami Inundation Mapping Effort (TIME) and the software was delivered to WC/ATWC and PTWC.

Pacific-wide tsunamis remain dangerous for many hours. The first waves may or may not be the highest waves. The time interval between wave peaks varies from 5-40 minutes. Later wave trains threaten rescue and recovery operations, especially when they arrive at high tide. Such waves also endanger vessels in shallow water. Emergency managers need wave height forecasts to help guide rescue and recovery operations. They also need them to decide when to issue the all clear. By combining wave height and tidal forecast information, emergency managers could decide when to allow emergency personnel to enter low-lying areas. If a low wave forecast is coupled with a low tide, the dangers from the tsunami are reduced and emergency personnel could be deployed if needed.

Section 3: Established Tsunami Evacuation Notification Systems

The tsunami warning centers discussed in Section 2 issue only warnings. The tsunami evacuation notification systems discussed in this section are the next step. They are used to notify the general public that evacuation is necessary after a warning is received from the center. Notification systems tend to be either more advanced and coordinated such as the Japan, Hawaii, and Chile systems (discussed in detail below) or less advanced and coordinated such as those found in the states of Alaska, California, Oregon, and Washington. Advanced systems incorporate all regions of the country or state into the system. Although Alaska, California, Washington, and Oregon do contain jurisdictions with advanced and coordinated systems, such as Kenai Borough in Alaska and Cannon Beach in Oregon, the entire state is not one coordinated system and therefore they are not considered advanced.

Japan System

Japan is an island nation that is exposed to frequent seismic activity and tsunami risks. Like Alaska and the Pacific Northwest, Japan is located near an active subduction zone. However, Japan experiences significantly more tsunamis than the United States and Canada. As a result, Japan developed one of the more extensive systems in the Pacific.

The Japanese Meteorological Agency (JMA) is responsible for issuing tsunami warnings. There is one main observatory (in Tokyo) and five regional observatories, all capable of issuing a warning. Data is continuously collected using satellites and cellular communication techniques to avoid failures associated with landline and Internet technologies. The goal is to broadcast a tsunami warning less than five minutes from the initial sensing of the earthquake.

If an earthquake occurs offshore, the observatories close to the epicenter will issue tsunami bulletins to their areas of responsibility. The bulletins will go to the prefectures (similar to U.S. states) through the Local Automatic Data Editing and Switching System (L-ADESS). L-ADESS will also send forecast results (tsunami heights) to the main observatory and other observatories. The main observatory will issue bulletins to other prefectures and alert other government agencies through the Central Automated Data Editing and Switching System (C-ADESS).

There are three types of tsunami bulletins (warning, watch, information). The bulletins are well defined and are similar to those of the United States Tsunami Warning Centers.

Ministries and agencies at the national level that contribute to disaster mitigation are linked together in the Central Emergency Management Communication Network (CEMCN). Members of the CEMCN include Ministry of Construction, Tokyo Electric Power, and Nippon Broadcasting Corporation. Once notified by the Japanese Meteorological Agency, the CEMCN transmits tsunami bulletins to their own regional offices. Redundancy is built into the Japanese system, so no one will be missed.

The prefecture receives the bulletin at the same time as the CMCN. The prefecture then transmits the bulletin to the local governments (cities, towns) for action.

The following are local notification methods:

Simultaneous Announcement Wireless System (SAWS)

SAWS is a dedicated system of transmitters and receivers installed by local authorities for all types of messages. The transmitters are located in the local government office and receivers are found in hospitals, schools, fire stations, emergency management offices and other places. Many residents have purchased receivers for their homes; the receivers are activated when a message, such as a tsunami bulletin, is being transmitted. Receiver towers or posts with loudspeakers are also installed on streets and roof tops of prominent government and commercial buildings. SAWS effectiveness is reduced (as much as 15-20 % in urban areas) during inclement weather, when people close their windows. There is also an attachment to the telephone that can serve as a dedicated radio receiver. A triggering signal from the broadcast source will turn on the loudspeaker and the SAWS message can be heard. SAWS is known as tone alert radio in the United States.

Mobile Announcer System

This system is designed for those areas without SAWS. Fire trucks mounted with loudspeakers cruise their area of responsibility to announce the warning that they receive.

Television and radio

Tsunami warning announcements have priority to cut into ongoing programs on government and commercial television and radio stations. Stations receive tsunami bulletins from the main and regional observatories by C-ADESS or L-ADESS, respectively. On television the message is either a subtitle on the bottom of the screen or a window. Later, the window has a map where the watch or warning applies. However, the map would not be shown fast enough in the case of a local tsunami. In the case of the radio, an ongoing program is interrupted with the message. This would have more impact than a message on a television screen.

Sirens and bells

Sirens are found in some villages. The sirens prompt residents to turn on their radio or television for further information. Some villages stick to traditional ways by clanging a bell to announce tsunami warnings.

Telephone network and word of mouth

Some communities have formed telephone networks to spread important information. In some communities, the only way to reach people is by going from house to house. Both methods are time consuming, but are necessary to reach populations that lack the other systems.

Finally, local communities have extensive training, allowing them to respond automatically to tsunami warnings. Tsunami awareness is part of coastal Japan's culture — to the extent that upon sounding a "high level" tsunami warning, the majority of the at-risk population, even if asleep, have evacuated to safe ground within five minutes.

Hawaii System

The state of Hawaii is centrally located in the Pacific Ocean and is exposed to tsunamis generated throughout the Pacific Ocean. Hawaii is primarily at risk from distant tsunamis rather than local ones. There have been only two destructive local tsunamis (1868, 1975) recorded in 200 years of Hawaiian history.

The Hawaiian system includes the following elements:

1. Tsunami awareness is part of coastal Hawaiian culture. Local communities have conducted training to enable them to promptly respond to tsunami warnings. Tsunami information is readily available in the front of the telephone white pages. Monthly siren and Emergency Alert System (EAS) radio and television broadcasts educate the public in how to respond to emergencies including coastal evacuations.
2. The PTWC monitors seismic activity throughout the Pacific, coastal tide gauges, and warnings issued by other tsunami warning centers.
3. Tsunami hazards of the Hawaiian Islands have been mapped. This mapping identifies areas according to their risk, based on historic tsunamis approaching the islands from different directions.
4. Data analysis techniques have been developed that allow forecasts of major tsunami hazards for various locations. In a distant tsunami scenario, the goal is to evacuate Hawaii coastlines (200,000 to 300,000 residents and tourists) in a minimum of three hours prior to first wave arrival. In a large local earthquake on the island of Hawaii, PTWC will issue an urgent local tsunami bulletin to at least two counties (Hawaii and Maui), based on historic tsunami risk records.
5. The Hawaiian System is a coordinated effort between the Pacific Tsunami Warning Center (PTWC), Hawaii State and County Civil Defense, and police departments. Uniform state and county tsunami emergency evacuation response plans are in place. These evacuation plans are well understood, coordinated, and exercised between PTWC, the State, and County. When the PTWC issues a Tsunami Watch, State and County Civil Defense issue an initial "Prepare to Evacuate" notice. When the PTWC issues a Tsunami Warning, Civil Defense plans to commence coastal evacuation. After discussion between these four groups, a decision is made to evacuate. The county administrators and police then activate sirens and the Emergency Alert System (EAS), as well as authorizing Civil Air Patrol aircraft to fly over isolated coastal areas announcing evacuation.

   The siren sound is the National Standard alert signal (a three minute steady signal) that prompts people to turn on their radio, which carries the evacuation notice and refers the public to the tsunami evacuation maps in the telephone book. They still maintain the old Emergency Broadcasting System (EBS), because there can be simultaneous activation of the EBS with the sirens. The EBS also has the capability of sending out a longer message than EAS, which is limited to a maximum of two minutes. After PTWC issues a cancellation of warning, County Civil Defense will issue all clear announcements over EAS. No sirens are sounded. The EAS will be discussed in more detail in section 4.

6. Hawaii has several models of sirens (327 total) manufactured by Federal Signal Corporation. The model of siren is based on a professional analysis of the area to be warned, because one model of siren may be more effective in some locations than other models. Most of their sirens are electronic, omnidirectional, and nonrotating. Some have voice capabilities. They have a few older rotating mechanical and rotating electronic sirens. They prefer nonrotating, electronic, and omnidirectional, because rotating sirens do not send the signal out equally in all directions and electronic sirens have voice capability. They also have a few directional sirens placed in specific locations that only require one signal direction. Approximate cost of one nonrotating, electronic and omnidirectional siren is $40,000-45,000. This includes design, installation, and voice capability. Their mechanical sirens cost half as much.

Other systems

The states of Oregon, Washington and California contain various notification systems and procedures. The systems in coastal communities range from advanced to none at all. Nevertheless, once they receive the tsunami warning from the WC/ATWC, they issue a local evacuation notification over whatever system they have. The following usually takes place.

1. Warning is created and disseminated

   The WC/ATWC issues a tsunami warning through its standard notification protocol. This includes distribution of a text bulletin through NOAA Weather Wire Service (NWWS) and a verbal notification, for state warning points via the National Warning System (NAWAS). Local National Weather Service offices immediately receive the text warnings.

2. Response agencies receive and further disseminate the warning

   State emergency management agencies receive the bulletin via NWWS and rebroadcast over state owned teletype systems, e.g. Law Enforcement Data System (LEDS) in Oregon. They also receive a verbal notification directly from WC/ATWC via NAWAS. Once the text bulletin is received, the state agency makes verbal notification to local jurisdictions via NAWAS, telephone, or other communication systems

3. Local agencies receive the warning

   Local jurisdictions on the coast receive a hard copy of the warning via the state-owned teletype system, typically within about 3-4 minutes from when the state receives the message. Local jurisdictions most often receive these bulletins at 911 centers where NAWAS equipment would be ideally located. However, not all coastal 911 centers have dedicated NAWAS drops, although there is usually one per coastal county.

   Very few local agencies receive warning bulletins independent of the state-owned teletype. However, NWWS and a similar wireless system known as EMWIN, are available at moderate or very low cost. Both are satellite-based and require no landlines or telephone connections.

4. Warning goes to the general population

   The general public can receive an audible voiced warning directly from NOAA Weather Radio and the Emergency Alert System (EAS). Local NWS offices maintain a network of NOAA Weather Radio stations that continuously broadcast weather forecasts and special warnings along the West Coast. In Oregon, approximately 70% of the at-risk population are within range of one of these transmissions.

   NOAA Weather Radio transmission of the Tsunami Warning will activate alarms on specially designed receivers. Similarly, the

EAS system receives the warning from NOAA Weather Radio and can automatically rebroadcast the message over commercial radio, television, and cable TV systems. All radio and television stations and cable systems with at least 10,000 subscribers are required by the FCC to have EAS equipment installed and functional. Commercial broadcast of state and local warnings, including tsunami warnings, is voluntary. However, if the local EAS plan specifies that a particular message type requires activation of EAS, broadcasters must either carry the message or go off the air. A community relying on EAS must be vigilant about encouraging broadcaster participation, periodic testing, and maintenance of a complementary public education program.

5. Local action is directed by designated authorities

   Communities may choose to evacuate on receipt of a tsunami warning. However, this would likely be problematic and lead to a perception of over-warning. In nearly all communities, at least some part of the warned area will not be affected. Local officials can use the EAS system, sirens, telephone calls, or other means to give explicit evacuation directions, or other pertinent instructions, following the warning.

