Designing for Tsunamis
Background Papers

A multi-state mitigation project of the National Tsunami Hazard Mitigation Program (NTHMP)

National Oceanic and Atmospheric Administration (NOAA)
U.S. Geological Survey (USGS)
Federal Emergency Management Agency (FEMA)
National Science Foundation (NSF)
State of Alaska
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The opinions and recommendations contained in this report do not necessarily represent those of the member agencies of the National Tsunami Hazard Mitigation Program Steering Committee.

March 2001

CREDITS

PROJECT MANAGER

On behalf of the National Tsunami Hazard Mitigation Steering Committee

Richard Eisner
Regional Administrator
State of California
Governor's Office of Emergency Services

CONSULTING TEAM

J. Laurence Mintier
Rik Keller
J. Laurence Mintier & Associates

L. Thomas Tobin
Tobin & Associates

Robert A. Olson
Robert Olson Associates, Inc.

Bruce Race
RaceStudio

Jeanne Perkins
Association of Bay Area Governments

GRAPHICS

Daniel Jansenson
Daniel Jansenson Architect

EXPERT ADVISORS PANEL

James E. Russell
Building Code Consultant

Robert L. Wiegel
Department of Civil and Environmental Engineering
University of California-Berkeley

Mark R. Legg
Legg Geophysical

Costas E. Synolakis
Department of Civil Engineering,
Tsunami Research Group
University of Southern California

NATIONAL TSUNAMI HAZARD MITIGATION PROGRAM (NTHMP) STEERING COMMITTEE

Chairperson

Eddie Bernard
NOAA/PMEL

NOAA

Frank Gonzalez
PMEL

Richard Hagemeyer
NWS Pacific Region

Richard Przywarty
NWS Alaska Region

Charles McCreery
Pacific Tsunami Warning Center

Tom Sokolowski
West Coast and Alaska Tsunami Warning Center

FEMA

Michael Hornick
NFIP, Region IX

Chris Jonientz-Trisler
Earthquake Program, Region X

USGS

David Oppenheimer

Craig Weaver
National Earthquake Hazards Reduction Program

NSF

Clifford Astill
Civil and Mechanical Systems Division

Alaska

Gary R. Brown
Alaska Division of Emergency Services

Roger Hansen
Geophysical Institute, University of Alaska

R. Scott Simmons
Alaska Division of Emergency Services

California

Lori Dengler
Department of Geology, Humboldt State University

Richard Eisner
Governor's Office of Emergency Services

Hawaii

Laura Kong
Hawaii Division, USDOT, FHWA

Brian Yanagi
State of Hawaii Civil Defense Division

Oregon

Mark Darienzo
Oregon Emergency Management

George Priest
Oregon Department of Geology and Mineral Industries

Washington

George Crawford
Washington State Military Department, Emergency Management Division

Timothy Walsh
Division of Geology and Earth Resources

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We greatly appreciate the contributions and review comments from the following individuals:

Alaska

Bob Bright, Community Development Director
Kenai Peninsula Borough

Linda Freed, City Manager
Eileen Probasco, Planner
City of Kodiak

Scott Janke, City Manager
Rachel James, Planning Technician
City of Seward

Carol Smith, Acting Director/Planning Technician
Community and Economic Development Department
City of Valdez

California

Tina Christiansen, Director
Werner Landry, Senior Engineering Geologist
Planning and Development Review Department
City of San Diego

Don Olson, Director
Barbara Shelton, Environmental Analyst
Community Development Department
City of Santa Barbara

Ernest Perry, Community Development Director
Del Norte County

Hawaii

Dee Crowell, Director
Keith Nitta, Planner
Planning Department
County of Kauai

Virginia Goldstein, Director
Rodney Nakano, Planning Program Manager
Planning Department
County of Hawaii

Oregon

Rainmar Bartl, City Planner
City of Cannon Beach

Washington

Ken Kimura, Director, Planning Division
Department of Public Services
Grays Harbor County

Connie J. Manson, Senior Library Information Specialist
Lee Walkling, Library Information Specialist
Washington Department of Natural Resources
Division of Geology and Earth Resources

Other

Alan L. Yelvington, Project Officer
U.S. Coast Guard

TABLE OF CONTENTS

INTRODUCTION

The following seven background papers provide supporting information for the report *Designing for Tsunamis: Seven Principles for Planning and Designing for Tsunami Hazards. Designing for Tsunamis*, intended for use primarily by local government officials, sets out guidelines for mitigating tsunami risk through land use planning, site planning, and building design.

Background Paper #1, *Understanding the Tsunami Risk*, is intended to help guidelines users understand the source and nature of tsunamis and how a tsunami may affect their community. Background Paper #2, *Local, State, and Federal Framework for Land Use Planning and Coastal Development*, describes the planning/regulatory context for the mitigation measures discussed in the guidelines.

Background Papers #3, #4, and #5 discuss approaches to addressing the tsunami hazard and identify mitigation measures at three levels within the land use planning/development regulation hierarchy. Background Paper #3, *Land Use Planning*, discusses mitigation planning at the broadest level in local government—the local comprehensive plan. Background Paper #4, *Site Planning*, discusses the application of mitigation techniques through design review and approval of individual projects. Background Paper #5, *Building Design*, discusses how tsunami hazards can be mitigated through building design.

Background Paper #6, *Infrastructure and Critical Facilities*, explores how these special types of development can or should be treated within the land use planning/development regulation hierarchy.

Finally, Background Paper #7, *Vertical Evacuation*, looks at how the strategy of moving at-risk populations to upper floors of buildings might influence development siting and building design.

BACKGROUND PAPER #1: UNDERSTANDING THE TSUNAMI RISK

INTRODUCTION

This background paper describes the nature and effects of tsunamis as a foundation for mitigation efforts by users of the guidelines—local government staff and officials and other people involved in comprehensive planning, zoning, building regulation, and development-related activities.

Tsunami risk is a function of three factors: 1) the nature and extent of the tsunami hazard; 2) the vulnerability of facilities and people to damage; and 3) the amount of development or number of people exposed to the hazard.

Tsunamis are natural events that can alter the landscape and destroy human settlements, infrastructure, and economic activity. Communities may be vulnerable because of the location and quality of the built environment. The principal exposure will be people, buildings, and infrastructure located in the low-lying potential tsunami inundation area. Locally-generated tsunamis preceded by earthquake groundshaking may result in tsunami losses in the low-lying coastal areas in addition to building and infrastructure damage throughout the area due to strong shaking and possible soil failure.

While the guidelines and these background papers provide general information, local policy decisions and the application of the information should be based on the results of specific tsunami hazard studies so the local potential of inundation is well understood. Appended to this paper is a suggested scope of work for a local tsunami hazard study (see Appendix 1-1: Suggested Contents of a Tsunami Hazard Study).

KEY CONCEPTS AND FINDINGS

This background paper presents two key concepts. They are intended to facilitate users' understanding of tsunamis and community risk so locally-appropriate and practical loss prevention programs and measures can be initiated by applying the guidelines and the advice contained in the other background papers.

Concept 1: Understand Your Community's Tsunami Risk

Effective mitigation measures are based on an understanding of the risk faced by a community. This background paper describes tsunami risk on a broad scale, but it is no substitute for a local evaluation of the hazard and community vulnerability.

Principal considerations in such evaluations include:

- Understanding that natural hazards are ever-present, but catastrophic incidents are rare for individual localities;
- Using local vulnerability studies to design specific loss prevention measures and programs; and
- Knowing that in the aftermath of major damaging events, people will frequently assign blame to those they believe are responsible for not taking precautionary actions.

The waterfront area of Crescent City, California, flooded by the 1960 tsunami.
Credit: USGS

Concept 2: Acquaint Community Officials and Leaders with the Community's Tsunami Risk

People are preoccupied with relatively immediate issues and decisions. The mitigation of risk from natural hazards requires a long-term and sustained commitment, the benefits of which may not be visible for decades. Regardless, mitigation practices should be built into ongoing programs, procedures, and processes to assure that tsunami risk is managed on a regular basis.

Important considerations include:

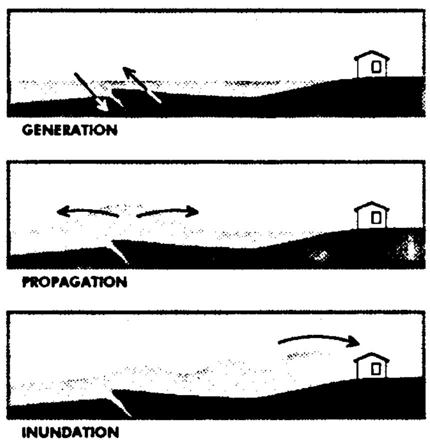
- Making special efforts to regularly inform key officials and community leaders about risk and the status of mitigation;
- Mobilizing community interest and support for mitigation through effective means;
- Assembling example materials from other threatened communities and states to demonstrate what others are doing and to adapt it for local application; and

- Designing community-based mechanisms, such as task forces and committees, to maintain a focus on risk mitigation measures.

HAZARD DESCRIPTION

Tsunami Definition

A tsunami is a series of long waves generated by any sudden displacement of a large volume of water. Tsunamis are triggered by submarine earthquakes, submarine volcanic eruptions, underwater landslides or slumps of large volumes of earth, meteor impacts, and even onshore slope failures that fall into the ocean or a bay. Tsunami waves can propagate as a series of long waves across entire ocean basins. The hazard can last for many hours as the tsunami passes, and waves may resonate in some harbors and bays for days after the initial attack. For example, tsunamis from the 1960 offshore Chile event were recorded for more than one week in some locations.

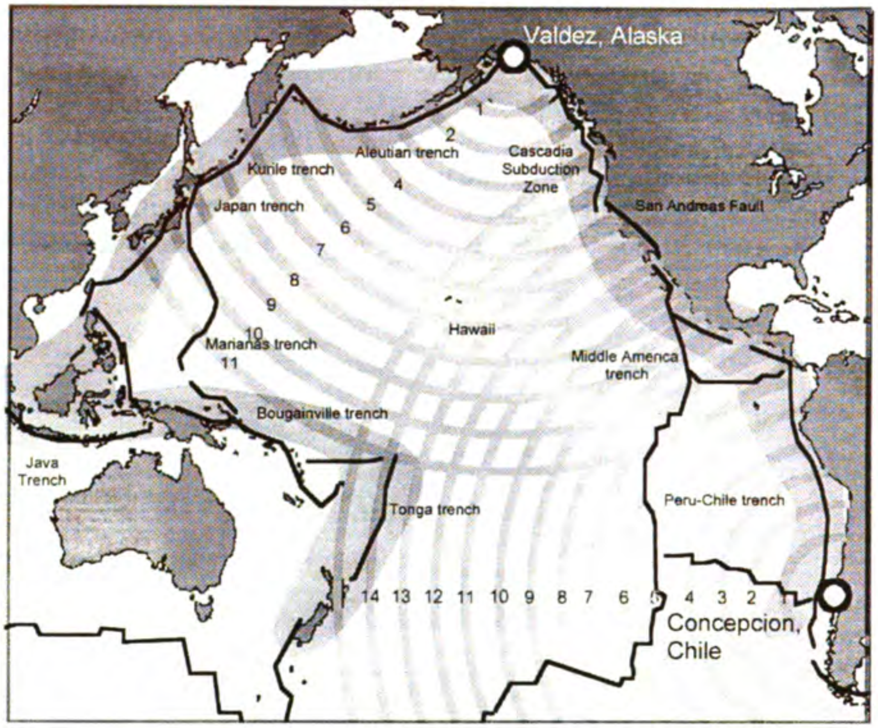


A tsunami is a series of deep, long waves
Generated by a sudden displacement of a large volume of water.

Seiches (or harbor oscillations) are a related hazard for enclosed bays, inlets, and lakes. Alaska and parts of Washington and British Columbia, in particular, have numerous communities vulnerable to such events. These destructive tsunami-like waves can be generated by earthquake motions, subsidence or uplift of large blocks of land, submarine and onshore landslides, sediment failures, and volcanic eruptions. Large tidal bores, strong currents, and the interaction of ocean swells and surf outside of bays and inlets may amplify the waves. The strong currents associated with these events may be more damaging than inundation by waves.

Source Zones

Tsunamis are associated primarily with seismic activity. The Pacific "Ring of Fire," one of the most active seismic features on earth, circles the Pacific Ocean from the southern tip of Chile, north along the west coasts of both South and North America, turning west along the Aleutian Islands arc of Alaska, and south through Japan, the Philippines, and the eastern Indo-Pacific region. Occasionally, tsunamis generated within this region threaten almost every island and coastal settlement in the Pacific Rim, including those in the five Pacific states: Alaska, California, Hawaii, Oregon, and Washington.



The Pacific "Ring of Fire" is the most active seismic feature on earth. Tsunami waves triggered by seismic activity can travel across the Pacific Ocean at up to 500 miles per hour, striking distant coastal areas in a matter of hours. The figure shows the estimated number of hours for tsunami-generated waves to travel across the Pacific Ocean from Alaska and Chile, respectively.

While not on the Ring of Fire, Hawaii sits in the center of a tectonic hot spot. Earthquakes and large landslides along the flanks of Hawaii, associated with the injection of magma into volcanoes' "plumbing systems," have generated tsunamis. In some areas, the risk of tsunamis from landslides may be greater than that posed by offshore earthquakes. Some locations, like parts of Alaska and Hawaii, may be stricken by multiple tsunamis from different sources such as volcanic eruptions, submarine earthquakes, and landslides, which may occur at the same time, greatly compounding the hazard.

Local and Distant Sources of Tsunamis

Tsunamis are typically classified as either local or distant. These two types of tsunamis have different implications for comprehensive planning; zoning; building siting, design, and construction activities; and evacuation warning. For example, local tsunamis likely will follow associated earthquake groundshaking and possibly ground failures that may produce additional damage. Evacuation will have to be nearly instantaneous when responding to local tsunamis, but assuming effective warning systems exist, many hours may be available to evacuate people from exposed areas before distantly-generated tsunami waves arrive.