Section 4. Types of Tsunami Evacuation Notification Systems and Procedures

Introduction

Local notification systems and procedures have two purposes. In the case of a distant tsunami, they take a warning from the Pacific and West Coast/Alaska Tsunami Warning Centers and issue the evacuation notification along the coast. They also respond to local tsunamis triggered by locally felt earthquakes. A local community notification system incorporates personal observation/notification, community and agency training, sirens, radio/TV broadcasts, etc.

The effectiveness of any local community warning system depends on the reliability of the interface between the community and the source(s) of information, training, and the accuracy of the source information. A poorly defined interface results in a poor system. A well-defined system can result in a response that is protective, predictable, and reliable.

In all cases, training, including regular public information, is of singular importance. Special information must be provided to transients, such as tourists and seasonal workers, who are less likely to know how to react to tsunami warnings.

To fully address evacuation notification systems and procedures, there are two questions that need to be answered.

1. Is the tsunami local or distant?
2. Should the notification to coastal communities and the decision to evacuate from low lying areas come from centralized or decentralized locations?

Local vs. distant

If the tsunami were local, the notification to evacuate would come from the strong shaking of the ground or rapid draw down or sudden rise of the ocean. The evacuation must be immediate. Local notification systems, normally designed for distant tsunamis, would probably not be functional and should not be relied upon. If communities would like functional notification systems that survive the ground shaking, then it would be necessary to strengthen the system hardware (towers, power lines, generators, etc.) and provide uninteruptable power sources. If operational, the local notification system should be triggered quickly as an additional reminder that evacuation is necessary. The system is also useful for the all clear notification.

However, there are four types of earthquakes that create problems as far as using only “strong shaking” as the trigger for evacuation: slow earthquakes, smaller subduction zone earthquakes, inland earthquakes, and earthquake-induced submarine landslides.

1. Slow subduction zone earthquakes could produce a devastating tsunami but not shake the coastal region much. A good example is the 1992 M7.2 Nicaragua earthquake. However, a tsunami warning will be issued by the warning centers within 15 minutes of the earthquake origin time. In the case of the Nicaragua earthquake and tsunami, it took about 45 minutes for the damaging waves to reach shore. So the warning center messages should be timely for an event like this. Nevertheless, detecting these types of earthquakes and determining their tsunami potential will be a challenge.
2. An earthquake along one short segment of a subduction zone would be smaller in magnitude and shorter in duration than an earthquake from a longer segment or the complete subduction zone. It might not be felt as strongly in adjacent regions, but the tsunami would still arrive relatively all along the coastline. Time of arrival in adjacent areas would vary from minutes to 1-2 hours depending on distance to the segment. There would be loss of life if evacuation were based only on strong ground shaking. Once again a warning from the centers will go out within 15 minutes of the earthquake origin time and thus arrive in those areas, 1-2 hours away, in a meaningful time frame for evacuation.
3. Local ground shaking does not necessarily indicate that a tsunami is approaching. The earthquake focus could be onshore miles from the coastline, but still be felt. Examples are the 1993 Scotts Mills earthquake in Oregon and the 1999 Satsop earthquake in Washington. The Satsop earthquake triggered evacuation by 50-100 people.

   The local notification systems would probably function and the halting of evacuation could be accomplished quickly. These earthquakes would require advanced rapid earthquake detection systems that would notify coastal areas immediately that evacuation is not necessary or halt evacuation in progress. Public notification would then go out via the established system. The RACE system in Oregon and Washington and CUBE and REDI in California are systems that automatically provide a preliminary earthquake location and magnitude. They could be important in the decision to stop evacuation already in progress. Subsequent bulletins from the West Coast/Alaska Warning Center would also indicate that evacuation should be halted. However, there is no notification system that will set off an alarm immediately following a felt earthquake that would notify coastal communities that evacuation is not necessary. Existing systems can halt evacuations in progress once they are officially notified of no tsunami threat.

4. Local onshore or offshore earthquakes could cause a submarine landslide that could generate a very localized tsunami. The tsunami would arrive in minutes. A rapid earthquake detection system would need to take this into account. Off southern California, several submarine landslide blocks have been identified. There is concern there that local onshore earthquakes could induce submarine landslides and tsunamis. Local tsunamis in southern California have occurred in the past. A submarine landslide triggered by a M5.2 earthquake near Santa Monica Bay in 1930 generated a tsunami with up to 6 meters (19.5 feet) of run-up in the bay. This is not just a California problem. Earthquake-induced landslides, no matter the earthquake source, could conceivably occur off the coasts of Oregon, Washington, Alaska, and Hawaii.

Defining “strong shaking” and minutes of shaking for coastal residents and tourists could also be a challenge. These descriptors are highly subjective. One possibility is to use “shaking” as the trigger for evacuation to account for these types of tsunamis and err on the side of caution. If all clear notifications are rapid enough, the disruption caused by false alarms should be reduced. Another possibility is to leave the descriptor up to local government, so areas with more background seismicity could choose a higher threshold than those with a lower background.

Distant tsunamis arrive hours after they are produced. Local notification systems and procedures should be operational and can be activated. Most of the discussion that follows will be on distant tsunami notification systems and procedures. The local tsunami issue will be incorporated where pertinent.

Centralized versus decentralized evacuation notification

A warning from the Tsunami Warning Centers usually reaches the coast from many sources, including NAWAS (National Warning System), the Internet, EAS, news media, and NOAA Weather Radio. Therefore it will be difficult to develop a sole information source for the tsunami warning. As long as the message is consistent, multiple warning sources should not be a problem.

However, the decision to evacuate is another issue. In the case of a distant tsunami, the decision to evacuate all low-lying areas could be made from a central location, such as the state emergency management agency office and the coastal notification systems could be triggered from there. The decision could be made in coordination with coastal jurisdictions. Another option is for the decision to be made centrally, in coordination with local jurisdictions, but trigger the notification system (sirens, etc.) locally. Hawaii is an example of this system. Finally, the decision to evacuate could rest on local centers or individuals who would activate the local notification system through pre-planned procedures once they receive the warning from the Tsunami Warning Centers. In reality, local jurisdictions in the five Pacific coastal states, except Hawaii, are solely responsible for making the decision to evacuate.

Local decision-making would result in more local control. However, some jurisdictions or individuals might be unwilling or slow to make the decision, and trigger alarms where appropriate, to evacuate after they receive the tsunami warning.

Decision-making could be slowed for several reasons. The public would be unnecessarily alarmed, especially if inaccurately warned about an event that is infrequent but of high consequence. The official making the notification or society in general could be harmed socially, economically, and politically. Delayed, muddled, or suppressed warnings from official sources would give importance to unofficial sources, creating credibility problems.

Going it alone in each community might result in conflicting instructions and behaviors in adjacent communities. However, with a distant event, there is enough time to make a regional decision by locals in a cooperative and coordinated way with input from state and federal agencies. This should involve discussion among locals to develop regional plans for this coordinated effort.

Central decision making would remove the decision-making burden from locals. However, the federal government and the states are not willing to take on that responsibility. Connecting the central decision center with local notification systems would also be expensive. Finally, central decision-makers might not have as good a grasp on local and variable evacuation issues as would local officials. Nevertheless, wherever the decision lies, the notification to evacuate must be simple, clear, and as consistent as possible.

Available notification systems and procedures

Various types of systems and procedures for notifying coastal residents and visitors of tsunamis are available and discussed in detail below. Notification systems include sirens, telephones, NOAA weather radios, the Emergency Alert System, and others. The goal for any community is to have the most effective coverage for the lowest cost. Therefore, it is critical to have local needs professionally evaluated. The costs of implementing new systems can be relatively high. They include not only systems costs, but costs for other component systems (such as radios for activation), labor, maintenance, and training. However, new systems are more reliable than older ones. The high costs associated with purchasing new systems could be offset by higher maintenance costs of older systems. In addition, if several adjacent communities decide to use the same system, costs could be reduced by purchasing equipment in quantity.

Sirens

General considerations

Sirens are devices that transmit different sounds or voice messages depending on the action that is required. They are either electro-mechanical or electronic. These two types, along with siren placement, sound projection, and alternate power supplies, will be discussed in more detail in Appendix 1. Sirens can be triggered locally or centrally. They can also be triggered automatically. For example, the warning from the Tsunami Warning Center or the state (who receives the warning via NAWAS) could be dropped into a community intelligent receiver that is linked directly to the alarm. There are three principal parts of a siren system: the siren, controller, and actuator. The siren produces the noise, the controller controls the siren as to signal type, duration, etc., and the actuator triggers the controller either remotely or directly.

Siren units, whether electro-mechanical or electronic, are essentially of two basic types: Those designed to project sound at once in a 360 degree pattern (omnidirectional), or those designed to project sound in one direction while the unit rotates or oscillates through 360 degrees. Sirens can also be fixed.

Sound source	Configuration	Installation
Electronic	Fixed	Pole mounted
Mechanical	Rotating	Mobile
	Directional	
	Omnidirectional	

Units rotating through 360 degrees require a commutator ring and brush system providing an electrical circuit from the mounting base to the siren motor (or, in the case of electronic siren, to the loudspeaker assembly). Units oscillating back and forth 360 degrees eliminate commutator ring and brush maintenance problems by using flexible electric cabling between the mounting base and siren motor or loudspeaker assembly. Directional sirens have a speaker or speaker array pointing in one direction.

The benefit of a directional siren is coverage only in those areas that are needed. The main difference between fixed and rotating is the amount of coverage area. A rotating siren increases the coverage area. For example the coverage area for a fixed siren would be a 1,000-2,500′ feet radius from the siren; a rotating siren would increase the coverage to a one mile radius. For a stationary listener, the sound from a rotating siren goes up and down in loudness, while sending out the sound wave in all directions.

An electronic siren warning system can be augmented by public address announcements.

Announcements can be on pre-recorded disks or chips containing short instructive announcements sent through the same speakers as the siren.

Controllers that control electronic sirens produce up to seven signals

Wail	Pulsed wail	Alternate wail
Steady	Pulsed steady	Alternate steady
Westminster chime		

The coverage area for an electronic siren can be increased by adding more amplification. Electronic models are often omnidirectional and fixed and are more expensive than electromechanical. Some electronic models are directional and rotating and can provide 360 degree coverage.

Ultimately, the siren system a community adopts will depend on the amount of funds available, and the type and area of coverage a community needs and wants. This will eventually require an on-site analysis that only specialists can provide.

The signal or voice message from the siren should be clear, concise, and distinct. There should be one tone for evacuation that sounds a distinct period of time. The alarm or message should be uniform over as broad an area as possible. One advantage of sirens is they can reach all populations, including those in isolated but populated areas (e.g. beaches). It can also reach populations that have no or limited access to other warning devices, such as NOAA Weather Radios, telephones, and commercial television and radio, or do not have them activated.

Siren Coverage in the Pacific Coastal States

The Hawaiian system, covered in detail in an earlier section, is a well-established and tested system. In the other states the systems are local and quite variable, ranging from very good to nonexistent. The systems vary with respect to type, age, and condition.

Even if several communities have siren systems, there can be significant differences. For example, the length of time the siren sounds is quite variable. Depending on the community, sirens are sounded for 90 seconds, 3-5 minutes, 1 minute on/off, and 10-30 minutes straight if applicable. One community sounds the siren continuously for 3-5 minutes to announce a tsunami and continually for one minute (cycled at one minute intervals three times) to announce the all clear. In addition, a few communities transmit voice messages in addition to or in lieu of tones. Sirens are also used to signal people to turn on their radios or televisions for an emergency announcement. For example, fire stations in Clatsop County, Oregon use three blasts with each blast lasting one minute. Sirens used in this way are all-purpose rather than tsunami specific. This adds a layer of complexity in developing a consistent siren system for tsunamis. Is it better to have an alarm, which prompts people to turn on radios or televisions, or should there be a specific tsunami warning signal? It would probably be more effective and simpler to have an all hazards siren that prompts people to turn on the radio or television. Radio and television messages, which provide more information, would probably be clearer than a siren sound.

Inland warning systems and procedures, and potential new standards, must also be part of developing a coastal warning system to ensure consistency and reduce confusion. For example, the Portland Region Risk Management Planning Group and the Oregon Local Emergency Management Council are recommending national adoption of a siren signal, developed in Denmark, that alerts the public to peacetime emergencies. The planning group was formed as a result of the Federal Clean Air Act 112r, which required a public meeting for chemical release warning systems. The signal, which is different from a regular siren signal, would mean to all persons in the United States, “Turn on radio or TV. Listen for essential emergency information.” Although there is already a national signal that prompts people to turn on their radio, the recommended signal would be an improvement. The distinct tone wavers, enabling people of different hearing abilities to hear it. There is also a distinct and different all clear tone.

Costs of selected siren systems

The costs of sirens of selected systems for specific communities are outlined below. Costs range between $10,000 and $40,000, with electromechanical at the low end and electronic at the high end. Manufacturers include Whelan Engineering Company, Inc., Federal Signal Corporation: Federal Warning Systems, and American Signal Corporation (Appendix I contains addresses and telephone numbers).

Electro-mechanical sirens

The specifics and costs of a directional, rotating electro-mechanical siren from Federal Signal Corporation: Federal Warning Systems (FSC:FWS) for the small coastal town of Winchester Bay, Oregon are outlined below. The costs are based on an estimate given to the community in November, 1999. FSC-FWS has several models with different coverage capabilities. The 2001 model, used in this example, has a signal strength of 127 dBC at 100 feet, three distinct warning signals (steady, wail, and fast wail), and a weather resistant coating. The siren can be radio activated which can minimize installation costs by eliminating the need for leased dedicated control lines. The siren will supply a minimum of 15 minutes of full power output from its batteries after AC power loss. Siren controls are available with battery operation (2001 SRN model), AC operation, and AC operation with battery backup. One unit covers a radius of approximately one mile with a 60 degree projection. To cover just the greater Winchester Bay area they would need one siren unit at $7,800, siren control at $3,100, radio control at $1,500 and four back up batteries at $75 each. The total unit costs for one site would be $12,700. This does not include the mounting pole or installation costs. If FSC:FWS does the work they estimate it would cost about $5,000 for each siren installation.

Used sirens have also been purchased by several communities in Oregon and Washington. Portland General Electric (PGE) recently sold 102 and 107 decibel electro-mechanical (various fixed and rotating models) and Whelan rotating electronic sirens from the closed Trojan Nuclear Power Plant. They sold for $1,000 each. The cost included the siren, electric controls, mounting brackets, radio receiver box, and technical manual. Rockaway Beach, Oregon, one of the purchasers, estimated that the purchase/installation and operation/maintenance costs per site were approximately $5,000 and $200, respectively. The 102 decibel sirens are single phase (regular outlet connection) and have an effective range (102-70 decibels) of 1750 feet and an extended range (70-0 decibels) of another 1000 feet. The 107 decibel sirens are three phase (require special electrical outlet connection, have an effective range of 3000 feet and an extended range of another 1300 feet.

Electronic sirens

Systems installed in Cannon Beach, Oregon and Kenai Peninsula, Alaska are outlined below.

Cannon Beach, Oregon purchased and installed a Whelan electronic system that includes a public address component. The sirens operate from a simple storage battery power supply. The system is run with solar powered batteries totally independent of the commercial system. The costs of the system are based on present costs rather than costs at time of purchase.

1) $27,000 for equipment per station and $6,300 for technically qualified labor installing and testing equipment (total is $33,300 per station). The system without a public address component would cost $13,000 less. There are four units in Cannon Beach and two in Arch Cape to the south
2) $2,000 for central triggering equipment (magneto-optical mini disc for pre-recorded DTMF (Double Tone Multiple Frequency) and announcements) plus encoder (with suitable transmitter on hand).
3) $4,000 for site survey prior to installation of units
4) $5,000 per year for maintenance

Kenai Peninsula Borough has 28 Whelan omnidirectional, fixed electronic sirens located throughout the borough. The system has been very reliable, with only two failures in 15 years. They estimate the cost of one siren, including installation, to be approximately $15,000. The age of their sirens varies and they plan to upgrade the system. One upgrade would be to install a two way communication component, that allows for silent testing and testing for each function. They use the National Standard alert signal (wavering sound) for tsunami warning and evacuation and a person to person verbal message for all clear, because they have a small population. They also use a three minute continuous national alert signal that prompts people to turn on their radio. However, often people can not distinguish the waver from the continuous siren due to high winds. Therefore, Kenai Peninsula educates the public to evacuate from low-lying areas no matter what siren signal is transmitted. They also recommend the use of only two very distinct tones to reduce the risk of confusing one tone with another. Their sirens have voice message capabilities, but they are not used, because the voice message from the speaker is often garbled, probably due to inadequate speakers. In well-constructed houses, people often cannot hear sirens, even though they are in the hearing radius of the siren. Therefore Kenai Peninsula uses other systems to ensure the public is warned. They also use a sole source for sirens to insure consistency in product and service.

Telephones

Telephone notification systems are designed to automatically ring in the operational area (homes and businesses) and notify recipients of the need to evacuate. The pre-recorded telephone message would announce evacuation in a clear and concise manner. The trigger would be from the emergency operation center (either local or central). Cordova and Kenai Peninsula Borough, Alaska, and Lane County, Oregon have installed or are in the process of installing these systems and their efforts will be summarized.

The auto dial system (Viking Model DVA-1000 is no longer available) has been in place in Cordova since 1984. The local telephone company purchased, installed, and maintains the system. The system is tested at least once a year and the list is updated monthly. The telephone company absorbs the annual maintenance cost into its budget. The 1984 cost to purchase and install the hardware was approximately $15,000-20,000.

The Kenai Peninsula Borough contracted with the Community Alert Network Inc. (CAN), a private company, for high-speed telephone notification of citizens for tsunami evacuation. It costs them $11,000/year. CAN is considered a supplemental warning system to complement sirens, mobile public address systems, door to door contact, and the Emergency Alert System (EAS). However, not all answering machines are designed to pick up the recorded message, although the system is designed to call back two more times. CAN recalls up to three times if the phone is busy or if there is no answer. Contra Costa County in California has also used CAN, specifically for petrochemical plant emergencies.

Lane County, Oregon is proceeding with the development of a Community Emergency Notification System (CENS). CENS will give public safety officials the ability to send an outgoing telephone message to every phone number within a specified warning area or evacuation zone. The warning/evacuation area can be pre-determined, or (at full implementation) can even be determined 'on the fly' (for example, in the event of a hazardous material release, taking into account the properties of the material, prevailing winds, etc.). In the initial phase of CENS, the first area planned for implementation is a Tsunami Warning/Evacuation Zone for the City of Florence and surrounding coastal areas of Lane County. A digital representation of the warning/evacuation zone is required.

CENS is a county wide public/private partnership and is 50% funded by private industry. Lane Council of Governments (LCOG) is the planning/coordination/partnership-funding administrator. LCOG contracts with Qwest for the service and SCC Communication Corp. provides the service. CENS can send out 2,000 messages of 30 second length per minute under ideal conditions; however 500/minute on average is what is expected. It has no limit on the number of telephones connected to the system. It can provide call-out lists and can set up preplanned event areas (for example, tsunami evacuation zones). It can stagger calls if needed, contacting the areas that will be affected first. It has an auto call back feature, and deaf and other language capabilities.

The approximate costs for all of Lane County, population 300,000, are:

1. $24, 000 for one time set up
2. $45,000/year for operating costs based on 100,000 telephone lines ($0.02/line)
3. Activation of the system during an emergency is $0.20/completed call.

A test of the telephone warning system was conducted in Florence (population 6,800) using a tsunami evacuation message. It resulted in:

1. 500 telephones rung in 7 minutes,
2. 364 answers and 126 busy signals, no answers or messages left,
3. No tie up of the phone system, and
4. 42 out of 43 positive feedback responses.

With a prerecorded message, telephones can reach large audiences quickly. The system can be used for multiple hazards. There are, however, limitations. You must be near a telephone. Phone lines might not be functional if damaged by an earthquake. The lines could become overloaded if people call to confirm what they heard about a distant tsunami or to confirm that the shaking felt is from a tsunami-producing earthquake. At present, cellular phones are not connected to the system. It calls direct dial numbers only (both listed and unlisted). In certain cases where a building has a switchboard (e.g. motels and businesses or government agencies with extensions), only the switchboard would be called and not individual rooms or offices (unless the facility has a direct inward dialing system). When people move they can retain their old phone number and if they are away from the coast they would still be notified of a tsunami threat. This would cost money if the call is completed and it might be considered an inconvenience to the recipient of the call.

A telephone system would be effective for distant tsunamis, because there are hours between the earthquake and when the tsunami reaches the distant shore. With a local tsunami, the system might not be robust enough to withstand a large earthquake. If the community relied solely on waiting for the telephone calls to evacuate, precious minutes would be lost. Nevertheless, a seismically strengthened telephone notification system, if in place, should be activated. It would reinforce evacuation that should begin once earthquake shaking stops. If local tsunami arrival times are more than 20-30 minutes, such a system might well have enough time to operate.

NOAA Weather Radios

National Weather Service broadcasts all its warnings, including tsunami warnings, on its existing VHF-FM network, known as NOAA Weather Radio. Upon broadcast, these warnings activate alarms on specially designed receivers. Confirmation of who has received the message is not part of the system. The general public will likely seek confirmation of the warning from local authorities. The entire network was recently upgraded to interface with the new Emergency Alert System (EAS), which will be discussed in more detail in a later section. NOAA Weather Radio and EAS now work in tandem. A warning broadcast on NOAA Weather Radio can be automatically rebroadcast on commercial radio, television, and cable. Local authorities could use the EAS system to provide urgent follow-up information to the local public, such as an evacuation order, after the tsunami warning is broadcast. EAS and NOAA Weather Radio use a digital encoding scheme known as Specific Area Message Encoding (SAME). SAME allows a warning to be broadcast over a large area while activating alarms on only certain receivers. SAME encoding is a digital burst of data which describes a geographic area by county; the nature of the hazard by warning type; as well as the date, time, and identification of the originating agency.

NOAA weather radio is considered a primary notification system for the general public and a secondary system for emergency managers. Receivers can be operated by battery or AC power. A household receiver typically costs $20-$80 depending on features and sophistication. Commercial quality receivers add reliability and functionality with costs rising commensurately. For a list of manufacturers of NOAA Weather Radios, visit the National Weather Service web site (www.nws.noaa.gov/nwr).