Tsunamis from Local Sources

Tsunamis from local sources usually result from earthquakes occurring off nearby coasts. In the Pacific Northwest, including Alaska, these typically involve large subduction earthquakes in the Cascadia Subduction Zone or the Alaskan-Aleutian Subduction Zone. The Cascadia zone, where the Farallon (or Gorda or Juan de Fuca) Plate is sliding beneath the North American Plate, lies approximately 60 miles (100 kilometers) seaward of Cape Mendocino, California, and extends north along the coasts of Oregon, Washington, and British Columbia to the Queen Charlotte Islands. The Alaskan-Aleutian zone, where the Pacific Plate is sliding beneath the North American Plate, extends from southeastern Alaska to the westernmost tip of the Aleutian Islands.

Along active subduction coasts, tsunamis may also be generated by large landslides, both submarine and above water, into coastal waters (e.g., Lituya Bay, Alaska), and by volcanic activity (e.g., Krakatoa, Indonesia), especially along the Aleutian volcanic island chain.

In Hawaii, two of the largest tsunamis in the historic record (1868 and 1975) were caused by normal-fault earthquakes on the flank of the island. A few other much smaller Hawaii tsunamis may have been caused by onshore or submarine landslides. Volcanic activity is associated with these events such as the eruptions of Kilauea in 1975. Although explosive volcanic eruptions are uncommon in Hawaii, such activity does occur and may trigger local tsunamis.

In California south of the Cascadia Subduction Zone, local tsunamis may be generated by large offshore or coastal fault movements. Some parts of the coast are cut by active reverse and thrust faults, which push up the coast or offshore ridges during large earthquakes. Other parts are dominated by strike-slip faulting, where large areas of seafloor uplift or subsidence occurs due to local irregularity in the fault trends. In southern California, large submarine landslides along the steep and unstable slopes of the continental shelf edge and offshore borderland ridges can generate locally-destructive tsunamis for the adjacent coastal areas.

The travel time for a locally-generated tsunami, from initiation at the source to arrival at coastal communities may be within five to 30 minutes. For example, a series of destructive tsunamis began striking coastal communities on Okushiri Island, Japan, about eight minutes after the July 12, 1993, Hokkaido-Nansei-Oki earthquake mainshock. At least one village was hit by tsunami waves estimated to be 12 meters high (39.5 feet) while waves at other locations were between five and ten meters high (about 16.5 to 33 feet). Located almost directly above the epicentral area, the island received tsunami warnings about five minutes after the earthquake, about the best warning time possible with present technology. Fortunately, casualties were limited because people fled to evacuation sites on higher ground immediately after feeling the earthquake without waiting for an official warning. Public information and training programs were effective in reducing losses from this event.

Tsunamis from Distant Sources

Tsunamis from distant sources are the most common type observed along the Pacific Coast of the United States. Large tsunamis generated anywhere around the Pacific "Ring of Fire" propagate across the ocean with little energy loss before striking populated U.S. coastlines. The Pacific states may suffer both regional and Pacific-wide tsunamis. By definition, regional tsunamis affect smaller areas than Pacific-wide tsunamis, either because the energy released is of insufficient magnitude for Pacific-wide propagation or because the geographical configuration of the source area restricts the tsunami's spread. The combined impacts of the earthquake and regional tsunami that originated off the Philippine Islands on August 16, 1976, killed approximately 8,000 people in the affected area. Regional destructive tsunamis within the Sea of Japan in 1983 and 1993 were unable to propagate out into the larger Pacific Ocean basin.

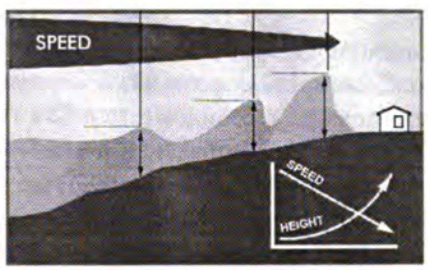
Pacific-wide tsunamis, although less frequent than regional tsunamis, have greater destructive potential because the waves are larger, travel farther, and affect broader coastal areas. The time required for a distant tsunami to reach the Hawaiian and mainland coasts will vary between approximately 5½ to 18 hours, depending upon the tsunami's place of origin. The effects of a distant tsunami on a coastal area may be negligible or severe depending upon the magnitude of the tsunami, its source distance, and its direction of approach. For example, the tsunami generated by the May 22, 1960, Chile earthquake spread death and destruction across the Pacific Ocean from Chile to Hawaii, Japan, and the Philippines. The coastal and offshore source zone measured about 135,000 square miles (approximately 218 miles by 622 miles), nearly the same area as the state of California. The length of the fault rupture may have reached 750 miles. As a result, over 2,000 fatalities occurred in Chile, due mostly to the tsunami. Losses also were severe in Hilo, Hawaii (61 fatalities and 282 serious injuries), and in Japan (122 fatalities). In contrast, Kodiak Island, Alaska, noted less than one meter rise in the water level, and losses in California were mainly in harbors where strong currents smashed, sank, or grounded small craft, and damaged dock facilities.

Tsunamis generated by the March 28, 1964, Alaskan earthquake caused both distant and local impacts, including losses in all five Pacific states, as well as other Pacific Rim countries. Alaska suffered 106 fatalities and over $84 million in damage, but in Hawaii, compared to the 1960 Chilean event, damage was minimal. In contrast, Crescent City, California, suffered ten fatalities and over $7 million in damage, and Kodiak Island, Alaska—one of several Alaskan cities and communities to suffer losses—experienced land subsidence of about 6.5 feet followed by ten waves that contributed to the destruction of about 80 percent of the industrial and commercial areas and killed 15 people. Kodiak's bedrock location limited earthquake shaking damage to only minor losses. Valdez, Alaska, experienced submarine landslides and local tsunamis where the highest wave reached 23 feet, destroying much of the town. Consequently, Valdez was rebuilt at a higher elevation to minimize future tsunami damage. Seward, Alaska, experienced tsunamis 30 to 40 feet high due to both fault rupture and local submarine landslides, causing extensive damage to the docking areas and fires in petroleum storage facilities.

Tsunami Characteristics

Tsunamis travel outward from the source area and may be highly directional. For example, for an earthquake-generated tsunami, most of the energy propagates at right angles away from the long axis of the source fault rupture. The wave speed depends on the water depth, undergoing accelerations and decelerations as the ocean bottom depth varies. Such wave speed changes cause the wavefronts to bend (refract), creating area where the energy is focused (wave height increases) and defocused (wave height decreases). In the open ocean, wave speeds may reach 500 miles per hour (800 kilometers per hour)—as fast as a jet airplane—with the distance between successive crests (wavelength) often exceeding 100 miles. Wave heights in deep water may be only a few feet high, and due to their long wavelength, produce only a gentle rise and fall of the sea surface that is usually unnoticed.

As a tsunami enters the shoaling waters near the coast, its wave speed diminishes, its wavelength decreases, and its height increases, often greatly. The first wave may not be the largest, with the initial wave typically being followed by several larger and more destructive waves. Even though the waves slow upon reaching the coastline, they still travel faster than Olympic long-distance runners—faster than 15 miles per hour.



As a tsunami approaches shore, it slows down and dramatically increases in height.

The configuration of the coastline, the shape of the ocean floor, and the characteristics of the advancing waves play important roles in the potential for destruction. For islands, no matter from which direction the tsunami arrives, all sides usually will be affected. As the wave wraps around the island, the height or run-up may be small at many points along the coast, but increases greatly where the two opposing wavefronts meet on the backside of the island. Focusing effects due to the wavefront bending on irregular coasts may also result in locally high wave amplification. Bays, sounds, inlets, rivers, streams, offshore canyons, islands, and flood control channels may cause various effects and result in greater damage than many people would expect. It has been estimated, for example, that a tsunami wave entering a Southern California flood control channel could reach a mile or more inland, especially if it enters at high tide. Offshore canyons can focus tsunami wave energy and islands can filter the energy. The orientation of the coastline determines if the waves strike head-on or are refracted from other parts of the coastline.

Unlike earthquake shaking where damage may occur over large areas in the source region—hundreds of square miles in many cases—tsunamis impact long, low-lying stretches of linear coastline, extending inland for relatively short distances. After striking a coast, the wave reflects back to sea, but may also be reflected back to the coast again and again from offshore islands or submerged ridges, banks, and shelves, as a series of waves.

Rather than rising water, the first visible indication of an approaching tsunami could be receding water (drawdown) caused by the wave trough preceding a large inbound wave crest. Rapid drawdown creates strong currents in harbor inlets and channels that can damage coastal structures due to erosive scour, such as around piers and pilings. As the water's surface drops, piers can be damaged by boats or ships straining at or breaking their mooring lines. The vessels can overturn or sink due to strong currents, collision with other objects, or impact with the harbor bottom.

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

Moreover, under certain conditions the crest of an advancing wave may overtake the preceding trough while some distance offshore, causing the wave to proceed shoreward as a "bore" with a churning front. The bore phenomenon resembles a step-like rise in the sea level that advances rapidly (from 10 to 60 miles per hour). Normal tidal bores at the Bay of Fundy, Canada, or the Yellow River, China, provide examples of this phenomenon.

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

FACTORS UNIQUE TO TSUNAMI RISK MANAGEMENT

Coastlines have always been a favored location for human settlements. Attractive coastal locations and a growing affluent population have combined to increase development of housing, maritime facilities, and resorts in coastal communities in recent times. Long gaps between devastating tsunami events (and apparent disregard of more frequent hazards such as strong storms, sea level changes, and coastal erosion) have produced a coastal population that seems to ignore the destructive tsunamì threat. According to one recent estimate, 489 cities in Alaska, California, Hawaii, Oregon, and Washington are susceptible to tsunami inundation, with an estimated 900,000 people living or working within areas that could be inundated by a 50-foot tsunami.

Table 1-1.
Potential Destructiveness of Tsunamis in the Five Pacific States

State	Cities susceptible to tsunamis	Population endangered by a 50-foot tsunami
Washington	102	96,000
Oregon	60	31,500
California	152	589,500
Hawaii	123	131,000
Alaska	52	47,000
Total	**489**	**895,000**
Source: TsuInfo Alert, v.2, no. 2, March-April 2000. Terry Wallace, University of Arizona, Department of Geosciences.		

Mainland coastal states and Hawaii have several unique factors that affect the siting of development and design of buildings. Recently prepared maps for several locations show potential tsunami inundation areas along different types of coastlines. Important factors affecting tsunami exposure include:

- All or parts of the mainland states are located near active subduction zones (Cascadia and Alaska-Aleutian) or other well-defined tsunami-producing zones. Local tsunamis generated by these zones will reach the coasts extremely quickly (within 5-30 minutes, depending on the distance to the zones).

- Strong earthquakes, whether accompanied by tsunamis or not, are rare events in most low-lying coastal communities. With little strong groundshaking experience, these communities have little awareness of earthquake hazards. Yet even with minimal earthquake activity, the risk of damage from a major tsunami is considered high for these communities.

- Except in Hawaii and a few mainland coastal communities, tsunami awareness is not currently embedded in coastal community "culture."

- Coastal communities vary in size, but with some notable exceptions, such as Los Angeles, Honolulu, Santa Barbara, San Francisco, and San Diego, most communities are relatively small.

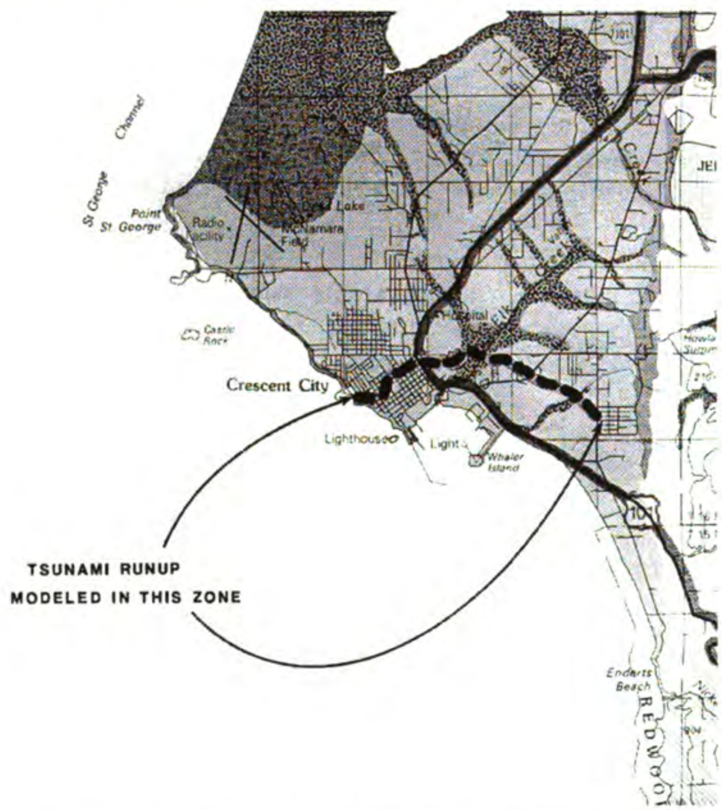
- Many coastal communities are largely recreational, having many short-term and seasonal visitors. This presents a special problem as losses could be very high if a destructive tsunami occurred at a seasonal peak population time.

Case Study: Planning Scenario For Humboldt and Del Norte Counties

In 1995, the California Division of Mines and Geology published Special Publication 115, entitled *Planning Scenario in Humboldt and Del Norte Counties, California for a Great Earthquake on the Cascadia Subduction Zone*. This report includes a description with supporting maps of the potential effects of a tsunami on the cities of Eureka (Humboldt County) and Crescent City (Del Norte County). This report is an example of how local hazard and risk information can be used to support mitigation efforts.

The scenario earthquake generates a local tsunami that arrives minutes after the earthquake mainshock. The maps depict potential structure and infrastructure damage and show locations likely to be flooded by a tsunami caused by a potential great earthquake (magnitude 8.4) occurring offshore on the Gorda segment of the Cascadia Subduction Zone.

The planning scenario includes damage probability and assessments for a variety of facilities, infrastructure, and services including: schools and colleges, hospitals, highways, airports, marine facilities, railroads, and facilities for electric power, natural gas, petroleum products, water supply, and wastewater. These assessments are intended to assist localities in planning for emergency response efforts and pre-disaster retrofitting and other risk mitigation efforts.



Excerpt from Scenario Map for Humboldt and Del Norte Counties.

Collateral Hazards and Compound Disasters

When considering the impacts of natural hazards on existing and future development, it is important to understand that, depending on the triggering event, many other problems may result. For example, earthquakes that generate local tsunamis also cause damage from strong shaking and secondary hazards such as ground failures from liquefaction and landsliding in the nearby coastal areas. Therefore, in developing mitigation programs it is important that all relevant hazards be considered, including the potential for their interactions to have combined effects on the area.

Insofar as tsunamis are concerned, onshore groundshaking and ground failures accompanying earthquake-generated local tsunamis may increase community vulnerability to the damage run-up area and make evacuation difficult. While perhaps unlikely coincidences, storm surges or outflows from rivers and streams during the rainy season could, depending on local circumstances, also increase inundation of higher elevation areas and the extent of tsunami damage due to higher water levels.

Also of concern are secondary emergencies that could be created by the initial disaster event, such as fires or spills at facilities that store or use hazardous materials. While not all variables can be controlled through mitigation programs, it is important to consider how various hazard-specific mitigation measures might be combined to help avoid compound disasters, such as properly bracing an elevated home that sits in a tsunami flood zone and is also subject to strong earthquake ground motion.

For local tsunamis, like Cascadia Subduction Zone events, liquefaction (the loss of strength and the settling or spreading of wet soft soil areas) and slope failures triggered by the earthquake are real possibilities. The combination of earthquake shaking and tsunami inundation and withdrawal may result in the loss of electricity, communications, potable water, wastewater, and natural gas services. Damage to local transportation systems, such as roadways, causeways, and bridge approaches, further adds to response problems by isolating barrier islands and peninsulas, and by making evacuation and search and rescue operations more difficult. In addition to tsunami-borne projectiles such as boats, shipping containers, logs, floating automobiles, and other materials, debris from earthquake-damaged buildings and coastal structures can increase damages.

Fires caused by ruptured fuel tanks and gas lines can be spread quickly by the tsunami inundation, as can spilled toxic materials. A unique characteristic of tsunami damage is the churning up and spreading of industrial and domestic wastes deposited for generations on the seafloor. While the highly regulated earthquake-resistant design of nuclear power plants far exceeds that required of new buildings, nuclear power plants located on the coast must be designed to prevent tsunami damage.

THINKING ABOUT MANAGING THE RISK TO YOUR COMMUNITY

Mitigating the risk from natural hazards can draw on a wide range of activities that have one overriding goal: to lessen future losses from natural hazard events. The Federal Emergency Management Agency (FEMA) defines "hazard mitigation" as "sustained action taken to reduce or eliminate long-term risk to people and property from hazards and their effects. In the context of coastal...construction, mitigation usually takes the form of siting, design, construction of the building...and (sometimes) the form of protective works..." (FEMA, 1999, 4-4)

As with other natural hazards, it is important to distinguish between the terms used in this field. Hazard is generally defined as the existence of a possible source of danger, such as a tsunami, that is capable of occurring at various places and times. FEMA, in the same 1999 publication, offers the following definitions:

> **Hazard Identification** means the process of defining and describing a hazard (including its physical characteristics, magnitude, severity, frequency, and causative factors) and the locations or areas it affects.
>
> **Risk** means the potential losses associated with a hazard, defined in terms of expected probability and frequency, exposure, and consequences.
>
> **Risk Assessment** means a process or method for evaluating risk that is associated with a specific hazard and defined in terms of probability and frequency of occurrence, magnitude and severity, exposure, and consequences.
>
> **Risk Management** means measures taken to reduce, modify, offset, or share risks associated with development in areas subject to...hazards. (FEMA, 1999, 4-4)

While the concept of mitigation is simple, there are many complex issues involved in achieving effective mitigation. Mitigation actions involve public policy, intergovernmental relations, public-private partnerships, economics, acceptable risk, and a wide range of specialized activities and programs. In all cases, mitigation programs and procedures are based on understanding the nature and probable severity of the hazard and the vulnerability of the area. Vulnerability assessments describe the weaknesses of buildings, systems and communities that make them susceptible to damage from the hazards.

Not all areas share the same hazard, vulnerability, and exposure. In general, a greater hazard justifies more rigorous mitigation measures. The key question becomes "How severe a problem are we dealing with in each community?" The answers to this question provide the basis for making public safety policy choices.

As with many natural hazards, exact probabilities or return intervals are extremely difficult to define, but two comparisons are instructive. First, California's building designs have been based on earthquakes expected to occur once every 475 years with the intent that collapse will not occur. In the Midwest, designs are based on avoiding collapse in earthquakes occurring once in 2,500 years. Second, flood loss prevention policies deal with events expected to occur every 100 to 500 years. While Hilo, Hawaii, has experienced numerous tsunamis, and Crescent City, California, experienced two damaging tsunamis in four years (1960 and 1964), many communities at risk have little or no recent history with tsunami damage.

Where development has not yet occured, one mitigation action is to avoid the hazard. This takes a combination of knowledge and a willingness by decisionmakers to set aside such areas and define them as unacceptable risks. Where development already exists or is virtually certain to occur, two fundamental strategies are available to help ensure that the potential effects of natural hazards are considered during the planning process. Although oversimplified, these two approaches are: 1) managing the hazard; and 2) managing the development. For example, managing the hazard by improving drainage can help control small-scale flooding and keep developed areas dry. Managing the development, for example, by avoiding constructing improvements in high-velocity floodplains and landslide-prone hillsides may be more effective and less environmentally disruptive than building expensive structures to control flooding or landslides.

Although probabilities of occurrence may be extremely difficult to establish for tsunamis, using an approach similar to the application of probabilities to other hazards may be helpful. For example, a possible approach for tsunami mitigation is to prevent development or limit it to coastal-dependent facilities designed to the expected tsunami forces where tsunamis are expected once in every 100 years. Near-shore rapid-onset events (locally-generated tsunamis) could be subject to similar controls where tsunamis are expected once in every 500 years. In areas likely to experience tsunamis once in every 2,500 years, at least adequate evacuation precautions should exist, such as designing for vertical evacuation, designating "safe buildings," and maintaining effective plans for horizontal evacuation from low-lying to higher ground areas. This is especially true for areas with large resident or visitor coastal populations "at risk," such as beach communities.

Land use and mitigation actions taken for other reasons may also help limit tsunami damage. For example, preventing construction in floodplains, because of their highly saturated soils and low elevations, could reduce losses from tsunami inundation and earthquake groundshaking. Low density uses, such as parkways or protected habitat areas, could also help mitigate tsunami losses. For example, Hilo, Hawaii, and Crescent City, California, have large parks adjacent to their coastal areas. In Hilo, the park helped to significantly prevent greater losses from the March 28, 1964, tsunami generated by the Alaska Earthquake. Crescent City's park was created after the 1964 tsunami (although it existed as a broad beach previously). Buildings can be located, designed, and built to withstand tsunami inundation and serve as "vertical" evacuation centers. All of these subjects are discussed in other background papers.

APPENDIX 1-1:
SUGGESTED CONTENTS OF A TSUNAMI HAZARD STUDY

Objective: To define tsunami intensity and frequency in terms useful to comprehensive planning, regulatory, and design decisions. This information should establish the importance and describe the consequences of the hazard, and be useful for evaluating mitigating options and analyzing vulnerability of building and other facilities. It needs to provide a sound basis for planning and regulatory findings and for design criteria for structures located in the hazard zone. The information would be used for evacuation by defining likely time to evacuate and designations, and, if vertical evacuation is necessary, to evaluate the vulnerability of shelter buildings.

1. Description of potential sources and historical records affecting the site;
2. Description of the potential for subsidence and uplift of the area;
3. Elevation of wave at the beach above mean sea level (+/- 1 sigma range). The height of the breaking wave;
4. Drawdown elevation (give a +/- 1 sigma range);
5. Inundation depth (< 3 feet, 3 to 10 feet, > 10 feet) and limits of run-up at various points;
6. Current velocity for run-up and drawdown and bore potential at various locations;
7. Areas of expected erosion (e.g., current velocity > x feet per second and location of wave break);
8. Debris load estimates for typical pre-tsunami conditions and during an event:
   None—Debris unlikely, inundation < 3 feet, low velocity currents;
   Low—Little potential for debris, low velocity currents and inundation depth < 3 feet;
   Moderate —Moderate potential for amount and size of debris, moderate velocity currents and inundation depth (3 to 10 feet);
   Severe—High potential for a large amount and size of debris, high velocity currents, inundation depth >10 feet;
9. Potential for entrained and tossed stones in the wave break;
10. Time between event initiation and arrival at the site;
11. Number of waves or time span of event;
12. Probability of occurrence:
    Occasional—50 percent chance of exceedance in 50 years (1/72 years);
    Rare—10 percent chance of exceedance in 50 years (1/475 years);
    Very Rare—2 percent chance of exceedance in 50 years (1/2,500 years);
    Maximum Considered Event—Worst case possible under consideration (1/2,500-5,000 years);
13. Level of certainty:
    Low—Based on the opinion of a tsunami specialist after a site reconnaissance, review of published hydrographic and topographic maps, and review of written and paleoseismological history;
    Moderate—Based on the above factors plus modeling of waves from a variety of source zones;
    High—Based on the above plus probability of events calculated by combining individual events andrun-up and drawdown model.

BACKGROUND PAPER #2: LOCAL, STATE, AND FEDERAL FRAMEWORK FOR LAND USE PLANNING AND COASTAL DEVELOPMENT

INTRODUCTION

This background paper describes the local, state, and federal framework for land use planning and coastal development in the five Pacific states. For each state the paper summarizes the basic legal structure of state and local planning, with particular regard to seismic safety and tsunami hazards.

The paper starts with a summary of federal policies and requirements, including the Coastal Zone Management Program, the Coastal Zone Enhancement Program, and the National Flood Insurance Program (NFIP). The paper then discusses land use planning requirements for the five Pacific states, including state requirements for local comprehensive plans, local development regulations, and local zoning ordinances; state requirements for local building codes; and state coastal management policies.

KEY CONCEPTS AND FINDINGS

The following is a summary of the land use planning and development regulations in the five Pacific states:

- All five Pacific states require local land use planning, and all except Alaska have statewide planning guidelines. Alaska has statewide planning guidelines for coastal resource districts.

- Oregon and Washington require local plans to be consistent with statewide planning goals. California and Hawaii have statewide planning guidelines that are advisory only. Alaska requires a consistency review of coastal resource district plans with statewide standards and with other districts' plans.

- California, Oregon, and Washington require hazard mitigation as part of their general land use planning process. Alaska requires it for coastal resource district plans only. Hawaii only suggests that this topic be addressed.

- Three of five Pacific states require conformance with a state model building code based on the Uniform Building Code (UBC). Alaska only mandates adoption of a fire code and Hawaii does not have a state-mandated building code. All of the counties in Hawaii and the larger cities in Alaska have adopted a version of the UBC. Codes and standards are discussed in more depth in Background Paper #5, *Building Design*.

OVERVIEW OF FEDERAL POLICIES AND REQUIREMENTS

While the federal government has supported state and local planning through numerous programs over the years, there are no federal requirements for statewide or local land use planning. There are, however, federal programs that have implications for land use planning in coastal areas.

In 1972, Congress passed the Coastal Zone Management Act (CZMA) to promote the orderly development and protection of the country's coastal resources. The CZMA established a voluntary partnership among the federal government, coastal states, and local governments to develop individual state programs for managing coastal resources.

The national system for the management of the nation's coastal and ocean resources, put into place by the CZMA, has federal and state components. The federal component is located within the Office of Ocean and Coastal Resource Management (OCRM), which is part of the U.S. Department of Commerce's National Oceanic and Atmospheric Administration (NOAA). The state component consists of federally-approved coastal management programs (CMPs) in 32 coastal states and territories. The National Coastal Zone Management (CZM) Program is authorized by the CZMA to:

- Preserve, protect, develop, and where possible, restore and enhance the resources of the coastal zone;

- Encourage and assist the states to exercise effectively their responsibilities in the coastal zone to achieve appropriate use of land and water resources of the coastal zone, giving full consideration to ecological, cultural, historic, and aesthetic values as well as the need for compatible economic development;

- Encourage the preparation of special area management plans to provide increased specificity in protecting significant natural resources, reasonable coastal-dependent economic growth, improved protection of life and property in hazardous areas, and improved predictability in governmental decisionmaking; and

- Encourage the participation, cooperation, and coordination of the public, federal, state, local, interstate and regional agencies, and governments affecting the coastal zone.

Since 1974, with the approval of the first state Coastal Management Program (CMP) in the state of Washington, a total of 28 coastal states and five island territories have developed CMPs. Together these programs protect more than 99 percent of the nation's 95,439 miles of oceanic and Great Lakes coastline. CMPs are expected to consider or undertake the following:

- Protection of natural resources;
- Manage development in high hazard areas;
- Manage development to achieve quality coastal waters;
- Give development priority to coastal-dependent uses;
- Have orderly processes for the siting of major facilities;

- Locate new commercial and industrial development in or adjacent to existing developed areas;
- Provide public access for recreation;
- Redevelop urban waterfronts and ports, and preserve and restore historic, cultural, and aesthetic coastal features;
- Simplify and expedite governmental decisionmaking actions;
- Coordinate state and federal actions;
- Give adequate consideration to the views of federal agencies;
- Assure that the public and local government has a say in coastal decisionmaking; and
- Comprehensively plan for and manage living marine resources.