The radios issue a warning only and not a call to evacuate. The message from the NWS would include, “take appropriate action or contact local authorities.” This will be effective if the public is properly educated. However, state and local emergency management can send other information, such as a call to evacuate, out over NOAA radio to areas in need of evacuation information. The state can either request that NWS send out an evacuation notice or set up a system (requiring extra equipment) that allows a state or local jurisdiction to send an audio EAS message to NWS. The message would either be automatically sent to the targeted areas or reviewed by NWS and then transmitted to the targeted areas. The State of Washington has this automatic system in place. It is functionally much easier and faster for locals to initiate EAS activation directly via an EAS Encoder than utilizing NWS for local messages. This would work for distant tsunamis. For local tsunamis, the system should be activated quickly to reinforce the evacuation notification provided by the earthquake shaking.

Weather radio can also be used with a call back option by individuals who have received the warning message and want to verify the warnings content. Either the broadcast itself, or the supplemental information the broadcast refers to, can contain a phone number that a person can call to confirm that a warning is true. However, this can easily overload the telephone system.

NOAA Weather Radio receivers are highly portable and a tourist population could be encouraged to carry them when away from home. But educating and encouraging a transient population to use NOAA Weather Radio would be a formidable challenge. A simpler solution would be to encourage operators of hotels, restaurants, conference centers, campgrounds, and the like to have a receiver on site in an area where a responsible authority can monitor it (e.g., the front desk, camp host, and so on). A significant challenge remains getting receivers into the hands of the public.

However, there are some limitations to using the radio as a tsunami notification system. Tourist populations would not be served unless the lodging facilities (hotel, motels, campgrounds), restaurants or stores have radios. Owners and managers of these facilities are then relied upon to spread the information to their immediate area, which has been previously designated in a tsunami warning plan. In addition, tourists who visit isolated beaches or other low-lying areas would not normally have a radio and would not be served. Not all local residents and businesses would have radios, because either they do not want to own one or it is not a high priority, especially for low-income households. Some models have to be on all the time and this may not be acceptable. Other more expensive models can be on standby and come on when a tsunami warning is issued. Bulk purchases would reduce costs. If funds were available to purchase the radios and distribute them to all households and businesses free of charge, they would be very effective. An alternative would be to provide rechargeable NOAA Weather Radios for rent in parks and campgrounds along the same line as avalanche transponders are available for mountain climbers and Emergency Position Indicating Radio Beacons are available for boaters.

Washington Emergency Management Division has a program encouraging the purchase of NOAA Weather Radios for coastal communities. In partnership with the National Weather Service they promote the purchase of radios. At times this has included offers of discounts through specific vendors. They have also partnered with the Washington State Grange to provide a weather radio receiver to each school district and are expanding that program to include hospitals.

On the transmission side of the equation, there are also challenges. Not all areas are within range of a transmitter. For example, parts of Lane, Douglas, Coos, and Curry counties lack sufficient signal strength to reliably activate alarms. The existing transmitters require a line of site for adequate reception. This is hard to accomplish along the rugged Oregon Coast. However, the network can be expanded and improved. A new transmitter typically costs $15,000 to 20,000.

In Washington, the state is providing $19,000 for equipment and installation of a new weather radio transmitter. The NWS provides engineering, licensing, and other operating costs. In Oregon, Tillamook County set up a joint commission to fund an upgrade of the county owned Tillamook NOAA Weather Radio station. The project extended the coverage area by relocating the transmitter and increasing output power, and improved reliability by providing backup power.

Emergency Alert System (EAS)

In 1996, the EAS replaced the outdated Emergency Broadcast System. EAS is now the nation's primary method for notifying the general public of emergency for all hazards. EAS stations include all radio, television, and large cable operators. Messages can originate from any designated authority: from the nation's president, to the state governor, down to the local incident commander. For example:

1. NOAA/NWS receives the WC/ATWC tsunami warning, rewords the message for media purposes, and retransmits it over EAS.
2. The state receives the warning over NAWAS and transmits the tsunami warning message over EAS. Oregon, for example, sends out the tsunami warning to coastal county 911 centers via a dedicated telephone line.
3. Local emergency managers can obtain and use their own radio equipment to broadcast messages into the EAS network. In essence they can simultaneously commandeer all broadcast facilities within a given area. This level of functionality comes with a price, however. Local broadcasters must voluntarily agree to pass locally generated messages. The system is not automatic by any measure and its usefulness depends on a community's willingness to make the system work. The local broadcasters and emergency managers must work together to develop and exercise a local EAS plan. However, once the EAS plan is in place the broadcasters must carry messages specified in the plan. Manufacturers of EAS equipment include, but are not limited to, TFT (www.tftinc.com)

and Harris Corporation (www.broadcast.harris.com/customer-service/sage).

4. The EAS system can allow tsunami warnings to jump directly from the NOAA Weather Radio network onto the EAS network.

However, it may be advisable to send the warning message out over EAS from only one source, preferably NOAA, to avoid media and public confusion. NWS has 13 offices that receive and transmit EAS messages from the Tsunami Warning Centers.

Radio and television stations receive and retransmit the message. Radio transmits voice message as is. Television may transmit as is or take the voice message and write it up and present it as a bottom scroll message. Media may pick up the tsunami warning from the TWC independently and transmit the warning anyway. It is important to work with media to insure the proper dissemination of the warning.

A key advantage to the EAS system is the flexibility it allows local authorities to develop their own emergency messages. EAS can be used to provide multiple announcements, including evacuation notices, once a tsunami warning has been broadcast. Messages can be prerecorded and stored for immediate use.

The coverage is wide: everyone has a television and/or radio at home, business, and in their vehicle. However, not everyone would be listening to the radio or watching television. Current technology requires that the radio or television be turned on to receive the EAS bulletin. Future receivers will automatically turn on and display or play an EAS bulletin when it is received. Those people who are watching television via satellite dishes will not receive the EAS message. In addition, many coastal radio and television stations are not staffed 24 hours. Even if staffed, the audience would probably be minimal between midnight and 6 a.m. The message is not a call to evacuate, because the information passed on from the Tsunami Warning Center is only a warning and not a decision message.

Cable networks offer unique challenges to implementing an EAS system. Small systems are not able to insert an EAS bulletin on all channels because of the hardware expense. One option is for the cable company to provide dedicated EAS receivers that monitor a given channel and notify the listener when there is an alert. Receivers are also available that meet the requirements of the Americans with Disabilities Act (ADA) by sounding an alarm or switching on a light.

Critical problems with EAS are the existing and potential non-participation by broadcasters and the need for continuous education and testing. At present, the system should not be considered fully reliable. Many local jurisdictions have no functioning plans and are not actively pursuing them. If functional, this system should not be used as the sole notification system for local tsunamis. It would, however, quickly reinforce the idea that people should immediately evacuate to high ground after an earthquake.

Emergency Managers Weather Information Network (EMWIN)

The EMWIN system was developed by the National Weather Service especially for the emergency management community. It is an increasingly reliable and easy way to receive official NWS warnings and forecasts. It delivers official critical warnings, watches and advisories, as well as a vast array of routine weather forecast information, for any area in and around the United States. The data is free. The costs are simply for the initial hardware and software used to receive and display the information. There are other methods available, at higher cost to the end-user, including various commercial weather distribution systems. Visit the EMWIN web site for a list of commercial vendors at iwin.nws.noaa.gov/emwin/index.

Data can be received over the Internet or via direct satellite downlink. The satellite broadcast is placed on two geo-stationary satellites owned and operated by NOAA. The signal footprint is the entire Western Hemisphere. Full information on the system is available online at weather.gov. The signal received from satellite can be rebroadcast locally via radio. This adds a point of failure, but is useful where a large number of users would not be able to afford $1,000-$1,500 for the one-time purchase of a satellite receiver.

EMWIN users typically have a personal computer to ingest, display, and print weather warnings. Software can be obtained that will activate pagers upon receipt of a user-selected warning or even forecasts. A typical use might be for an Emergency Operation Center (EOC) to have an

EMWIN in place that will sound an audible alarm and print the text of any WC/ATWC bulletins received. These bulletins would likely beat the Law Enforcement Data System (LEDS) and perhaps NAWAS notification by a minute or two. EMWIN is considered a secondary notification system for emergency managers and the general public. For example, the Internet is convenient but may be difficult or impossible to access in an emergency due to server overloads. Therefore, the Internet should not be used as the sole source of information for tsunami warnings and evacuation notifications. However, all possible efforts are made to ensure 24/7 availability.

Grays Harbor County in Washington reported an EMWIN success story during the Nisqually earthquake in Washington on Feb 28, 2001. The earthquake was centered northeast of Olympia and was felt on the Washington coast. Grays Harbor County received the information from their EMWIN System immediately after the earthquake. They received preliminary data in the first few minutes (1857 UTC) from the ATWC. When the emergency manager, Karen Frinell-Hanrahan, arrived in the Emergency Operations Center there was a Tsunami Information Message waiting on the printer. It gave the preliminary magnitude and location of the earthquake.

When the emergency manager reviewed the information from the ATWC, she immediately briefed the Sheriff's Office and called the local radio station. The statement issued included the magnitude and location from the ATWC bulletin and stated that a tsunami had not been generated and the residents could return to their homes, schools, and businesses. Unfortunately, she was not in the office at the time of the earthquake and it took approximately ten to fifteen minutes to broadcast the information. She would like EMWIN to do a simultaneous broadcast page directly form the machine to the Sheriff and officials in the coastal communities in Grays Harbor County, so that they get the information even when she is not in the office.

NOTE: At the end of 1999, they purchased an UPS 30 minutes backup power system for their system to allow it to continue to receive data until their generator engaged in the Emergency Operations Center. They were able to receive data the entire time.

AlaskAlert

Alaska does not have an accurate, timely geographically-based, all hazards alert and warning, or civil notification system. With the exception of EAS, the systems in place in Alaska are old, limited in coverage, unreliable, and difficult to use. They also frequently warn an area much larger than that affected by a hazard, resulting in citizen complacency. NAWAS is present in only 20 communities. From these NAWAS points, additional locations are warned using telephone or radio fan-out procedures. EAS is only marginally effective in Alaska because of inherent design deficiencies caused by lack of local broadcasting infrastructure, which is available in the lower 48 states. Local notification systems, such as sirens, can be effective in Alaska but their deployment is limited to only a few locations. NAWAS, EAS, or other notification systems do not provide accurate reliable warnings to the citizens of Alaska.

AlaskAlert is a notification system that is being developed by the State of Alaska, but is adaptable to all states and territories. AlaskAlert is based on the MITRE Corporation's MITREcasttm system. The MITRE Corporation is an independent, not-for-profit systems engineering firm engaged in scientific and technical activities in the public interest. Over the past several years MITRE has developed a technique to provide geographically-specific messages using wireless technologies. MITRE is working with FEMA to identify potential applications and is assisting in the development of a possible use in Alaska. The MITRE Corporation web site is www.mitre.org/tech_transfer.

AlaskAlert will provide timely, precisely defined and geographically specific alerts and warnings to all citizens. It consists of encoding and transmitting equipment located at state and local government locations. It uses existing and future communications infrastructure for transmission of alerts and warnings. Transmission systems include landline, microwave, satellite, fiber-optic cable, television, FM radio sub-carrier, etc.

Stationary units will have a basic receiver and will have a Global Positioning System (GPS) receiver or will be programmed with the location of the unit. Receivers (chips) can be imbedded in a multitude of devices including smoke detectors; television, cable and radio receivers; hand held, portable, automotive or marine radios; or stand alone audio or video devices (for the hearing impaired). Mobile units, automotive, marine or hand-held radios will contain a simple GPS. When one of these devices receives an alert signal it will turn itself on and broadcast an audio or video alert signal or message. The receivers do not have to be in use at the time of the event. Larger stationary systems located in towns or villages could have the ability to return an alert-received message back to the initiator, confirming that a community had received the alert.

The cost of a system would vary depending on area of coverage and number of receivers. The cheapest method would be to use a FM radio sub-carrier with receivers imbedded in dedicated FM or NOAA weather radios. The costs would be $1500 for the sub-carrier plus the costs of the dedicated radios. The costs of the radios would depend on the number of radios needed, which would in turn depend on the area of coverage. GPS capabilities would cost extra. Buying in large quantities would reduce the costs.

Miscellaneous systems

Other possible public notification systems include aerial flares, explosive reports, billboards, aircraft, mobile loudspeakers, alpha-numeric pagers, e-mail, and amateur radio.

Aerial flares or explosive reports: Aerial flares and explosive bangs (blank ammunition) would be useful for beach goers or others who are remotely located and, often by desire, not near conventional information sources. They could be used to supplement other notification systems in the case of a distant tsunami. They could be used to notify people to evacuate in the case of a local tsunami only if there is action within seconds after earthquake shaking stops. The liabilities of aerial flares or explosive reports are:

1. They would likely attract people to the source rather than encourage them to leave.
2. They are considered distress signals and can generate false alarms that must be investigated by the Coast Guard while they are dealing with the tsunami alert.
3. Pyrotechnics are dangerous to store and use without proper training.

Billboards: Strategically placed billboards are an excellent method to educate the public to the significance of other alert systems. Supplemental light signals (strobes or flashers) can be used to draw attention to them to clarify the meaning of a primary public alert system when it has been activated.

Aircraft: Aircraft could announce the evacuation notification for distant tsunamis from a loudspeaker. This system would most likely be coordinated by local fire, police and emergency management offices in coordination with Civil Air Patrol or Air National Guard units. The contact would be personal and perhaps more believable. Aircraft can cover isolated areas effectively.

Voice delivery requires a significant public address system that is not typically installed in Coast Guard or Civil Air Patrol aircraft. It is important to use pre-scripted messages. Text delivery requires designing, preparing, and staging leaflets in advance. Once dropped, all of the leaflets would need to be recovered or quickly (less than a week) decomposed to prevent false alarms or pollution. Towed banners or message boards are a possible option. (Towed banners for fixed wing; message boards for helicopters.)

Fixed wing aircraft have significant range and are relatively quiet; however, flying low and slow to deliver a message places the aircraft in significant risk. Helicopters are able to fly low and slow; however, they are very noisy and have limited range. Aircraft could be called on to fly at any time and in any weather conditions. However, flying in foul weather or at night requires specialized aircraft and training.

Having the appropriate resources available on short notice requires significant prior planning. Coast Guard aircraft are available on a 24/7 basis, but are primarily needed for search and rescue. National Guard and CAP aircraft are rarely available on short notice. The use of the National Guard requires the prior approval of the Governor.

Mobile loudspeakers: Public address vehicles are a viable option for areas where installing fixed public address systems is not cost effective. The system can be designed to quickly bolt onto an existing vehicle and amplify a pre-recorded or transmitted message. This system could be practical for large beaches and parks. However, there would be limited staff covering a large area by vehicle.

Pagers: Supplying alpha/numeric pagers to people in tsunami vulnerable areas would simplify technologies, increase coverage, and minimize maintenance. The initial purchase price and subscriber cost-of-ownership make pagers an overpriced option for public notification. While it may not be feasible in many places to do this on a large scale, it may be practical for some small or special settings. Pagers allow direct communication with responsible authorities (e.g., teachers), who then can direct actions to be taken. Pagers can be triggered by a broadcast calling service, through e-mail, or by a government-owned paging system. Pagers can be discontinued if not needed at far less cost than other systems and they can be distributed quickly without the planning, engineering, bidding, and contracting processes involved with establishing siren or other hardware-intensive systems.

E-mail: E-mail is useful when a text message is needed. E-mail can be used not only to activate pagers, but can transmit text messages to digital cell phones. Digital messaging for cellular phones does not operate if digital service shared with your cell provider is unavailable.

Amateur radio: Amateur radio operators can transmit messages along the coast for distant events. They are especially important in situations where power is out. This notification system is limited, because correspondence would only be between individual operators and homes and businesses adjacent to the operator.

Conclusions

Which system is best?

There is no system that is best. The pros and cons of each notification system are summarized in Table 1. Notification systems should be tailored for the community being evacuated. You need to know something about the people that you are notifying to select the system that is best. When you look at your audience, you need to find out who they are, where they are, and what they might be doing. All the issues below factor into selecting the correct notification system for your audience.

Audience?

Your audience can vary a great deal. Here are a few examples:

Elderly
Emergency responders
Tourists
Hospitals
Schools
Parks
Marinas/boaters
Children
Elected officials
Locals
Factories
Shopping centers
Beaches
Transient workers

Activity?

What the person is doing can affect how quickly they receive your warning. Here are a few examples:

Driving
Sleeping
Watching TV
Shopping
Working at a desk
Cooking
Talking on the phone
Playing
Listening to the radio
Walking/running
Working in a factory
Camping

Cost?

Cost is a major, possibly limiting, factor. Each jurisdiction has different budgets and priorities. Although a community may decide on the best system for them, cost could be the main reason why that system is never installed.

Size and Layout?

A large, spread-out community might require multiple notification systems (for example, NOAA Weather Radios for the town center and sirens for the adjacent beaches).

Effective notification systems and procedures require clear, concise, and consistent signals and messages. Ideally, there should be redundancies to ensure all people are notified and the decision to evacuate is positively reinforced. For example, a community may decide to use a telephone system and NOAA weather radios. The various sources should not provide conflicting information. Conflicting information may decrease the credibility of the system and cause people to ignore the notification to evacuate. Therefore, planning and education are required to insure efficient and timely evacuation.

How uniform should notification systems be? Should the ultimate goal be to install the same system everywhere? For the tourist or transient who travels between coastal cities, states, and countries, a consistent system might be important. Siren signals with different tones or duration could cause confusion as individuals travel. However, uniform systems could be difficult to implement at a local and state level. Communities have strong preferences, established and working systems, and limited funds.

Uniformity, if desired, would probably require a large investment of money from the federal government. Perhaps communities and states that use similar systems could adopt similar signals and voice messages. For example, the standard siren signal used by Hawaii (wail), and considered the national standard, could be used by all communities to notify residents and tourists to turn on their radios in case of a distant tsunami. Or if a specific tsunami signal tone is preferred, then one of the other possible siren tones could be used exclusively for tsunami evacuation. Voice messages do not necessarily have to be the same message as long as the message is clear and distinct. Nevertheless, uniformity would require planning and coordination between multiple jurisdictions.

The all clear should be distinct from the warning cancellation by the tsunami warning centers. The locals should have control over who returns to low-lying areas and when. The all clear should probably be considered part of the emergency public information function rather than the evacuation notification system. EAS and other methods may be a more appropriate avenue for disseminating an all clear message than a distinct siren tone designated for that purpose.

Finally, even if systems are different the evacuation notification should be clear and distinct, whether it goes out over radio and television,

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Table 1. Pros and cons of the evacuation notification systems

Notification system	Pros	Cons
Sirens	Wide area of coverage	Testing of actual siren could be public nuisance
	Coverage of isolated areas (beaches)	High cost (includes purchase, installation, labor and maintenance)
	Audio component (electronic only) would probably be more understandable than siren signal	Damaged by sand and salty air
	Widely recognized and has single focus to direct people to seek further information	Not-audible with high winds and topographic barriers
	Can be activated through various channels	High turnover in staff with manual trigger responsibility
	Control from central point for rapid notification	Connection difficult with a diverse group of sirens
	Maintenance is low if continually tested	Siren meaning not recognized and ignored
		Confusion if adjacent communities have sirens with different tones and durations
		Nondedicated frequency can cause interference
Telephone	Wide area of coverage (all telephones with direct dial)	Must be near a phone and not using it
	Cost effective for small areas and if used for all hazards	Expensive for single use
	Audio component (more understandable than siren signal)	Direct dial only (e.g. motel rooms and offices may not be connected)
	Reduces 911 calls	Taxes phone system already stressed by local earthquake
	Pre-recorded message saves time	Lack of human contact on telephone
	Can tailor message for special-needs population	Cell phones not covered
		Presently has problems serving large populations
NOAA Weather Radio	Easy to use	Area of coverage limited to those with radios
	Widespread and mobile	Band width too narrow
	Inexpensive	Must have on at all times (unless model has hazard specific call up feature)
	Audio component (more understandable than siren signal)	Warning message can be picked up by media and individuals and announced prior to consultation with responsible official
	Message is rapidly transmitted, consistent, and capable of being tailored	Not all coastal areas are covered
	Compatible across systems	High rate of false alarms (people do not use them)
	Hand-crank and solar models available	Potential encroachment by commercial industry
	Tied to Tsunami Warning Centers	Alarm is triggered without cause and radio is turned off
	Mechanism for personal responsibility	
	Reduces 911 calls	

(Continued on next page)

Notification system	Pros	Cons
Emergency Alert System (EAS)	Established system with wide coverage	Radio and television must be on
	Can be used to broadcast evacuation notice	Not all radio and television stations are staffed 24 hours (old EAS)
	New EAS is totally automatic so staff is not needed	Does not work on satellite TV or small cable networks
	Reduces 911 calls	Power dependent. Some radio stations might not have back up power.
	Inexpensive	Some areas have no coverage
	Message is consistent and rapidly sent (message can be modified by locals)	Voluntary system and not always used (unless local EAS plan is in place)
EMWIN	Inexpensive	Not a stand alone system (secondary system)
	No reliance on land lines (satellite based)	Dish vulnerable to wind, rain, and snow (can lose signal)
	Continuous broadcast	
	Can be teletyped into NAWAS	
AlaskAlert	Accurate, timely, precisely defined, and geographically specific	Transient populations might not have the proper receivers with them or in their vehicles.
	Receivers (e.g. televisions and radios) do not have to be on at the time of the event	
	Relatively inexpensive, but depends on the coverage and number of receivers needed	
Ground shaking	Known and intuitively simple	Tsunami producing earthquakes not consistent with respect to shaking intensity and duration
	Warns hearing impaired	Non-tsunami-producing earthquakes have potential for false alarms. This is a big issue in California and Alaska where there are many earthquakes of this type.
		The above are educational problems
Miscellaneous—Aircraft, amateur radio, mobile loud speakers	Reaches remote areas (aircraft, amateur radio), reach accessible areas not covered by other means (mobile loud speakers), complements other systems	Limited in number and coverage. Slow response by aircraft
Flares, explosives	Complements other systems	Dangerous to store and use. Considered distress signal and may be misinterpreted
Billboards	Simple, available 24/7, multicultural, complements other systems	Vandalism
Pagers	Inexpensive if used for specific audiences, complements other systems	Coverage limited
Tone alert radio (SAWS)	Useful for caregivers of dependent populations and for low population areas with adequate radio reception coverage	
Travel Advisory Radio	Tourists notified	Need microwave upgrade, need to be on, not everyone has one
E-mails	Rapid dissemination of information, text message, complement other systems	Coverage limited—access dependent

(Continued from page 27)

telephone, a public address system, NOAA weather radio, or the Emergency Alert System. An effective evacuation notification system requires continuous public education. A system can never be totally effective without education, no matter how expensive or sophisticated. Whatever system is chosen, all groups that are part of the notification process (emergency managers, media, etc.) should be involved in the planning and implementation of their systems.