In 1990, to meet mounting public concern for the well-being of the nation's coastal resources, the Congress created the Coastal Zone Enhancement Program, a new program under the Coastal Zone Management Act. The Coastal Zone Enhancement Program provides incentives for states and territories to make changes in any of eight areas of national significance. They are:

- Wetlands protection;
- Coastal hazards;
- Cumulative and secondary impacts of development;
- Public access to the coast;
- Special area management planning;
- Ocean governance;
- Marine debris; and
- Government and energy facility siting.

The National Flood Insurance Program (NFIP) established in 1968 and amended by the Flood Disaster Protection Act of 1973 and Title V (National Flood Insurance Reform Act) of the Reigle Community Development and Regulatory Improvement Act of 1994, is part of a comprehensive approach to reduce flood damage and to cope with the disastrous effect of floods. The NFIP is administered by the Federal Insurance Administration (FIA), a component of the Federal Emergency Management Agency (FEMA). The NFIP makes federally-backed flood insurance available in communities that adopt and enforce floodplain management ordinances to reduce future flood losses.

The NFIP consists of two essential components:

1) Management guidelines for new development and major changes to existing development in Special Flood Hazard Area (SFHAs); and

2) Insurance to cover the risks of existing construction.

The Special Flood Hazard Area (SFHA) is the land in the floodplain that has a one percent or greater chance of flooding in any given year. The purpose of the management component is to minimize the potential for flood damage by controlling reconstruction and/or development in SFHAs. To accomplish this, communities are required to adopt and administer regulations for the efficient and effective use of SFHAs and for the control, location, and design of structures in order to minimize damage by flooding. The community can protect residents against disasters and avoid and/or minimize the disruption of public services. Communities are encouraged to plan and achieve a development pattern that:

- Avoids damage-prone uses in floodplains;
- Reduces development pressure in flood hazard areas; and
- Encourages compatible uses.

The role of the FIA in hazard mitigation is to identify the 100-year hazard areas, including the elevation of flooding above sea level and ensure that the regulations of participating communities comply with the NFIP floodplain management requirements. The NFIP defines specific regulatory standards that local communities are required to meet to participate in the program. This "standards" approach is much more specific than the "goals" approach of the CZM Program and requires, for example, that communities regulate structural design standards. FIA studies conducted in the 1970s identified only the threat from distant tsunamis.

Floodplain management means a comprehensive community program of corrective and preventive measures for reducing future flood damage. These measures may take a number of forms, but typically include improved building codes and subdivision regulations, as well as zoning, drainage provisions, and other special-purpose floodplain ordinances. The cumulative effect of these measures and ordinances is the construction of new structures that are better protected from the affects of flooding, whether it be tidal or inland.

There are several SFHA zones that apply specifically to coastal areas:

- Zone V: SFHAs along coasts subject to inundation by the 100-year flood with the additional hazards associated with storm waves. Because detailed hydraulic analyses have not been performed, no base flood elevations or depths are shown. Mandatory flood insurance purchase requirements apply.

- Zones VE and V1-30: SFHAs along coasts subject to inundation by the 100-year flood with additional hazards due to velocity (wave action). Base flood elevations derived from detailed hydraulic analyses are shown within these zones. Mandatory flood insurance purchase requirements apply. (Zone VE is used on new and revised maps in place of Zones V1-30.)

FEMA's V Zone mapping does not examine tsunami hazards and only accounts for tsunamis coincidentally where coastal flood areas overlap tsunami hazard areas.

Wave generated by the 1946 tsunami in the Keaukaha area of Hilo, Hawaii.
Credit: Pacific Tsunami Museum

STATE POLICIES, REQUIREMENTS, AND PROGRAMS

All five Pacific states require local land use planning, and all except Alaska have statewide planning guidelines (Alaska has statewide planning guidelines for coastal resource districts only).

Building construction in the United States is governed at the local level by building codes. Building codes establish minimum acceptable requirements for protecting life, addressing property damage, and preserving the public health, safety, and welfare in the built environment. The local building codes used in the states bordering the Pacific Ocean are modified or unmodified versions of the Uniform Building Code (UBC) prepared by the International Conference of Building Officials. Three of the five Pacific states require adoption and enforcement of the statewide building code at the local level.

The following is an overview of the land use planning, building code, and coastal management policies of the five Pacific states: Alaska, California, Hawaii, Oregon, and Washington.

Alaska

Local Comprehensive Plan

Title 29 of Alaska Statutes (Municipal Government) requires all first or second class boroughs in Alaska to "provide for planning, platting, and land use regulation on an areawide basis" (Sec. 29.40.010). Areas of the state that are not within the boundaries of an organized borough constitute a single unorganized borough. The Department of Natural Resources is the platting authority for the state except within a municipality that has the power of land use regulation and that is exercising its platting authority.

Each first and second class borough is also required to establish a planning commission by ordinance. The planning commission is required by state law to prepare and submit to the borough assembly a proposed comprehensive plan for the systematic and organized development of the borough. The commissions also review, recommend, and administer measures necessary to implement the comprehensive plan.

The comprehensive plan "is a compilation of policy statements, goals, standards, and maps for guiding the physical, social, and economic development, both private and public, of the first or second class borough, and may include, but is not limited to, the following:

- Statements of policies, goals, and standards;
- A land use plan;
- A community facilities plan;
- A transportation plan; and
- Recommendations for implementation of the comprehensive plan." (Sec. 29.40.030).

The State of Alaska specifies the elements of land use plans for coastal resource (coastal plans), and requires a hazard mitigation element for these plans.

Local Development Regulations/Programs

Alaskan communities must have an adopted comprehensive plan before they may adopt land use regulations such as a zoning ordinance. Section 29.40.040 states that, in order to implement a comprehensive plan, "the assembly by ordinance shall adopt or amend provisions governing the use and occupancy of land that may include, but are not limited to:

- Zoning regulations restricting the use of land and improvements by geographic districts;
- Land use permit requirements designed to encourage or discourage specified uses and construction of specified structures, or to minimize unfavorable effects of uses and the construction of structures; and
- Measures to further the goals and objectives of the comprehensive pl an."

The Alaska State Code, based on the fire code provisions of the 1997 Uniform Building Code (UBC), applies to all types of structures in the state, except for residential structures. State law allows for some modifications at the city/county level based on unique local conditions. All of the larger cities in Alaska have adopted a version of the UBC.

State Coastal Policies

The Alaska Coastal Management Program (ACMP) implements the Alaska Coastal Management Act passed by the State of Alaska in 1977. The ACMP was designed to respond to the federal Coastal Zone Management Act (CZMA). The Alaska Division of Governmental Coordination (DGC) in the Office of the Governor is the lead agency responsible for the overall administration and operation of the ACMP.

The ACMP is intended to improve stewardship of Alaska's coastal land and water uses, and natural resources, by creating a network of local, state, federal, and applicant interests in the project approval process. While the program is coordinated at the state level, coastal districts develop locally-specific program standards that are incorporated into the state program and used for project reviews. The Coastal Policy Council, which provides general program oversight, brings together representatives from 17 state agencies and includes nine members representing local governments.

The ACMP requires that projects in Alaska's coastal zone be reviewed by coastal resource management professionals and found consistent with the statewide standards of the ACMP in a "consistency review process."

The ACMP applies to projects within or affecting Alaska's coastal zone. Alaska's coastal zone boundaries include the coastline proper and can extend inland along river drainages as far as 250 miles. The statewide standards (6 AAC 80) and coastal district enforceable policies of the ACMP provide direction for coastal resources and uses, such as:

- Coastal development (whether a project is water-dependent or water-related);
- Habitats (such as wetlands, tideflats, or streams);
- Air, land, and water quality;
- Transportation and utility routes and facilities;
- Timber harvest;
- Mining and mineral processing;
- Subsistence opportunities;
- Recreation designations;
- Geophysical hazard areas (defined as "those areas which present a threat to life or property from geophysical or geological hazards, including flooding, tsunami run-up, storm surge run-up, landslides, snowslides, faults, ice hazards, erosion, and littoral beach process" (6 AAC 80.900(a)(9));
- Historical and archaeological resources;
- Energy facilities; and
- Fish and seafood processing.

Using the statewide standards and local enforceable policies, the ACMP evaluates the effects a project will have on the above coastal resources and uses. A finding of consistency with the ACMP must be obtained before permits can be issued for the project.

Coastal districts are generally local governments, such as cities and boroughs, that contain a portion of Alaska's coastal area. In coastal areas outside the boundaries of local government, coastal districts known as Coastal Resource Service Areas (CRSA) may be formed. Most coastal districts develop a coastal management program that requires a rigorous state and federal approval process. A district coastal management program contains enforceable policies that guide development affecting the coastal resources within its boundaries. Once approved, a district coastal management program becomes a part of the ACMP.

State Role

While state law in Alaska requires preparation of general plans and specifies the basic content of the general plan, there are no statewide goals that general plans are required to meet.

The Coastal Management Programs of Coastal Districts are required to be reviewed and approved by the state before they become a part of the Alaska Coastal Management Program (ACMP).

The Alaska Constitution specifically provides for local self government. However, the Constitution also recognizes that many local governments in the state were not fully developed and would not have the resources to achieve strong local self-determination unless they were assisted in this effort. A large part of the state consists of the "unorganized borough" in which there is no regional form of government. The Municipal and Regional Assistance Division (MRAD) of the Department of Community and Economic Development (DCED) fulfills the mandated assistance function by offering local governments and other community entities a broad range of support for local development efforts.

MRAD's Community Planning Program provides assistance to communities on regional and community planning issues. The main areas of assistance include: Alaska Coastal Management Program implementation through local districts; National Flood Insurance Program (NFIP) administration and planning; and technical advice and training on general community and regional planning efforts.

California

Local Comprehensive Plan

In California, comprehensive plans are known as "general plans." By state law, every city and county must adopt its own general plan for long-term physical development (Government Code Section 65300 et seq.). The plan serves as the basis for all land use decisions within the jurisdiction. It is required to be comprehensive, internally consistent, and long term.

The plan is required to cover a jurisdiction's entire planning area and address the broad range of issues associated with a city's or county's development. State law requires that each general plan address at a minimum a comprehensive list of development issues falling under seven major categories or "elements": land use, circulation, housing, conservation, open space, noise, and safety.

The goal of the safety element is to reduce the potential risk of death, injuries, property damage, and the economic and social dislocation resulting from hazards such as fires, floods, earthquakes, landslides, and other hazards such as tsunamis. The safety element's identification of hazards and hazard abatement provisions are intended to guide local decisions related to zoning, subdivisions, and entitlement permits. Policies in this element are supposed to address the identification of hazards and implications for emergency response, as well as mitigation through avoidance of hazards by new projects and reduction of risk in developed areas.

Prior to preparing or revising its safety element, a city or county must consult with the Office of Emergency Services and submit one copy of its draft safety element to the Division of Mines and Geology for review (Government Code Section 65302(g)).

Local Development Regulations/Programs

State law authorizes implementation of the local general plans through zoning, subdivision procedures, preparation of specific plans, capital facility programming, redevelopment, and development agreements. Based on statutory and case law, the use of all these implementation tools must be consistent with the local general plan.

State law requires that all cities and counties adopt building codes that are consistent with state-adopted model codes (as of July 1, 1999, based on the 1997 Uniform Building Code (UBC)). State law provides for State modification of the model codes and allows for some variations at the city/county level based on unique local conditions.

State Coastal Policies

The California Coastal Management Program (CCMP) was designed to respond to the federal Coastal Zone Management Act (CZMA) and was certified by the federal government in 1978. The enforceable policies of that document are contained in Chapter 3 of the California Coastal Act of 1976 (Public Resources Code Section 30000 et seq.). The California Coastal Commission is the lead agency responsible for the overall administration and operation of the CCMP.

Coastal cities and counties are subject to both the Planning and Zoning Law (as described above) and the California Coastal Act. The California Coastal Act applies to the coastal zone, a strip along the California coast generally "extending seaward to the state's outer limit of jurisdiction, including all offshore islands, and extending inland generally 1,000 yards from the mean high tide line of the sea." (Public Resources Code Section 30103)

Each city or county lying wholly or partly within the coastal zone must prepare a Local Coastal Plan (LCP) for that part of its jurisdiction within the zone or request that the Coastal Commission prepare an LCP for them. An LCP consists of a coastal land use plan (i.e., portions of a city's or county's general plan), zoning ordinance, zoning district maps, and where required, other programs necessary to implement the Coastal Act. In addition, it must contain a specific public access component to assure that maximum public access to the coast and public recreation areas is provided.

While the Coastal Act provides that the content of each LCP is to be determined by the local government in full consultation with the Commission and with full public participation, the LCP must address a list of policies that can be grouped under the following seven headings: access, recreational and visitor-serving uses, marine resources, agriculture, new development, public works, and coastal-dependent industrial development. The contents of coastal land use plans overlap most of the required content of general plans, and, for this reason, many local governments have integrated their coastal land use plans in their general plans. The specific contents of local coastal plans (LCPs) are not specified by state law. However, LCPs must be certified by the Coastal Commission as consistent with policies of the Coastal Act. It should be noted that since tsunami hazard areas can and do exceed the boundaries of the Coastal Zone, LCP policies cannot be relied upon exclusively to mitigate the tsunami risk.

The Coastal Act (Public Resources Code, Division 20) has provisions relating to geologic hazards, but does not mention tsunamis specifically. Section 30253(1) states that "new development shall minimize risks to life and property in areas of high geologic, flood, and fire hazard." Section 30610.1(c)(3) states that coastal development permits shall be required for the construction of single-family residences on vacant lots that are "located within an area known to the affected local government, or designated by any other public agency, as a geologic hazard area or as a flood hazard area...", unless it has been "determined by the affected local government to be a safe site for the construction of a single-family residence."

The 1965 McAteer-Petris Act established the San Francisco Bay Conservation and Development Commission (BCDC) as a state agency. The San Francisco Bay Plan, completed in 1969 and subsequently incorporated into state law, includes policies on 18 issues critical to the use of the Bay ranging from ports and public access to design considerations and weather. The 1969 revisions to the Act further specified that the San Francisco Bay Conservation and Development Commission is the permanent agency responsible for maintaining the Bay Plan and carrying out the provisions of the law. Over the years, the Commission has adopted a number of amendments to the Bay Plan, and the Legislature has amended the McAteer-Petris Act several times.