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Acronyms

CENS (Community Emergency Notification System)

A system that gives public safety officials the ability to send an outgoing telephone message to every phone number within a specified warning area or evacuation zone.

CREST (Consolidated Reporting of Earthquakes and Tsunamis)

A project funded through the National Tsunami Hazard Program to upgrade regional seismic networks in Alaska, Washington, Oregon, California, and Hawaii and provide real-time seismic information from these networks to the tsunami warning centers.

CUBE (Caltech USGS Broadcast of Earthquakes)

This system, designed for southern California, provides preliminary earthquake epicenters and magnitudes (above a defined threshold) within minutes of the earthquake's occurrence.

DART (Deep Ocean Assessment and Reporting of Tsunamis)

DART is a real time distant tsunami detector system developed by NOAA's Pacific Marine Environmental Laboratory (PMEL). PMEL is installing the systems (buoys and bottom sensors-figure 9) in the open ocean off Alaska, Oregon, and Washington. The system uses sensitive water-depth detection equipment, underwater modems, satellite telemetry, and advanced signal processing to detect and measure tsunami waves in the open ocean. Its purpose is to confirm that a potentially destructive tsunami has indeed been produced.

EAS (Emergency Alert System)

The EAS, which replaced the emergency broadcast system, is the primary method for state and local officials to notify the public of an emergency, using the broadcast industry system.

EMWIN (Emergency Managers Weather Information Network)

The Emergency Managers Weather Information Network (EMWIN) is a satellite or Internet service developed by the National Weather Service and FEMA and operated by the National Weather Service and NOAA. EMWIN receives forecasts, warnings, and climate data from NOAA Weather Wire and prioritizes it by message type. The system provides end users with direct access to weather and warning information without reliance on landlines, multiple layers of human intervention, or recurring subscriber fees.

GPS (Global Positioning System)

GPS is a technology that uses satellites to determine the latitude and longitude of a position anywhere in the world.

ITIC (International Tsunami Information Center)

ITIC was established in 1965 and monitors international activities of the Pacific Tsunami Warning Center and assists with many of the activities of ICG/ITSU, the International Coordination Group for the Tsunami Warning System in the Pacific.

LEDS (Law Enforcement Data System)

The use of LEDS is restricted to criminal justice purposes, except for emergency public safety messages such as storm warnings, disaster warnings, etc. sent out by agencies responsible for those areas.

NAWAS (National Warning System)

NAWAS is a regional telephone hotline system set up within each of the Federal Emergency Management Agency regions. The phone system enables any member of the NAWAS circuit to immediately initiate a conference call with all the other members of the circuit. NAWAS provides prompt communication when simple voice messaging is adequate. NAWAS is considered a primary notification system.

NWR (NOAA Weather Radio)

The National Weather Service broadcasts all its warnings over NOAA weather radio, including tsunami warnings.

NWWS (NOAA Weather Wire Service)

NWWS is a satellite or leased line subscriber service that distributes weather and warning data from the National Weather Service. NOAA Weather Wire is considered a primary notification system.

NOAA (National Oceanic and Atmospheric Administration)

NOAA is a federal agency under the Department of Commerce responsible for tsunami warnings and monitoring.

NWS (National Weather Service)

The branch of NOAA which operates the tsunami warning centers and disseminates warnings.

PTWC (Pacific Tsunami Warning Center)

Established in 1948 and located in Ewa Beach near Honolulu, the PTWC is responsible for issuing warnings to Hawaii, to U.S. interests in the Pacific other than the West Coast and Alaska, and to countries located throughout the Pacific.

RACE (Rapid Alert Cascadia Earthquake)

This system, designed for Oregon and Washington, provides preliminary earthquake epicenters and magnitudes (above a defined threshold) within minutes of the earthquake’s occurrence.

REDI (Rapid Earthquake Data Integration)

This system, designed for northern California, provides preliminary earthquake epicenters and magnitudes (above a defined threshold) within minutes of the earthquake’s occurrence.

SAWS (Simultaneous Announcement Wireless System)

SAWS is a dedicated system of transmitters and receivers installed by local authorities for all types of messages.

THRUST (Tsunami Hazard Reduction Using System Technology)

Sponsored by the Office for U.S. Foreign Disaster Assistance/Agency for International Development, THRUST is a comprehensive program to mitigate tsunami hazards in developing countries.

WC/ATWC (West Coast/Alaska Tsunami Warning Center)

Established in 1967 originally to issue warnings to Alaska of local tsunami events. WC/ATWC is now responsible for issuing warnings for any event likely to impact either Alaska, the West Coast of the US, or the Pacific coast of Canada.

Appendix I
Siren Details

Sound Projection

Projection of sound from either type of siren is subject to natural law in which the sound energy (sound pressure) projected diminishes ten decibels at every doubling of distance between the source and point of measurement. This means siren output measured at 120 decibels 100 feet out from the unit will diminish to 110 decibels at 200 feet, 100 decibels at 300 feet, etc. Besides this fundamental rule, various factors apply to selecting equipment for the intended area in order to hear the projected sound. These factors are shapes of terrain to be covered by the sounding alarm, types and distribution of significant foliage, sides and roofs of structures within the area, prevailing wind patterns, prevailing air humidity and temperatures, and frequencies of the sound being projected (lower frequencies traveling better than the higher).

A vital consideration in planning a wide-area siren system is the effective reach of the siren signal. The ambient noise level of the area to be blanketed by the alarm signal must be part of that consideration. Typical beach-side noise levels from normal surf and normal wind is approximately 70 decibels. The standard rule is for the minimum level of the siren signal to be 10 decibels above (louder than) ambient noise level; thus maximum effective range for a warning signal should be considered no farther than the distance from the sound generator to where it generally delivers 80 decibels. Figure 12 illustrates effective range under ideal conditions for each of three sirens having different decibel power as measured 100 ft away from the unit. The chart shows significantly greater range of alarm coverage by what might appear as only moderate increases of siren output power (decibels measured 100 ft straight out from the siren).

High powered sirens, such as 1 and 2 in the fig-

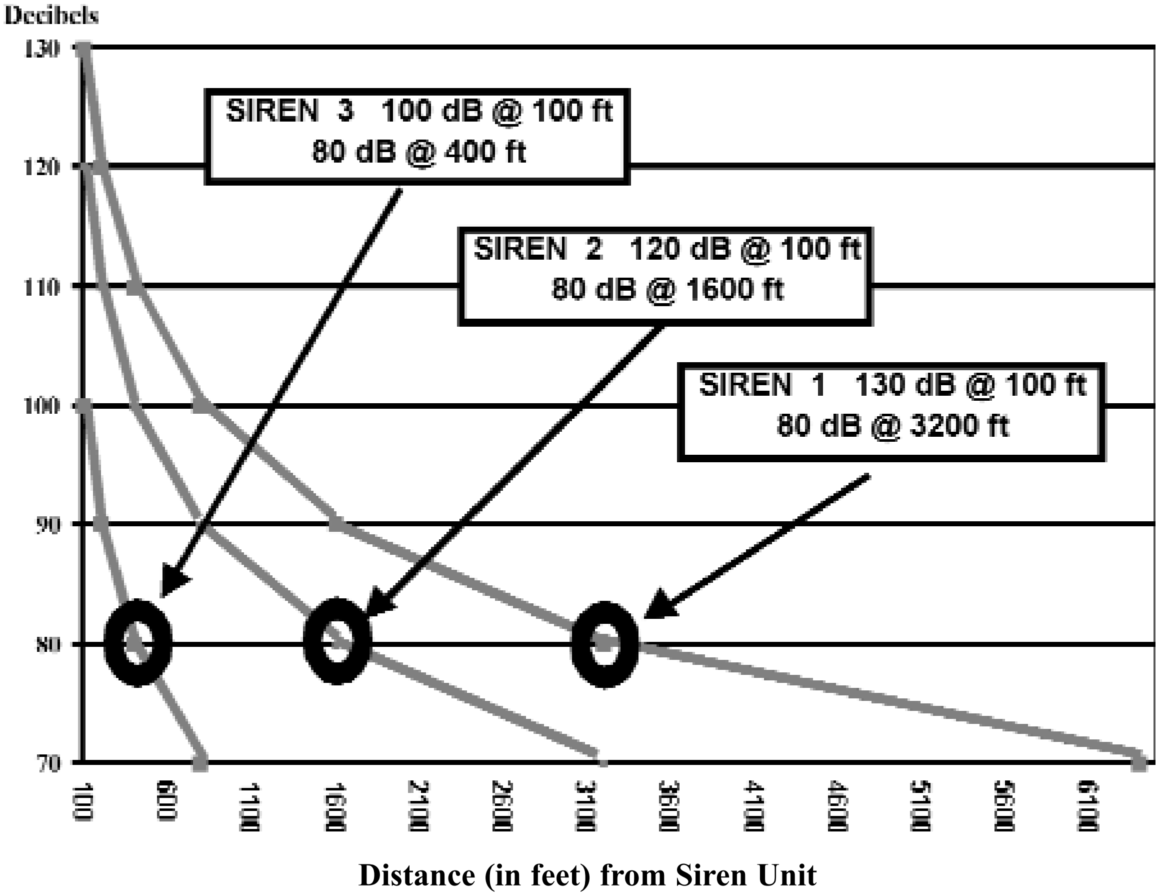

Figure 12. Range of effective warning sound by three sirens each with different output power against a general 70 decibel ambient noise.

ure, when properly engineered and installed on 40-50 ft utility poles, project their sound horizontally outward much like a jet of water from a hose nozzle. The main power moves straight out with relatively little dispersion from 40-50 ft above ground level, essentially passing overhead above nearby structures. As the projected energy's main stream disperses over distance, sound reaching ground level will be less forceful than when part of the energy's main stream departs from the siren.

High-powered sirens not specifically engineered to project their principal sound outward in horizontal focus are less suited for installation where people move about at ground level in the open or occupy buildings close to the siren's location. High-powered sound will blanket the siren's immediate area like a fire system sprinkler spray saturating everything nearby with full pressure.

Sirens rely on electricity and would therefore be of limited use if the system is destroyed by a local tsunami-generating earthquake. Backup systems or systems that do not rely on the AC grid, such as solar, are possible as long as they survive the earthquake. Solar energy collectors would add costs to the siren system. However, costs of solar panels have dropped significantly and allow placement in areas where there are no power lines, such as isolated beaches and parks. A solar-powered system, free from commercial connection, would provide service if commercial power is disrupted by earthquakes and protect the system from power surges.

Placement

Besides the distance over which the warning sound is to be heard, many important factors must be considered in the placement of sirens. Any of these other factors may in some circumstances become as important as the size of the intended coverage area.

For example, the character of the terrain around a siren station very clearly can deflect its projected energy away from an area expected (on basis of distance from the siren) to be covered. Shapes of terrain around the siren unit site can be so important that, for example, a siren station properly placed to take advantage of those terrain features might 'bounce' or reflect the sound to an area otherwise having its line of site from the siren blocked by a hill. Types of ground surface, including different kinds of foliage and their distribution, can significantly influence sound reflectance or absorption. Seasonal changes of deciduous foliage also can be critical in these regards.