State Role

While State law requires the preparation of general plans and specifies the basic content of the general plan (including the required elements), there is no state land use plan or set of statewide goals or policies that general plans are required to meet. The Governor's Office of Planning and Research publishes the *General Plan Guidelines*, but these are advisory only.

The specific contents of Local Coastal Plans (LCPs) are not specified by state law either. However, LCPs must be certified by the Coastal Commission as consistent policies of the Coastal Act. In practice, the Coastal Commission has been very aggressive in ensuring conformance with Coastal Act policies.

The Seismic Hazards Mapping Act directs the State Geologist to compile maps identifying seismic hazards for use by local governments. The Act does not require the State Geologist to prepare maps for tsunamis or seiche hazards unless there is supplemental funding. The State Geologist, however, can adopt tsunami and seiche hazard maps prepared by other agencies. The State hazards maps are to be used in preparing local general plans and trigger requirements for geotechnical reports in connection with local government review and approval of individual project proposals.

Hawaii

Local Comprehensive Plan

Hawaii's Land Use Law, passed in 1961, provides for the regulation of land use and development throughout the state. The Land Use Commission establishes boundaries for districting of all lands and serves as a quasi-judicial body in administering the land use law. The Land Use Law established four State Land Use Districts that are applied to all land in the state:

urban, agricultural, conservation, and rural. State law defines the standards for determining the boundaries of these districts and the permissible uses in these districts.

The State Planning Act (Hawaii Revised Statutes, Chapter 226), passed in 1978, was designed to improve the statewide planning process, improve coordination among different agencies and levels of government, and provide guidelines for future development. It provides overall goals, objectives, and policies to serve as guidelines for decisionmaking about future long-range development at the state and local level. The Hawaii State Plan is the long-range comprehensive plan. It includes the overall theme, goals, objectives, policies, priority guidelines, and implementation mechanisms established under the State Planning Act.

The Hawaii State Plan's section on air and water quality objectives and policies includes the following policy: "Reduce the threat to life and property from erosion, flooding, tsunamis, hurricanes, earthquakes, volcanic eruptions, and other natural or man-induced hazards and disasters." The State of Hawaii suggests, but does not require, that a hazard mitigation element be included in the required local comprehensive plans.

Local Development Regulations/Programs

Hawaii Revised Statutes (HRS) 46-4 mandate that zoning in all counties shall be accomplished within the framework of a long-range comprehensive general plan. Zoning is one of the primary tools available to the county governments to put the general plan into effect.

Hawaii does not have a state-mandated building code. However, all four county governments in Hawaii have adopted the 1991 Uniform Building Code (UBC), and are considering adopting the 1997 edition.

State Coastal Policies

The Hawaii Coastal Zone Management (CZM) Program (Chapter 205A, HRS) was promulgated in 1977 in response to the federal Coastal Zone Management Act (CZMA). The program includes the following policy areas: historical resources; recreational resources; scenic and open space resources; coastal ecosystems; economic uses; coastal hazards (including tsunamis); managing development; public participation; beach protection; and marine resources. The Department of Business, Economic Development, and Tourism is the lead agency responsible for the overall administration and operation of the Hawaii CZM Program.

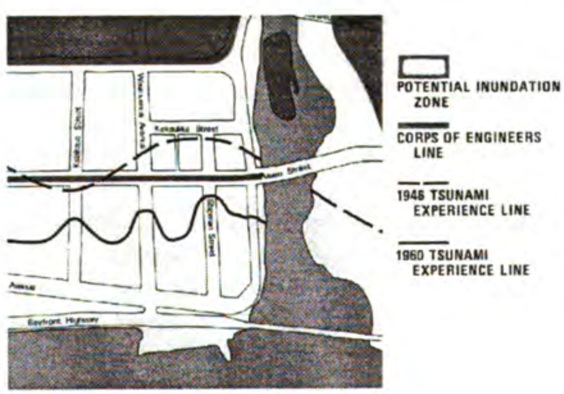
Other key areas of the CZM Program include: a permit system to control development within a Special Management Area (SMA) managed by the counties and the Office of Planning, and a Shoreline Setback Area which serves as a buffer against coastal hazards and erosion, and protects viewsheds. A major objective of the CZM Program is to reduce hazard to life and property from tsunamis, storm waves, stream flooding, erosion, and subsidence.

The Special Management Area (SMA) and Shoreline Setback Area are designated for more intensive management by the four counties. The SMA originally encompassed all lands extending not less than 100 yards inland from the shoreline. In some areas, the SMAs extend several miles inland to cover areas in which coastal resources are likely to be directly affected by development activities, such as Kawainui Marsh on Oahu and Waipio Valley on Hawaii. Counties may amend their boundaries to achieve the CZM objectives and policies. Amendments removing areas from an SMA are subject to state review for compliance with the coastal law.

No development can occur in the SMA unless the appropriate county (or for developments in the Community Development Districts, the Office of Planning) first issues a permit. Development is defined to include most uses, activities, and operations on land and in the water.

Since 1992, the CZM Program has commissioned a number of studies in support of hazard mitigation. The CZM Program supported two phases of a coastal hazard mapping project. These studies resulted in the Atlas of Natural Hazards in the Hawaiian Coastal Zone. The Atlas identifies and ranks the severity of a range of coastal hazards for the coastline of the main Hawaiian Islands, including tsunami, stream flooding, high waves, storms, erosion, sea level rise, and volcanic and seismic hazards. The Atlas does not define the inland boundary of the hazards. However, it is intended as a tool for planners, developers, and regulators in determining if a particular hazard needs to be assessed in planning development and reviewing permit applications for a specific shoreline area.

There have been other recent efforts in local hazard mitigation planning. The Coastal Hazard Mitigation Planning Project (CHMPP) began with support from the CZM Program. Phase I analyzed the hurricane risk in Hawaii and the costs and benefits of a range of hazard mitigation activities. It resulted in recommendations to the state to reduce the risk of hurricane damage in Hawaii including: adoption of the 1991 UBC by county governments; improving enforcement of shoreline setback regulations; evaluating the feasibility of variable (risk-based) shoreline setbacks; designating high hazard areas on planning and zoning maps; conducting risk audits and retrofits for public buildings; and providing incentives for retrofitting homes through tax incentives and risk-based hurricane insurance premiums. The 1994 Legislature adopted the majority of these recommendations by joint resolution. Since then, many recommendations have been implemented by state and county agencies.



An excerpt from the tsunami inundation map in the *Hilo Downtown Development Plan.*
Credit: County of Hawaii

Phase II of the CHMPP began in 1994. The project team worked with the county governments to evaluate the feasibility of designating high hazard areas in four specific geographic areas. The project team also developed a hazard mitigation plan for high hazard areas, including a risk-based premium rate structure with financial support from the Federal Emergency Management Agency (FEMA) with credits for mitigation. In addition, a brochure on hurricane awareness describing measures that homeowners can follow to reduce the risk of hurricane damage was prepared and distributed through county building departments.

State Role

The establishment of the location of and permissible uses in State Land Use Districts leaves county governments with a reduced role in land use planning. However, while county general plans or development plans are required to "further define the overall theme, goals, objectives, policies, and priority guidelines" of the State Planning Act, the specific content of these plans is not defined. While the formulation, amendment, and implementation of county general plans or development plans are required to include input from the state and county agencies as well as the general public, and to take into consideration statewide objectives, policies, and programs stipulated in state functional plans (including the Hawaii State Plan), there is no formal review or approval of county general plans at the state level.

Despite the efforts to coordinate coastal hazards planning, the Coastal Hazard Mitigation Planning Project concluded in a recent study that hazard considerations are not a routine part of permit and other land use planning decisions. To address this gap, a hazard assessment-identifying areas subject to coastal erosion, lava flow, flood, tsunami damage, earthquake zones, storm surge damage, and strong winds-has been recommended to be integrated into the various levels of planning, land use decisionmaking, permitting, and land management in Hawaii. The hazard assessment will identify the specific hazard exposures for proposed uses at a site and the mitigation measures that will be employed to reduce the risk of losses.

Oregon

Local Comprehensive Plan

Oregon's State Land Use Act, passed in 1973, created Oregon's Land Use Program (Oregon Revised Statutes, Chapter 197). The foundation of the program is a set of 19 statewide planning goals. The goals express the state's policies on land use and related topics, such as citizen involvement, housing, and natural resources. Oregon's statewide planning program is directed by the Land Conservation and Development Commission (LCDC).

Oregon's statewide goals are achieved through local comprehensive planning. State law requires each city and county to have a comprehensive plan and the zoning and land-division ordinances needed to put the plan into effect. The local comprehensive plans are required to be consistent with the statewide planning goals. Plans are reviewed for consistency by LCDC. When LCDC officially approves a local government's plan, the plan is said to be "acknowledged." It then becomes the controlling document for land use in the area covered by that plan. Oregon's planning laws apply not only to local governments but also to special districts and state agencies.

The laws strongly emphasize coordination-keeping plans and programs consistent with each other, with the goals, and with acknowledged local plans.

A comprehensive plan is an official document adopted by a city or county that sets forth the general, long-range policies on how the community's future development should occur. The local comprehensive plan guides a community's land use, conservation of natural resources, economic development, and public services. Plans must address all the applicable topics in the statewide planning goals, as well as issues of local concern. Plans must anticipate and provide for future land use needs. Comprehensive plans must include special plan elements for coastal resources including estuaries, shorelands, beaches, and dunes.

The State of Oregon requires that hazard mitigation be addressed in the required local comprehensive plans (under Goal 7: Areas Subject to Natural Disasters and Hazards). It requires that jurisdictions apply "appropriate safeguards" (floodplain zoning, for example) when planning for development in these areas.

As of September 2000, LCDC was considering amendments to Statewide Planning Goal 7. The Governor directed LCDC to review the effectiveness of Goal 7 in reducing risks from natural hazards after flood and landslide events in 1996 and 1997. The revised language refers directly to tsunami hazards. Also, in response to these issues, the Department of Land Conservation and Development (DLCD) released a new hazards planning guide in August, 2000, entitled *Planning for Natural Hazards: Oregon Technical Resource Guide.*

Local Development Regulations/Programs

State law requires adoption of implementing measures to carry out the comprehensive plan. The two most common measures are zoning and land division ordinances. Every city and county in Oregon has adopted such land use controls. All land use ordinances must be consistent with and carry out the comprehensive plan.

The Oregon Structural Specialty code, based on the 1997 Uniform Building Code (UBC), applies to non-residential and multi-family residential structures. The One and Two Family Dwelling Code applies to other residential properties. State law allows for some variations at the city/county level based on unique local conditions.

State Coastal Policies

Oregon's Coastal Management Program (OCMP) was approved in 1977 as a response to the federal Coastal Zone Management Act (CZMA). The objective of the OCMP is to develop, implement, and continuously improve a management program which will, as appropriate, preserve, conserve, develop, and restore the natural resources of the coastal zone. The Department of Land Conservation and Development (DLCD) is the lead agency responsible for the overall administration and operation of the OCMP.

The Oregon Coastal Management Program (OCMP) is part of Oregon's statewide program for coordinated land use planning. Relying on a partnership between the public, local governments, and state and federal agencies, the OCMP is based on three separate but coordinated sets of planning and regulatory authorities: 1) statewide planning goals adopted by the LCDC; 2) acknowledged comprehensive plans which local governments have developed and LCDC has approved; and 3) specified statutory authorities of various state agencies (these include the Removal-Fill Law), which regulates alterations to estuaries, lakes, and other waterways, and the Oregon Beach Bill which regulates uses and alterations along the ocean shore. Supplementing these laws are authorities and capabilities derived from the federal Coastal Zone Management Act.

Together, these authorities establish policies and procedures for planning and managing the balanced preservation, conservation, use, development, and restoration of the natural resources in Oregon's coastal zone. These authorities are tied together by two requirements in Oregon's Land Use Planning Act and the statewide planning goals. First, the Act requires all units of government to coordinate their actions affecting land use with affected citizens and with local, state, and federal agencies. Second, the Act requires that the plans and actions of all agencies and local governments comply with the statewide planning goals and acknowledged comprehensive plans.

Oregon's Coastal Zone includes all the lands west of the crest of the Coast Range Mountains, except in the Rogue, Umpqua, and Columbia River basins. The Coastal Zone encompasses seven coastal counties, five inland counties, and 33 cities.

Each coastal comprehensive plan includes special development restrictions to recognize and protect special shorelands values. Coastal shorelands boundaries are a minimum of 50 feet inland for the shorelands and may be more when special circumstances apply, including coastal geologic hazard areas and areas subject to coastal flooding. More than a third of the land in the coastal zone is owned by the federal government.

In cooperation with interested stakeholders, the Department of Land Conservation and Development (DLCD) developed and has been carrying out a multi-year strategy to improve coastal hazards management in Oregon. Projects and activities in the three general areas of hazard policy, assessment, and education were identified and have been conducted or funded by the department during the last several years.

These projects and activities are designed to improve some aspect of natural hazards management on the coast. For over two years, the Hazards Policy Working Group met to examine natural hazards policy in Oregon. Through an innovative "all-hazards, all-decisions" approach, they evaluated the effectiveness of existing policy and policy implementation. The group identified 23 coastal hazards issues and 79 recommendations for improved policies and practices in the areas of hazard assessment, land use, shore protection and emergency response. The *Planning for Natural Hazards: Oregon Technical Resource Guide* report has been widely distributed, and implementation of many of those recommendations is currently underway. The document is intended to help local governments strengthen the natural hazards element of their comprehensive land use plans. The Guide provides information on how to identify, plan for, and implement programs to address floods, landslides, wildfire, seismic, and coastal hazards. It provides information for communities to help implement both regulatory and nonregulatory programs to minimize the impact of natural hazards.