Structure sizes, heights, outer wall surfaces, types of roofs and their angles can all effect passage of the projected alarm sound throughout the area and reduce its effectiveness. Consideration is needed concerning the effectiveness of the 80 decibel range to awaken people sleeping at night inside insulated homes. Another factor that needs to be considered and might be significant is the prevailing seasonal wind patterns that can deflect projected sound from reaching its targeted area. Air temperature and humidity are also important to consider. Projected sound tends to rise in warm air. Failure to provide for that factor can shorten the system's range of effectively delivering 80 decibel alarm sound. Finally, a siren's metal parts can corrode in coastal areas and can be damaged by windblown sand in beachfront areas if not designed specifically for those conditions.

A common problem in the proper selection of a site for wide-area outdoor siren units is to locate them next to pre-existing and convenient AC power sources. Convenience is the determining factor rather than whether such a location provides maximum effectiveness for the siren. Another common siting problem arises due to public objection to a technically ideal location. The type of siren unit selected is not engineered to have minimal impact upon its immediate location, although it has the high power required to meet the extended area's needs. An ideal site may be also avoided because of public criticism about the aesthetics or the belief that the proposed siren will negatively impact property values.

These obstructions in the selection of proper siting can lead to expensive alternatives, e.g. having to install more units than otherwise would have been necessary or investing in inappropriately designed equipment. Such problems can perhaps be solved by well-planned public education as to the reality of the hazard and the need for siren systems and incorporation of the public in the planning process. Once this is accomplished, the location and thus resultant effectiveness of the proposed notification system would likely be more acceptable and considered a necessity to minimize casualties in the community.

Although testing is important to keep residents and tourists aware and educated, the public may also object to repeated testing. However, testing can be done without sounding the actual siren and thus reduce public complaints.

In summary, the selection of the appropriate types of siren units and their effective placement is best realized when:

1. There is general public acceptance within the community that the hazard the siren system is designed to guard against is very real, and
2. A professional specialist, who is experienced in acoustic surveys and types of siren equipment including their power supplies, triggering systems, and maintenance needs, is consulted. Such a specialist will be equipped with mobile siren units to test for maximum effective warning sound coverage by types of equipment best suited to various local factors. A system designed by this method will avoid costly errors made by inexpert siting and/or investment in siren equipment inappropriate to the local need.

Electro-Mechanical Sirens

Electro-mechanical siren units generate sound mechanically. That is, they are driven by an electric motor and available in various types of design and output power engineered for various uses. These range from small units on emergency vehicles to the large wide-area outdoor alarm system siren units requiring 3-phase AC power, from standard and available AC power sources (208, 240, or 480 volts supplied by power company special transformers). Some electro-mechanical siren units incorporate storage batteries for limited operation if AC power fails – battery charging having been maintained by AC power. During prolonged power outages, when an AC-dependent siren's use might be required more than once, or if equipped with backup batteries for limited use, electro-mechanical siren units could be operated by a portable generator. If centrally located, such as atop a fire station or city hall, auxiliary AC power is often available during general outages of AC service.

Control of siren operation can be by on-site manual switches or remote control over leased telephone line or radio link to a central emergency command center. Central or station controls can activate one unit, a group, or all units.

Sirens generating emergency signals especially for a community warning system may need to vary their sound in several ways to communicate different meanings to the public educated to understand them. For example, the familiar repetitive wailing sound, that usually signals an emergency, is achieved by speeding up or slowing down the siren's spinning rotor to generate, respectively, high and low sound frequencies.

Length of time for the sound to change from low to high frequency or vice versa, is the "Sweep Rate" and is varied by turning power to the motor on and off. The standard "Wail", for example, is about nine seconds for the spinning rotor to speed up from generating approximately 400 Hz to peaking at 1,000 Hz when power is cut off. The rotor then slows to the lower frequency until power is switched back on. The electro-mechanical siren's signal can be varied. For example, the standard "Attack" siren tone, distinctive from standard "Wail", has a faster sweep rate (two seconds) cycling between approximately 700 and 1,000 Hz.

Sound patterns to communicate other meanings to the public are available by other variations of sweep rate and/or length of time for the siren to operate. For example, some community sirens are turned on to run up to peak frequency and cycle back down once as a short activation (e.g. 15 seconds) to signal "Noon Time".

Electronic Sirens

Electronic siren units are actually powerful loudspeaker systems broadcasting amplified electronically generated standard tone patterns, e.g. "Wail", "Attack", "Hi-Lo", "Alert", etc. Some versions of electronic siren units also offer the advantage of broadcasting public address announcements as well. This is a valuable feature, making it possible to communicate local emergency information quickly and efficiently to the public, especially more transient populations. Versions providing a public address feature, depending on the specific model, can broadcast from microphone for live-voice announcements, from pre-recorded magnetic tape, or compact disk recordings. Some versions are equipped to broadcast pre-recorded messages stored in solid-state memory chips. Centralized or siren station controls can activate any single particular station, groups of stations, or all the system's stations for any of these functions.

Electronic siren units are available, competitively priced, in as many varieties of output power as the older technology electro-mechanical sirens.

The costs of selected units are discussed later in this section. Some units operate from 120 volt AC power while others are engineered to operate from low-voltage storage battery systems. In the event of AC power failure, some of those intended to rely upon such a power supply, have backup storage batteries enabling operation for a limited time.

Some of the electronic sirens' engineering design provides significant advantage over electromechanical sirens. One such advantage is the high-power electronic siren's ability to operate from a low voltage battery power supply. In a wide-area disaster, AC power outage may be prolonged and emergency services officials will likely need more than brief use of the community notification system (e.g. repeated notifications, public address advisories about hazards, or other emergency type announcements). Electronic siren units, engineered to operate regularly from their low voltage storage battery systems, offer lengthier service than siren units intended to operate on AC but having a limited battery backup. However, when backup batteries are found depleted, they can be replaced or a portable generator can supply AC power as needed. A disadvantage is electronic units often require more maintenance than electromechanical models in coastal marine environment.

A community notification system, comprised of electronic siren units specifically engineered to operate from low-voltage battery systems maintained by solar charging, will operate entirely independent of AC power. Solar charging equipment has plummeted in price during the last decade, making this method of maintaining batteries practical against costs of installing AC power connections. Additionally, battery systems maintained by solar power make it practical to install siren stations in strategic locations remote from AC power service. Powering an electronic siren unit with a solar-maintained battery system has other advantages. For example, the unit is entirely protected against AC system voltage spikes, surges, and other irregularities, which sometimes cause significant maintenance problems for the unit's control systems and other electrical elements.

Control of siren operation can be by on-site manual switches, remote control over leased telephone line, or radio link to a central emergency command center.

Alternate Power Supplies

Though briefly discussed above, the choice of power supply for siren notification systems is vital when planning a system and thus requires special mention. As already described, various versions of both electro-mechanical and the more modern electronic sirens rely upon either AC power of 120 up to 440 volts or low-voltage storage batteries.

A community notification system engineered to operate directly on AC service line power is constantly at risk from power outages or electrical irregularities capable of damaging siren unit controls. This is particularly the case when lightening strikes within the community. Lightening can decommission the entire siren unit regardless of protection devices. In addition, power lines connected to siren units broaden the exposure to lightning strikes. In the northern Pacific, power lines are also subject to adverse coastal atmospheric conditions during the frequently hostile winter season. Ongoing expenses for AC service should be factored in when making the decision about the type of power supply system.

Siren units engineered to operate directly on low-voltage storage battery power with the battery charge maintained by AC service have their siren controls and equipment far better protected. The batteries stand between the siren elements (except the battery charger) and the AC power line's potential for damage to elements of the station control system, e.g. relay coils and/or solid state electronic circuitry components.

Ideal protection for siren units and their controls is to have no connection at all with AC power lines, even for charging the battery power supply. Instead, maintain the battery system by a solar-powered charger. As already mentioned, during the last decade prices have fallen to make solar equipment competitive with costs of equipping alarm system stations with AC power. Wind systems are also cost effective.

Battery power supply systems need to be engineered properly. For example, where a siren unit is driven directly by AC power but is equipped with backup batteries in case of AC loss, it is necessary to recognize that the batteries' life span will be shortened if they are not regularly 'exercised'. Proper maintenance will require systematically using them for a full operational test of the siren unit (power drawn by the test should parallel what an emergency activation would require) to insure they can provide adequate backup power when needed. Simply relying upon the fact that there are backup batteries in the siren unit without maintaining proper testing routine would be imprudent.

Critical to the success of a battery power supply is the selection of proper batteries for their intended use. Use of sirens in one community, for example, may differ significantly from needs of another community: A community having a heavily populated tsunami inundation zone might anticipate the need to use their alarm system several times during an emergency. A coastal community without extensive exposure to tsunami hazards might foresee only the briefest use of sirens. The capacity of battery power supply systems would significantly differ between those two communities. This is true for siren units engineered to operate directly from battery power supplies as well as siren units operating directly from AC but having backup storage batteries.

Type of battery selected is very important. Experience shows that batteries for wide-area alarm systems should be robust deep discharge, uninterrupted power supply (UPS), 6-volt batteries rather than from half as many 12-volt batteries, because of less wear and tear on battery plates. Such 6-volt batteries have far sturdier plates. While discharging to power the siren, the load is also spread over significantly more plate surface than it would be in half as many 12-volt batteries. Service life of even the highest quality 12-volt batteries in similar circumstances can be extremely short due to their thin plates buckling from the heat developed while powering the siren.

Careful consideration of these principles is even more important when planning systems to be used both for broadcast of siren alarm tones and public address announcements. The latter puts a heavier load on the power supply than simple siren tone patterns.

In summary, where storage batteries will be used either as backup for loss of AC power or for basic operation directly, planners of a wide-area siren alarm system need to recognize the vital importance that properly engineered power supplies are the solid foundation for the proposed system. Equipment and power supplies for a system’s needs should not be determined by trial and error, but with guidance by specialized professionals having broad experience in wide-area alarm systems.

The following web sites have more information on sirens:

www.warningsirens.org

www.warningsirens.com

www.airraidsirens.com

www.sirensystems.com

Appendix II
Siren Manufacturers

1. American Signal Corporation
   10245 Enterprise Drive
   Mequon, WI 53092
   800-243-2911
2. Federal Signal Corporation: Federal Warning Systems
   2645 Federal Signal Drive
   University Park, IL 60466-3195
   800-548-7229
3. Whelen Engineering Company, Inc.
   Route 145, Winthrop Road
   Chester, CT 06412-0684
   800-63SIREN

Appendix III
Tsunami Warning Workshop Summary

Over 80 people from Alaska, California, Hawaii, Oregon, and Washington attended a day and a half tsunami warning workshop in Portland on May 14 and 15, 2001. They represented emergency management, communication, fire and police, public works, and science. The workshop was funded by the National Tsunami Hazard Mitigation Program. The workshop began with presentations on the Tsunami Warning Centers and six evacuation notification systems (sirens, NOAA weather radio, telephones, EMWIN, EAS, and AlaskAlert). The pros and cons of the different evacuation notification systems and system consistency and needs were discussed in two breakout sessions. The breakout group discussions were summarized in two main sessions. Several recommendations came out of the breakouts and presented during the main session. Consensus was reached on five of the recommendations. There were thirteen other recommendations that need further discussion and, if possible, consensus. The following is the workshop summary.