Existing policies do not address seismic hazards in any significant way. DLCD states that it needs to participate in the on-going debate and discussion on the risks of seismic hazards and ways to address them. The coast is particularly at risk from a Cascadia Subduction Zone event because of the proximity to the fault zone and the added tsunami hazard.

State Role

Most of the statewide planning goals are accompanied by guidelines, which are suggestions about how a goal may be applied. While the goals are mandatory and have been adopted as administrative rules (Oregon Administrative Rules Chapter 660, Division 15), the guidelines are not mandatory. In addition to the goals, LCDC has also adopted Administrative Rules to guide state and local planning.

Section 455.446 of the Oregon Revised Statutes (ORS) requires the State Department of Geology and Mineral Industries to define tsunami inundation zones (see Background Paper #6, Appendix 1). This ORS section also prohibits, with exceptions, new "essential facilities" and new "special occupancy structures" in tsunami inundation zones. Furthermore, the statutes provide that those new essential facilities, hazardous facilities and major structures, and new special occupancy structures that are allowed to locate in a tsunami inundation zone must consult with the State Department of Geology and Mineral Industries for assistance in determining the impact of possible tsunamis on the proposed development and for assistance in preparing methods to mitigate risk before a building permit is issued.

Washington

Local Comprehensive Plan

In 1990, Washington adopted the Growth Management Act (GMA) (Revised Code of Washington 36.70A.020). This law established a growth management program designed to reduce sprawl. Inspired by Oregon's program, the act has 13 statewide planning goals. In 1991, the Legislature established three regional Growth Management Hearing Boards located in Spokane, Olympia, and Seattle. The boards hear appeals brought by citizens and by the state to ensure that local plans are consistent with the statewide goals. The GMA requires the fastest-growing counties, and the cities within them, to adopt comprehensive plans. Twenty-nine counties and 215 cities, representing 95 percent of the state's population, are planning under the GMA.

County plans must harmonize with the plans of cities within the county, and the plans of neighboring jurisdictions must correspond with one another. Unlike Oregon, Washington opted for stronger local autonomy and does not require state approval of local plans. Jurisdictions that refuse to plan, or whose plans fail to address key issues, lose eligibility for state-infrastructure grants and loans. The governor may also withhold sales, liquor, and gas tax revenue.

Counties and cities required to complete a comprehensive plan are required to designate "critical areas," including geologically hazardous areas, and adopt regulations that preclude incompatible land uses or development in these areas.

Local Development Regulations/Programs

Within one year of adopting a plan, municipalities must enact zoning rules and capital improvement programs consistent with the plan. Local zoning decisions may be challenged in court if they contradict local planning policies.

The Washington State Building Code, based on the 1997 Uniform Building Code (UBC), applies to all types of structures in the state. State law allows for some modifications at the city/county level based on unique local conditions.

State Coastal Policies

The Washington Shoreline Management Act (SMA) requires that all shoreline uses and activities be consistent with the SMA and requirements of the local Shoreline Management Plan (SMP).

The Washington Shoreline Management Act (SMA) was designed to respond to the federal Coastal Zone Management Act (CZMA). All cities and counties with "shorelines of the state" are required to adopt shoreline master programs (SMPs). "Shorelines of the state" include all water areas of the state, excluding streams under 20 cfs and lakes less than 20 acres, together with their associated shorelands extending 200 feet from the water, their floodplains and associated wetlands, plus adjacent lands (Revised Code of Washington (RCW) 90.58.340). Shoreline Master Programs (SMPs) are both planning and regulatory (implementation) tools; they are analogous to comprehensive plan policies and development regulations respectively. The Department of Ecology is the state agency responsible for regulation of coastal shorelines.

The Department of Ecology prepares SMP guidelines and provides technical support and assistance to local governments. Local governments prepare SMPs to address local circumstances consistent with Department of Ecology guidelines. The Department of Ecology reviews and approves local SMPs upon finding consistency with the SMA and guidelines.

All shoreline uses and activities must be consistent with the SMA and requirements of the local SMP. Uses or activities identified in the SMP may require shoreline conditional use or variance permits. Only those actions defined as "substantial development" require a substantial development permit (SDP). Substantial development permits are approved by local governments. Certain federal actions trigger review for consistency with state CZM Program and local SMP requirements.

Substantial development permits are sent to the Department of Ecology, which may appeal the permit action to the Shoreline Hearings Board. Conditional use or variance permits are subject to review and approval by the Department of Ecology.

The SMA does not contain any references to geologic or tsunami hazards. Washington Administrative Code (WAC) Chapter 173-16, Shoreline Management Act Guidelines For Development of Master Programs, only mentions geologic hazards in the context of siting oil and gas facilities.

State Role

While state agencies may review and comment on draft comprehensive plans, comprehensive plans are not approved by a state agency. However, the Washington Department of Community, Trade, and Economic Development (DCTED) has adopted procedural criteria to assist local governments in the development of comprehensive plans. State agencies must comply with local comprehensive plans and development regulations (RCW 36.70A.103).

The Land Use Study Commission was created in 1995 to explore and eventually merge Washington's land use planning and environmental laws to encourage environmentally-responsible economic growth. The Commission was also charged to consider the effectiveness of state and local government efforts to consolidate and integrate the Growth Management Act, the State Environmental Policy Act, the Shoreline Management Act, and other land use, planning, environmental, and permitting laws.

In a report issued in December 1998, the Commission concluded that a consolidated land use code has the potential for many benefits. At this time, however, it stated there is not the consensus and funding necessary for its final development and adoption.

SUMMARY

Table 2-1, Comparison of Planning Requirements, provides a summary of state land use regulations, including hazard mitigation requirements based primarily on information published in 1998 by the Institute for Business and Home Safety. 'Vertical consistency' refers to required consistency of local plans with state plans. 'Horizontal consistency' refers to required consistency of local plans with each other.

Table 2-1. Comparison of Planning Requirements

	Statewide Planning Guidelines?	Vertical Consistency Required?	Horizontal Consistency Required?	State Specifies Elements of Comprehensive Plan?	Hazard Mitigation Element Required?
Alaska	No. Except for land use plans for coastal resource districts.	Management plans of coastal resource districts are required to undergo consistency review with plans of state agencies.	Management plans of coastal resource districts required to undergo consistency review with plans of coastal resource districts.	State specifies elements of coastal plans, and suggests elements for mandatory comprehensive plans of other communities.	Yes. For coastal plans. No. For other mandatory plans.
California	Yes	No. City or county must consult with state, but guidelines are advisory only.	No. State suggests but does not require that cities and counties refer plans to neighboring jurisdictions for comment.	Yes	Yes. As part of Safety Element.
Hawaii	Yes	No. Guidelines are advisory only.	No. State suggests but does not require.	No. State suggests but does not require elements.	No. State suggests but does not require.
Oregon	Yes	Yes. Local plans must be consistent with state planning goals.	No. State suggests but does not require.	Yes	Yes
Washington	Yes. For high-growth counties and cities.	Yes	Yes. Required of high-growth county/city plans but not of shoreline municipality plans.	Yes	Yes. For "Critical areas" which include "Geologically hazardous areas."

Sources:
Summary of State Land Use Planning Laws, Institute for Business and Home Safety, April 1998.
Mintier & Associates, 2000.

BACKGROUND PAPER #3: LAND USE PLANNING

INTRODUCTION

This paper describes how risk from tsunami hazards can be mitigated by avoiding or minimizing the exposure of people and property through land use planning. It examines the types, patterns, and densities of uses that could and should be allowed within potential tsunami inundation areas based on a consideration of the risk. This paper concentrates on large-scale land use planning issues, such as those that are dealt with in comprehensive plans, zoning ordinances, and subdivision regulations.

The paper starts with an overview of existing regulations and programs, including: statewide land use and coastal planning regulations and programs; special regulations, including the Coastal Zone Management (CZM) Program and the National Flood Insurance Program (NFIP); and descriptions of several local land use planning approaches that have been used by coastal communities to minimize or avoid tsunami hazards.

Next, the paper discusses the comprehensive planning process and the considerations that should be taken into account when formulating a community land use strategy for tsunami mitigation. Finally, the paper discusses specific land use planning measures for tsunami mitigation.

KEY CONCEPTS AND FINDINGS

There are three key concepts for land use planning in this background paper. The basic principle underlying this discussion is that development should be prevented or limited in high hazard areas wherever possible. Where development cannot be prevented or limited, land use density, building value, and occupancy should be kept to a minimum. Where these are not available strategies, and development will occur in possible tsunami inundation areas, planners and designers must look to mitigation through site planning as discussed in Background Paper #4 and/or building construction techniques as discussed in Background Paper #5.

Concept 1: New Development Should Be Avoided in Tsunami Hazard Areas

Land use and site planning should emphasize keeping new development out of hazard areas. Hazard areas should be kept as open space and may incorporate physical barriers such as landscape, berms, and engineered walls to slow and steer run-up (see Background Paper #4).

Concept 2: New Development that is Located in Hazard Areas Should Be Designed to Minimize Future Loss

When projects are built in hazard areas, communities can use a variety of land use planning and site planning methods to minimize damage. Land use planning measures include low-density and clustered development. Site planning measures include elevating inhabited floors above inundation levels; providing barriers to block inundation; and spacing and orienting buildings to avoid the full force of a tsunami on themselves and surrounding structures (see Background Paper #4, *Site Planning* for a more detailed discussion of these topics).

Concept 3: Existing Urbanized Development in Hazard Areas Should Be Redeveloped, Retrofitted, or Recycled into Other Uses

Over time, or as a result of tsunamis, communities are finding ways to recycle and retrofit existing urbanized areas at risk. They are moving higher density uses and critical facilities out of dangerous areas, adding protective barriers, and retrofitting structures.

OVERVIEW OF EXISTING REGULATIONS AND PROGRAMS

Land Use and Coastal Planning

All five Pacific states require local land use planning, and all except for Alaska have statewide planning guidelines (Alaska has statewide planning guidelines for coastal resource districts). California, Oregon, and Washington require hazard mitigation as part of their general land use planning process. Alaska requires it for coastal resource district plans only. Hawaii only suggests that this topic be addressed.

The following is a summary of land use and coastal planning requirements related to natural hazards from Background Paper #2.

Alaska

The State of Alaska specifies the elements of local land use plans for coastal resource (coastal plans), and requires a hazard mitigation element for these plans.

The Alaska Coastal Management Program (ACMP) requires that projects in Alaska's coastal zone be reviewed by coastal resource management professionals and found consistent with the statewide standards of the ACMP in a "consistency review process." Among the topics required to be addressed are "geophysical hazard areas," including tsunami run-up areas.

California

The State of California requires every community's general plan to include a "safety element." Tsunamis are specifically mentioned as a hazard to be addressed, where applicable.

The California Coastal Management Program (CCMP) under the California Coastal Act requires each city or county lying wholly or partly within the coastal zone to prepare a Local Coastal Plan (LCP). While the specific contents of Local Coastal Plans (LCPs) are not specified by state law, LCPs must be certified by the Coastal Commission as consistent with policies of the Coastal Act. The Coastal Act (Public Resources Code, Division 20) has provisions relating to geologic hazards, but does not mention tsunamis specifically. Section 30253(1) states that "new development shall minimize risks to life and property in areas of high geologic, flood, and fire hazard."

Hawaii

The State of Hawaii suggests but does not require that a hazard mitigation element be included in state-mandated local comprehensive plans.

The Hawaii Coastal Zone Management (CZM) Program requires that communities address coastal hazards, including tsunamis. Other key areas of the CZM Program include: a permit system to control development within a Special Management Area (SMA) managed by the counties and the Office of Planning; and a Shoreline Setback Area which serves as a buffer against coastal hazards and erosion, and protects viewsheds. A major objective of the CZM Program is to reduce hazard to life and property from tsunamis, storm waves, stream flooding erosion, and subsidence.

Oregon

The State of Oregon requires that hazard mitigation be addressed in the required local comprehensive plans (under Goal 7: Areas Subject to Natural Disasters and Hazards). It requires that jurisdictions apply "appropriate safeguards" (floodplain zoning, for example) when planning for development in these areas.

The Oregon Coastal Management Program (OCMP) is part of Oregon's statewide program for coordinated land use planning. Existing policies do not address seismic hazards and resultant tsunami hazards in any significant way.

Washington

Counties and cities required to complete a comprehensive plan are required to designate "critical areas," including geologically hazardous areas, and adopt regulations that preclude incompatible land uses or development in these areas.

The Washington Shoreline Management Act (SMA) requires that all shoreline uses and activities be consistent with the SMA and requirements of the local Shoreline Management Plan (SMP). The SMA does not contain any references to geologic or tsunami hazards. Washington Administrative Code (WAC) Chapter 173-16-Shoreline Management Act Guidelines For Development of Master Programs only mentions geologic hazards in the context of siting oil and gas facilities.

Special Regulations

As discussed in Background Paper #2, the Coastal Zone Management (CZM) Program is a partnership between the federal government and the U.S. coastal states and territories to preserve, protect, develop, restore, and enhance the resources of the coastal zone. Hazard mitigation is one of the management objectives of the program.

While state participation in the CZM Program is voluntary, there are federal funding incentives. Local compliance with the state plan is mandatory once a state has an approved Coastal Management Program (CMP). The CZM Program uses a generalized "goals" approach, meaning that State CMPs are required to meet national CZM Program goals.

As discussed in Background Paper #2, the National Flood Insurance Program (NFIP), administered by the Federal Insurance Administration (FIA) of the Federal Emergency Management Agency (FEMA), makes federally-backed flood insurance available in communities that adopt and enforce floodplain management ordinances to reduce future flood losses. The NFIP defines specific regulatory standards that local communities are required to meet to participate in the program. This "standards" approach is much more specific than the "goals" approach of the CZM Program and requires, for example, communities to regulate structural design standards.

Case Studies: Local Land Use Planning Examples

Following are descriptions of several local land use planning approaches used by coastal communities to minimize or avoid tsunami risks. These communities, all in Alaska and Hawaii, have sustained tsunami damage and put measures into place to mitigate future tsunami risks. The information is based on the case studies in *Land Management in Tsunami Hazard Areas* (1982) and other background documents, and on interviews with local planners conducted in fall 2000 by Mintier & Associates.

It is interesting to note that both the County of Hawaii and the County of Kauai had special overlay zones in their respective zoning codes that applied to tsunami hazards, but this approach was abandoned in time in favor of building design regulations as part of flood hazard ordinances administered by their public works departments. The overlay zoning approach was considered ineffective. The City and County of Honolulu (see case study in Background Paper #4) also addresses tsunamis through building construction and design regulations in its flood hazard ordinance. All the regulations aim at ensuring that structures withstand tsunami forces; however, they do not contain criteria to determine which uses are appropriate in the hazard zone.

The Alaskan communities have used a variety of approaches. Valdez moved their entire town after the 1964 earthquake and tsunami. Seward rezoned its waterfront for open space (park) uses. Kodiak did not adopt the more comprehensive response that they drafted, but instead has addressed the hazard through construction and design regulations in its Coastal Management Program. It is also interesting to note that all of the Alaskan communities, except for Seward, officially challenged the "high-risk" classification of land established by the Federal Reconstruction Commission for Alaska.

North Shore of Kauai Island, Hawaii

Kauai is the most northwestern of the principal Hawaiian islands. The North Shore of Kauai is relatively sparsely settled. Land uses includes agriculture, low-density residential, and commercial/resort uses around Hanalei. Access to the area is from the Kuhio Highway which extends from Lihue, the capital, to Haena at the western end of the North Shore. Portions of the highway are within the tsunami inundation zone.

The North Shore area is susceptible to tsunamis from both the north and south and has experienced frequent tsunami events. The North Shore experienced four large tsunami events in recent history. Each of these was distantly generated, with the 1946, 1957, and 1964 events originating in the Aleutian Island area of Alaska, and the 1960 event originating offshore of Chile.

The 1946 tsunami event in Kauai resulted in ten people dead, five missing, and eight injured, with 60 homes destroyed and 130 damaged. The wave run-up reached a maximum elevation of 45 feet, although the run-up elevation varied considerably across the inundation area because of reef and shoal protection. The 1957 tsunami destroyed 54 homes and damaged another 27. In addition, several public buildings and six bridges were damaged, with one bridge completely destroyed.

The Kauai General Plan was adopted in 1970 and updated in 1984. It is currently being revised and is scheduled for adoption by the end of 2000. The General Plan established four "Development Restriction Zones" for: 1) steep slopes; 2) areas subject to tsunami inundation; 3) areas subject to flooding; and 4) inadequate soil conditions. The General Plan policies continue the existing land use patterns to a large degree with low-density residential uses concentrated in the coastal areas, and agriculture and resort activity in the upland areas. All private land uses in the Hanalei Bay area are within the inundation zone.

The 2000 General Plan Update Draft contains policies and recommends implementing actions to limit development on shoreline lands within coastal flood hazard areas. These policies were developed more for hurricane mitigation than tsunami mitigation, but are still applicable to tsunami hazards. Hurricane Iniki in 1992 and Hurricane Iwa in 1982 caused a great amount of damage on Kauai and are much stronger memories than the last tsunami to cause significant damage on Kauai in 1957.

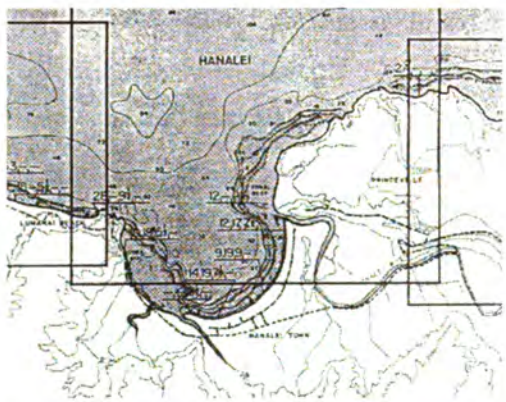
The proposed policies in the General Plan Update are as follows:

> *"Establish zoning and subdivision regulations that (1) strictly limit development on lands that are steeply-sloped and/or have highly erodible soils, in order to prevent flooding, landslides and nonpoint pollution; and (2) strictly limit development on shoreline lands within coastal flood hazard areas or susceptible to shoreline erosion."*

> *"The Planning Department shall review and revise the Subdivision Ordinance and the Comprehensive Zoning Ordinance, including the regulations for the Open District and the Constraint Districts, in order to: (1) assure effective regulation of steeply-sloped lands and drainageways; and (2) eliminate ineffective regulations and reduce unnecessary application requirements."*

The North Shore Development Plan was adopted in 1974 and updated in 1985 to address development in the North Shore area of the county. It includes zoning designations, a utilities and circulation plan, a recreation plan, and an implementation program consisting of urban design standards and recommended capital improvements. Approximately half of the tsunami hazard zone is designated low-density residential. All developments within the hazard zone fall within the special Tsunami Constraint District as an overlay zone in the Zoning Code. The overlay zone was intended to restrict development in the tsunami zone by not allowing public buildings intended for human habitation, schools, hospitals, nursing homes, and other similar uses. Additional requirements relating to public utilities, industrial uses, and hazardous materials were also to be specified. However, the Tsunami Constraint District has never been implemented and there are no additional development standards with which projects are required to conform.

The North Shore Plan proposed the creation of an additional resort/residential center outside of the tsunami zone on a plateau in the Princeville area east of Hanalei. The plan also proposed establishing medical facilities and moving the community's fire station and elementary school out of the tsunami hazard zone.



Excerpt from map of tsunami run-up heights in the Kauai North Shore Plan.
Credit: County of Kauai

The County adopted a Flood Damage Prevention Ordinance in 1981 to meet federal flood insurance requirements. The ordinance establishes minimum floor heights above flood levels and other structural requirements. The County, in response to the damage caused by Hurricane Iniki in 1992, adopted a new Flood Plain Management Ordinance in 1995. It is based on a 1994 study by the Federal Insurance Administration entitled *The Flood Insurance Study for the County of Kaua`i*, which included Flood Insurance Rate Maps (FIRMs). The ordinance, administered by the Department of Public Works, imposes mitigation measures on development within Coastal High Hazard Areas identified as VE zones in the FIRMs. The basic measures include raising habitable structures above the base flood elevation and more stringent construction standards.

In summary, the regulatory framework in Kauai uses a combination of low-density zoning to reduce the amount of potential property damage and development standards designed to ensure that structures will be able to withstand the wave forces.

Hilo, Hawaii

Hawaii is the most southeastern of the principal Hawaiian Islands. The city of Hilo is located on the northeast side of the island. Approximately half of the island's residents live in the greater Hilo area. Of the more than 305 miles of coastline on the island, approximately 225 miles, or 75 percent, is undeveloped cliff area that is not subject to property damage from coastal flooding or tsunami inundation.

The Hilo shoreline, which includes both Hilo Bay and the Keaukaha Coast, is one of the few coastal areas on the island that is not bordered by steep cliffs. Land uses along the coast in the Hilo area include residential and commercial/resort uses and a large port/industrial area. The main highway serving the coastline is located largely in the inundation zone.

Hilo has experienced tsunamis frequently, and, because of its orientation, is especially susceptible to tsunamis generated in the eastern and northern Pacific Ocean, including tsunamis generated from South America, the Aleutian Islands, Kamchatka, and the Kuril Islands. More than 47 tsunami events have been recorded since 1837, with 12 causing severe damage to Hilo. Run-up elevations of 35 feet were experienced in the 1960 tsunami generated off of the coast of Chile. The 1960 tsunami resulted in 61 people killed, 282 injured, and 537 buildings destroyed. The 1946 tsunami, originating in the Aleutian Islands, had wave run-ups of 27 feet and resulted in 173 people killed, 162 injured, 488 buildings destroyed, and severe damage to the breakwater.

Damage from the 1960 tsunami in the Waiakea area of Hilo, Hawaii.
Parking meters were bent by the force of the debris-filled waves.
Credit: U.S. Navy

Initial hazard mitigation efforts in Hilo from 1946 to the mid-1960s focused on offshore structural defense barriers, such as waterfront seawalls and breakwaters. These efforts were abandoned when it became clear that the aesthetic and economic costs were too high and the effectiveness of the schemes had not been adequately demonstrated.

On May 31, 1960, the County created the Hawaii Redevelopment Agency for the redevelopment or rehabilitation of the urban area devastated by the tsunami of May 23, 1960. On March 1, 1961, the County approved the Urban Renewal Plan for the Kaiko'o Project. The scope of the

Plan included: acquisition of specific real property; relocation, demolition, and removal of buildings; rezoning; and final disposition of acquired property.

The Urban Renewal Plan relocated downtown businesses destroyed in the tsunami event through a land exchange for state-owned property outside the hazard zone. The downtown shoreline area was never redeveloped and remains mostly open space today. There are hotels along the shoreline of Banyan Drive outside of the Plan area.

General plan studies in the County of Hawaii were initiated in the late 1950s on a regional basis. A *Plan for the Metropolitan Area of Hilo* was completed in 1961 for the districts of South Hilo and Puna. This plan incorporated the proposed zoning resulting from the Urban Renewal Plan. Along with two other regional plans, it was adopted in July 1965 as the General Plan for the County, but did not include all of the districts in the county. The County of Hawaii adopted its first island-wide General Plan in 1971. The current General Plan was adopted in 1989. As of fall 2000, the General Plan was being revised by the County.

The Flood Control and Drainage Section of the General Plan contains the most specific references to tsunami hazard management. One key policy in this section states:

> *"In areas vulnerable to severe damage caused by the impact of wave action restrictive land use and building structure regulations must be enacted relative to the potential for loss of life and property. Only uses which cannot be located elsewhere because of public necessity and character such as maritime activities and the necessary public facilities and utilities would be allowed." (Flood Control and Drainage Section of the Hawaii County General Plan)*

However, contrary to this policy, the 1971 General Plan map designated a large amount of the coastline for industrial, resort, and other high density uses. The 1978 revision to the General Plan changed some of these areas to open space or low-density residential uses.

Hawaii County has used the tsunami hazard risk as a basis for allocating land uses and for setting specific design and building standards. However, there has still been substantial development within the hazard area, including the Banyan Drive resort area which is located entirely within the tsunami hazard zone. There has also been considerable pressure for the development of high-density condominium complexes along the coastline.

Until it was revised in 1996, the Hawaii County Zoning Code included a Safety District Zone, which was an overlay zone that applied to hazard zone areas (e.g., tsunami, flood, and geologic). The Safety District boundaries that applied to the tsunami hazard area conformed with the inundation limits mapped in the General Plan. The Safety District is no longer part of the Zoning Code. However, potential tsunami inundation areas are still shown on General Plan Facilities Maps.

In place of this system, the County's Department of Public Works oversees construction in tsunami inundation areas as part of its responsibility in administering Chapter 27, Flood Control, of the Hawaii County Code. The tsunami inundation areas have been identified through the adoption of FEMA flood hazard maps. The following is the complete text setting out the standards for tsunami inundation areas in Chapter 27. This section was adopted in 1993.

Section 27-23. Standards for coastal high hazard areas.

Coastal high hazard areas, more commonly known as tsunami inundation areas, are identified as Zone V or Zone VE on the Flood Insurance Rate Maps. Within coastal high hazard areas, the following standards shall apply:

(a) All new construction and substantial improvements in a coastal high hazard area shall be constructed with materials and utility equipment resistant to flood damage and using methods and practices that minimize flood damage.

(b) New construction and substantial improvement shall be elevated on adequately anchored pilings or columns and securely anchored to such pilings or columns so that the lowest horizontal portion of the structural members of the lowest floor, excluding the pilings and columns, is elevated to or above the base flood level. The pile or column foundation and structure attached thereto shall be anchored to resist flotation, collapse, and lateral movement due to the effects of wind and water loads acting simultaneously on all building components. The wind and water loading values shall each have a one percent chance of being equaled or exceeded in any given year.

(c) New construction and other development shall be located on the landward side of the reach of mean high tide.

(d) New construction and substantial improvement shall have the enclosed space, if any, below the lowest floor free of obstructions and constructed with breakaway walls as defined in section 27-12. Such enclosed space shall not be used for human habitation and will be useable solely for parking of vehicles, building access, or storage. Machinery and equipment which service the building, such as furnaces, air conditioners, heat pumps, hot water heaters, washers, dryers, elevator lift equipment, electrical junction and circuit boxes, and food freezers are not permitted in such enclosed spaces. The enclosed space must only be achieved with breakaway walls, open wood lattice-work, or insect screening intended to collapse under wind and water loads without causing collapse, displacement, or other structural damage to the elevated portion of the building or supporting foundation system. A breakaway wall shall have a design safe loading resistance of not less than ten and no more than twenty pounds per square foot. Use of breakaway walls which exceed a design safe loading resistance of twenty pounds per square foot may be permitted only if a registered professional structural engineer certifies that the design proposed meets the following conditions:

1) Breakaway wall collapse shall result from a water load less than that which would occur during the base flood; and

2) The elevated portion of the building and supporting foundation system shall not be subject to collapse, displacement, or other structural damage due to the effects of wind and water loads acting simultaneously on all building components (structural and nonstructural). Maximum wind and water loading values to be used in this determination shall each have a one percent chance of being equaled or exceeded in any given year (one-hundred-year mean recurrence interval).

(e) Fill shall not be used for structural support of buildings.