I. Pros and cons of the evacuation notification systems

A. Sirens

1. Pros
    a. Controlled from central trigger point which has potential for rapid notification
    b. Can be activated through various channels
    c. Good for special conditions (beach, other remote area where tourists, transient populations are located and isolated, and confined communities)
    d. Easily integrated with audio component
    e. Single focus–direct people to seek further information
    f. Widely recognized as warning and partial systems already in place
    g. Maintenance is low if continually tested
2. Cons
    a. High cost (equipment and maintenance) especially for small communities
    b. Siren meaning is unknown (education and testing required)
    c. Non audible with winds and topography
    d. Old mechanical ones are in place or being installed (High maintenance-needs weather protection)
    e. Single focus use of siren (not cost effective as a mobile siren)
    f. Siren ignored
    g. Diversity of types with connection difficult
    h. Access to siren trigger is necessary and responsible person needed. If manual trigger (what if person cannot get there). If high turnover in staff, possible lack of understanding of warning information
    i. Difference in local systems (tones and duration) is confusing
    j. Non-dedicated frequency can cause interference/garbling

B. NOAA weather radio

1. Pros
    a. Wide-spread and mobile (cars, homes, business, boats etc.). Easy way to get information to public.
    b. Affordable

        c. Hand cranks, battery operated, solar models
        d. Can be on standby and turned on specifically for tsunamis
        e. Message is rapidly transmitted Message is consistent and can be tailored
        f. Mechanism for personal responsibility
        g. Adds redundancy
        h. Compatible across systems
        i. Tied into tsunami warning center
        j. Reduces 911 calls
    2. Cons
        a. Coverage problems
        b. Only works when on
        c. Need to know your location with respect to tsunami inundation zone
        d. High rate of false alarms (people do not use them)
        e. Band width too narrow
        f. Potential encroachment by commercial industry
        g. Alarm kept going off so was not used

C. Telephones
    1. Pros
        a. Out of state/off site
        b. Redundancy
        c. Good for distant tsunami
        d. Less calls that 911 has to make
        e. Pre-recorded message saves time
        f. Tailored warnings for special needs
        g. Goes to all with telephones
        h. Cost effective for small areas (all hazards)
    2. Cons
        a. Probably not operable during an earthquake
        b. Taxes systems that are already stressed during earthquake
        c. No human contact
        d. Problems serving large populations (new technology could solve this problem)
        e. Does not go to cell phones
        f. Not effective in short warning time situations

D. EAS
    1. Pros
        a. Redundancy
        b. Widest coverage
        c. Modifications can be made
        d. Can be made automatic with existing technologies
        e. System in place
        f. Local input possible (e.g., message from EOC)
        g. Message consistent and rapid. Both audio and visual message
        h. Inexpensive
        i. Relieves 911
    2. Cons
        a. Need to have receivers on
        b. Doesn’t work on satellite TV or small cable networks (<10,000 users)
        c. Power dependent
        d. No radio coverage in some areas
        e. Radio stations might not have back up power
        f. Limited applicability-not focused enough, difficult to make changes
        g. Regulatory issue - voluntary system not mandatory
        h. Maybe passe in future if new technologies are brought in
        i. In place but not always in use

E. Ground shaking
    1. Pros
        a. Known and simple
        b. Warns hearing impaired
    2. Cons
        a. Not consistent with respect to intensity and duration of shaking that triggers evacuation (low shaking intensity could still produce a tsunami-slow earthquakes). How strong is strong, how long is long, when do I evacuate
        b. Educational problem
        c. Not reliable indicator of tsunami (false alarm issue)
        d. In some states where there are more earthquakes (CA and AK), evacuation for any shaking would result in many false alarms

F. EMWIN

1. Pros
    a. Continuous broadcast
    b. Teletyped into NAWAS
2. Cons
    a. Dish is vulnerable to wind, rain, snow, and can lose signal

G. Others

1. Helicopter leaflet drops expensive
2. Travel advisory radios need microwave upgrade, sightseers drawn by warning, only activate when people turn them on. Not everyone has them
3. OASIS (CA) Satellite phone system that links counties to state with seismic networks, expensive and limited band width, effective in extreme rural areas
4. High Frequency/FM can simulcast large areas, may not communicate shorter distances, hard to get frequency allocation, linkless system
5. Civil Air Patrol (CAP) Slow response, for distant tsunami warning only

II. Consistency issues with evacuation notification

Regional consistency is possible only if there is central coordination at the national level. The United States population is very mobile and many people are unaware of hazards of regions they enter.

However, if consistency is reached and standards are created would communities need to comply and thus take a risk in not complying? There could also be issues with standards being considered an unfunded mandate. It is also difficult to standardize the system with differences in rural, semi-rural and urban areas. Neighboring communities differ in their response and it may become a political issue within states and even over state lines. Evacuation decision that are driven by specific policies within a community cannot be discounted. Standards should include a spectrum of choices for rural to urban areas.

Standards are also important because the news media crosses borders. If standards are in place economies of scale kick in, i.e., there are shared resources and templates, a common core of understanding (educational consistency), and a universal interface. A regionally consistent system, i.e. standard, would make education easier. Tsunami Ready and CRS-tsunami programs, with their incentives, would ease the adoption of standards. National standards are already in place for sirens. A three minute wail tells people to turn on the radio or TV to seek emergency information. Thus the siren would act as a multi-purpose warning system. However, existing sirens are inconsistent with respect to tone and duration. Can all existing sirens produce one tone and one duration (steady or wavering, three minute wail) if a standard is adopted? NWR can provide a consistent message if more transmitters are built and more people have them. A consistent educational message must follow the establishment of any standard.

Consistency issues are also associated with evacuation and warning cancellation (the all clear) and safe zones. Are there liability issues with safe zones? What is a safe zone? Is it an official gathering place or just a safe place to be? Are shelter or supplies there? Zones imply land use in California.

Is ground shaking a consistent notification? What constitutes a tsunami producing shake: is it strong shaking for several minutes? Is the public better trained for duration or intensity? If communities err toward safety, there could be false alarms, especially in California where strong shaking earthquakes are common. The Papua New Guinea earthquake was not strongly felt but produced a devastating tsunami (with loud noises and extreme water level changes).

III. Evacuation notification needs

A. Coordination/Standardization

1. National standards with flexibility for local jurisdictions
2. Focus and direction from the national level
3. An organization that will set consistent guidelines/standards and recommendations
4. Consensus from 5 state group on key issues
5. FEMA should include warning as mitigation
6. Realistic expectations of Coast Guard by locals
7. Governing agency for tsunami disasters
8. Take into account political constraints and state and regional differences
9. Acquire political backing at local, state, national levels

10. Regional communication and coordination
11. Develop positive partnership with local media (EAS)

B. Financial

1. Funds
2. Take into account monetary constraints of many communities when developing standards
3. Alternate funding sources and prioritization criteria for sirens in fund-strapped communities

C. Technical

1. New technology for improved warning system
2. Consistency with sirens (tone and duration).
3. Guidelines on how to set up a siren system
4. Reduction in false alarms from local non tsunami-producing earthquakes
5. Frequent testing of systems
6. Expand NWR (more installation of transmitters and radio purchase) to target as many people as possible
7. 24/7 coverage at local, state and federal level to improve delivery time of evacuation message
8. Back up tsunami warning center (in WA, OR, or CA)
9. Develop technology to send generic codes from ATWC direct to EAS
10. Use NWR to activate another system
11. Phone conference bridge that enables counties to speak at once so that state can get big picture
12. Integrate packet radio with paging Internet
13. Local ordinances/codes to require installation of appropriate devices (e.g., NWR interface via smoke detector chip)
14. Space based resources in conjunction with other uses to measure movement of wave across Pacific Ocean
15. Complete and redundant systems

D. Education

1. Siren test for awareness raising
2. Better communication and outreach education to residents, tourists, and transient workers both land and water based about tsunamis and non-tsunami-producing earthquakes. Education of people who speak different languages and have other special needs. Public education on what sirens mean. Continuous staff training at the state and local level
3. Incorporation of tsunami inundation information into NFIP maps
4. Education at the PSAP level which is the choke point for coastal dissemination of evacuation notification
5. Public education about local earthquakes (both tsunami and non-tsunami producing)

E. Message

1. Consistent messages, including all clear
2. Guidelines on how to set up media messages
3. Reduce time for communication of EQ/tsunami info
4. Rapid dissemination of event size and location (especially important for non-tsunami earthquakes) through improved seismic monitoring
5. Procedures for getting word out on Nisqually-type earthquake need to be clear, e.g., when to trigger an alarm
6. Information about non-tsunami producing earthquakes should be over NWR
7. Consistency in definition of key terms for evacuation and evacuation notification
8. Resolve all clear problem (how to hold back 1st responders (particularly volunteers))
9. Knowledge of the official source so locals can make decisions accurately
10. Streamline or improve tiered system of distribution (ATWC-state-local-public)
11. Follow up on evacuation message receipt
12. Flexibility with respect to WC/ATWC cancellation and local cancellation. Some communities will choose to maintain EOC activation and evacuation
13. State level all clear- however liability concern

F. Science

1. Knowledge of hazard areas and basic tsunami science
2. Improve uncertainties in tsunami research (inundation lines are not supported by hard science)
3. State tsunami advisor to interpret scientific data

G. Evacuation

1. Consistency in how evacuation maps are presented: same scale, color etc. using GIS
2. Standards for evacuation maps in phone books
3. Do more good than harm, e.g. not evacuating people to URM areas, moving huge populations down narrow streets preferred by developers

IV. Recommendations

A. Consensus reached

1. Adopt standard educational brochure that contain
    a. A glossary of terms
    b. See, hear, feel triggers for evacuation
        See water rapidly withdraw
        Hear loud roaring sound
        Feel earthquake shaking that makes it difficult to stand
    c. Five state logos
    d. Standardized map tailored for each state
    e. Sample Sign with running man
2. National recommendation for evacuation notification: Running man with tsunami symbol
3. If sirens are used for evacuation notification, the recommended national standard (three minute wail that prompts people to turn on radio or TV for further information) should be used regardless of siren type
4. All clear
    a. Standardized language
    b. Establish criteria/procedures for when it will be issued (separate criteria for local and distant tsunamis)
    c. Add definition to glossary in brochure
5. State level conference call during distant tsunami event
    a. Establish conference call number
    b. Include scientists on call
    c. Develop scientific group to assess tsunami hazard:
        Group needs to coordinate with emergency management
        Train scientists on tsunami science if needed
    d. If multi-state issue, FEMA responsible for bridge between states

B. Other recommendations (to be discussed and consensus reached)

1. Web site for 5 states emergency managers to develop guidelines
2. Patch communication holes to enable NWR/EAS coverage
    A. Original FEMA protocol
3. Trigger for warnings-evacuation, consistent activation for distant tsunamis
4. Embed NWR/EAS information into existing appliances (pagers, cell phones, etc.). As you enter area, notification is triggered
5. Watch would mean prepare to evacuate, warning would mean consider evacuation
6. All states have a tsunami advisor to interpret scientific data
7. PMEL provide scientists for expertise in interpreting various data post event
8. More research and analysis of landslide generated tsunamis
9. Schools in inundation zones should plan and practice evacuation drills
10. WC/ATWC and PTWC should establish voice grade HF. This requires working with FCC and FEMA for frequency set up. This would be good back up to wireline (which NWR is on), because wireline is not robust to ground shaking
11. Install multiple warning systems to insure complete coverage
12. Have tsunami warning workshop at the state level
13. NAWAS adopt pre alert message that allows time for state to bridge the counties