(f) *Man-made alteration of sand dunes which would increase potential flood damage is prohibited.*

(g) *All new construction, development, and substantial improvement within coastal high hazard areas shall be certified as required by section 27-17.*

The Hilo Community Development Plan (CDP) was adopted in 1975 to implement the Hawaii County General Plan in the greater Hilo region. For the Hilo area, the Hawaii Zoning Code is based on the land use designations and policies of the CDP. Some of the major provisions in the CDP regarding tsunami hazards are as follows:

- Minimize major new development of the ocean side of the 100-year tsunami inundation line through zoning and purchase for recreational uses;

- Require any development that does occur within the inundation zone to comply with the following design criteria: 1) buildings should be designed so that a tsunami will pass under them or wash through areas not intended for human occupancy; 2) buildings should be oriented to present their narrowest sides to a tsunami; 3) buildings should be sited on the highest natural elevation of their lot and earth platforms to gain foundation elevation;

- Expand the tsunami control forest as an attractive landscaped recreation area along the Bayfront to dissipate the energy of future tsunamis; and

- Develop a recommended extensive open space network along the shoreline area.

No significant tsunami control forest was ever developed. The shoreline area within the Kaiko'o Project area continues to be part of an extensive open space network that consists of a privately-owned golf course, county-owned park areas (passive recreation uses along with soccer and softball fields, and other facilities), and state-owned park areas.

Kodiak, Alaska

The Kodiak Island Borough includes a group of approximately 200 islands located off the southeast side of the Alaska Peninsula and all of the land on the Alaska Peninsula that drains into Shelikof Strait, from Cape Douglas in the north to Wide Bay in the south. In addition, Chirkof Island and the Semedi Islands are also located in the Borough. The city of Kodiak is the largest community in the Borough and is located on the northeastern shore of Kodiak Island, the largest island in the Borough.

The city of Kodiak has experienced numerous tsunamis over the past 200 years. However, only one produced waves large enough to cause property damage or casualties. While the 1960 Chilean tsunami only produced approximately a two-foot rise in the water level at Kodiak, the Great Alaska Earthquake of 1964 generated a large tsunami originating on the continental shelf in the Gulf of Alaska. Although the city of Kodiak experienced large amounts of groundshaking from the earthquake, the earthquake shocks caused only minor damage. The resultant tsunami, however, destroyed approximately 80 percent of Kodiak's downtown area and destroyed or damaged many other smaller settlements in the Kodiak Island Borough.

Damage from the 1964 tsunami in Kodiak, Alaska.
Credit: NOAA

The 1964 tsunami destroyed 158 houses and numerous other structures in the city of Kodiak, including docking facilities, Naval Station structures, and commercial buildings. In addition, most of the fishing vessels in the harbor were destroyed, as the tsunami turned them into projectiles that caused much of the other property damage in downtown Kodiak. After the tsunami event, the city decided to rebuild the commercial core of Kodiak in the same place where it had been. However, this required filling the land area that had subsided by 6.5 feet due to the earthquake. A breakwater was also built to reduce wave-generated erosion and to protect the reestablished boat harbor.

The Kodiak Island Borough Regional Plan and Development Strategy was proposed in 1978 as an update to the Kodiak Island Borough Comprehensive Policy and Land Use Plan (its comprehensive plan). The 1978 plan recommended the creation of a second business district near the rebuilt commercial core but outside of the tsunami experience zone. It also called for the expansion of industrial facilities in the tsunami hazard zone. However, the Regional Plan and Development Strategy was never adopted. The Borough is still using the 1968 version of the comprehensive plan for the downtown Kodiak core area. A second business center, quite a distance outside the downtown core, has been recently established, however, due to substantial community growth occurring north of the city of Kodiak.

While the Zoning Code does not include a special safety or tsunami district, the Borough has adopted a Coastal Management Program (CMP) that includes performance-based standards for tsunami hazard areas. The standards are specifically applied only to those activities that require review by the Kodiak Island Borough Planning and Zoning Commission (e.g., conditional use permits and subdivision reviews) and are deemed consistent with the zoning code and building code for staff-level permitting. Therefore, the performance standards have been applied primarily to outlying areas.

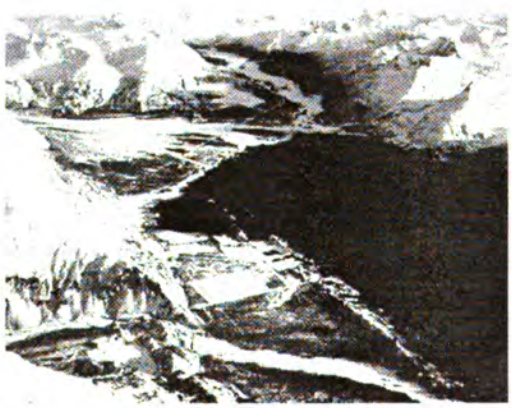
Construction in the port area emphasizes the utilization of the waterfront for non-habitable uses. The Kodiak Port and Near Island Master Plan has several provisions to mitigate tsunami risk, including the stabilization of Pillar Mountain against landslides that could create a locally-generated tsunami, the creation of several breakwaters, and the recommendation to locate residential uses outside of the tsunami inundation zone. In addition, critical facilities such as schools, and police and fire stations have been located in upland areas outside of the tsunami hazard zone. An interesting note is that in Kodiak, as in many Japanese communities, the industrial waterfront buildings are not designed to withstand tsunami forces and are treated as cheap throwaway structures. Economic considerations regarding the upgrading of these buildings to meet flood standards has been one reason why Kodiak has not participated in the National Flood Insurance Program.

Valdez, Alaska

Valdez is a town of approximately 4,500 people located at the head of Port Valdez. It is Alaska's northernmost ice-free port and is the southern terminus of the Alaskan pipeline and the Richardson Highway.

The Great Alaska Earthquake of 1964 triggered a massive submarine slide that completely destroyed the harbor facilities and nearshore installations in Valdez. Additionally, portions of the shore subsided below high-tide level and the entire area experienced strong groundshaking. Waves generated by the submarine slide and the earthquake itself did additional damage. Damage to the harbor and port facilities alone was estimated at almost $3.6 million in 1964 dollars.

The Federal Reconstruction Commission decided to abandon the old town site and reconstruct Valdez on a site four miles northwest of the old city because the old site was considered extremely vulnerable to future sliding, ground cracking, and flooding. This relocation was accomplished using urban renewal mechanisms, including the acquisition of land at the old site and development of the new site.



The old townsite of Valdez in the background and the new site in the foreground.
Credit: U.S. Army Corps of Engineers

The renewal plan called for public open space and park and recreation uses as the only allowed uses on the old site. No permanent structures were to be allowed in this area, although buildings could be relocated to the new site. The recreation uses were never developed, however, and part of the old site is used as a staging area for truck and barge shipping and large construction projects. Another part contains the city's sewage treatment facility and solid waste bailer facility, with the remainder of the land vacant. The City owns the old site and the land use restrictions imposed by the renewal plan will be lifted in 2014. The City does not plan to change the nature of uses on the site, however, and will continue to restrict high-impact, high-density uses.

Valdez is an example of completely changing land use in an area following a disaster and rebuilding in a new place to avoid the hazard in the future.

Seward, Alaska

The town of Seward is located at the head of Resurrection Bay on the southeast coast of the Kenai Peninsula. It is one of the few ice-free ports in south-central Alaska and provides year-round access from the coast to inland areas by railroad and highway. It is the southern terminus of the 470-mile long Alaska Railroad.

The Great Alaska Earthquake of 1964 completely destroyed Seward's harbor, shipping, and fishery facilities, which were the economic base of the town. Both the railroad yard and seaport facilities sustained heavy damage. The twelve fatalities in Seward during the earthquake were due to the local and the main tsunamis.

Seward is sited on an alluvial fan delta, and shortly after the groundshaking started, progressive sections of the waterfront slid into Resurrection Bay due to large-scale offshore sediment slump of the delta front. This submarine landsliding generated a series of local tsunamis that arrived within one to two minutes after the onset of the earthquake. The combined slump and tsunami caused the collapse of the dock fronts and the sinking of some boats within the harbor. Approximately 20 minutes after the earthquake began, the first wave of the main tsunami arrived and caused additional damage.

Fires erupted almost immediately after the earthquake began when a tank collapsed at the Standard Oil tank farm. A Texaco oil installation also ruptured and burned for days afterward. The tsunami spread the burning oil that was floating on the water. Tsunami run-up was up to 30 feet at the north end of Second Street. The Alaska Railroad yards were heavily damaged as were freight units in the yards. Most of the railroad dock was washed away by the waves. The railroad also lost two cranes and its waterfront tracks as rails were stripped from railroad ties by the tsunami.

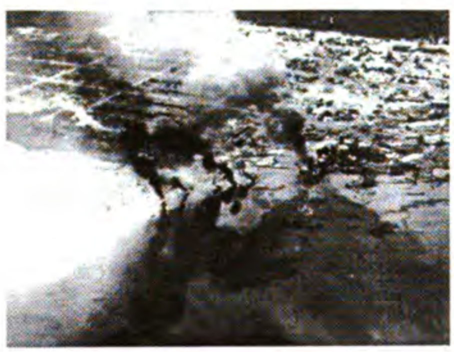
Damage to the railroad facilities at Seward Port from the 1964 tsunami.
Note the fire-damaged oil storage tanks.
Credit: NOAA/NGDC

It is estimated that 95 percent of Seward's industrial base was lost due to earthquake and tsunami damage. Fifteen percent of the town's residential properties were either totally destroyed or very heavily damaged. Total damage to public and private facilities was estimated at approximately $22 million in 1964 dollars.

An urban renewal plan for the revitalization of the community was prepared shortly after the disaster; however, the project boundaries were narrowed by the Federal Reconstruction Commission to include only the damaged waterfront area. The docks and harbor were relocated, and the Alaska Railroad facilities were reconstructed. No permanent habitable structures are allowed in the high-risk area along the waterfront, although there are public restroom facilities located there. Most of this area was publicly owned before the disaster, and acquisition was not a problem.

Seward rezoned the waterfront area for open space (park) uses. The land remains in park use and is used as an RV park in the summer. Although it is unlikely that any major permanent structure would be built in this high risk area, the waterfront is zoned for park uses and the Zoning Code allows "Permanent Visitor Attractions" and "Senior/Teen/Community/Civic Centers" in the Park Zone by conditional use permit. The harbor, docks, and other facilities that were moved to the head of the bay are still considered to be at risk from future tsunamis and flooding.

Seward has participated in FEMA's National Flood Insurance Program (NFIP) since 1986 under the Kenai Peninsula Borough. Seward adopted its own floodplain management ordinance in 1998. The ordinance addresses coastal high-hazard areas (V zones).



Burning petroleum storage tanks along the Seward, Alaska, waterfront
after the 1964 tsunami and earthquake.
Credit: Anchorage Museum of History and Art

COMPREHENSIVE PLANNING PROCESS

The following describes the considerations that should be taken into account when formulating a community land use strategy for tsunami risk mitigation.

Understand Locational Context

The importance of locational context for land use planning decisions must be understood. Opportunities for reducing tsunami risk differ depending on local circumstance, so a one-size-fits-all approach cannot be used. The presence or absence of development within tsunami hazard areas will determine the type of planning approach that is feasible. For example, vacant land conversion, such as expansion of an existing community or development of a new community, will require different mitigation strategies than will other forms of development such as infill, redevelopment, reuse, or changes in occupancy.

Understand Trade-Offs

Mitigation often means making trade-offs between or among competing goals when dealing with land use planning issues and tsunami hazards. For example, the public access emphasis in Coastal Zone Management (CZM) programs argues for locating visitor-serving development along the coastline; yet this access can be at direct odds with public safety objectives for minimizing new development in tsunami inundation areas.

Coastal-dependent development such as ports and harbors that, by their nature, have to be situated on the coast can also conflict with safety goals. Other planning goals such as compact/dense downtowns can also result in increased risk.

Aerial view of tsunami and earthquake damage to Valdez, Alaska, showing the extent of inundation along the coastline from the 1964 Great Alaska Earthquake. Coastal-dependent development can conflict with safety goals.
Credit: U.S. Department of the Interior

These trade-offs need to be recognized in the planning process. The revision process for a comprehensive plan is a good time to weigh alternatives and to balance competing goals.

Review and Update Existing Safety Element

The existing safety or natural hazards element of the comprehensive plan should be reviewed to determine if it adequately recognizes tsunami hazards and how the risk is managed when decisions are made. The following information should be inventoried and updated, as necessary:

- Technical information – such as inundation zones;
- Scenario information; and
- Goals and policies.

In addition, it should be recognized that tsunami hazards often overlap other hazards and that mitigation for other hazardous conditions can assist in mitigating tsunami risk. Such hazards might include riverine flooding, hurricanes/typhoons, landslides, coastal erosion, and earthquakes.

Erosion along the Oregon coast.
Mitigation for other hazardous conditions such as erosion, flooding, hurricanes, and seismic hazards can assist in mitigating tsunami risk.
Credit: Oregon Department of Land Conservation and Development

Review Existing Land Use Elements and Other Plans

The existing land use element, other comprehensive plan elements, and special plans should be reviewed to determine what changes are needed to address the tsunami hazard and be updated as necessary. Land use policies and programs should address tsunami hazards as part of a comprehensive tsunami mitigation program.

Such an update should focus on the location and vulnerability to damage of existing and planned land uses in the community, including the following:

- Residential;
- Commercial/visitor-serving;
- Industrial (general);
- Industrial (hazardous materials);
- Public facilities (transportation and water systems); and
- Critical facilities and systems (communication, emergency response, electrical power, water supply, and natural gas systems).

Review and Update Existing Zoning, Subdivision, and Other Regulations

Existing zoning, subdivision, and other regulations should be reviewed and updated with an eye to mitigating future tsunami losses. Requirements for consistency between the comprehensive plan and zoning and subdivision regulations vary among the states. In California for example, the zoning code is considered part of the local coastal program (LCP) for coastal communities and is required to be consistent with the general plan.

Planning for Post-Tsunami Reconstruction

Disasters create the opportunity to eliminate nonconforming uses and reshape existing patterns of development to minimize future losses. On the other hand, they can also create enormous pressure to rebuild the community quickly and exactly as it was before the disaster. These rebuilding issues should be addressed through the land use planning process before a disaster strikes so that a community is prepared to deal with rebuilding issues in the event of disaster.

In communities that have suffered tsunami damage, redevelopment can be based on planning principles that emphasize avoiding run-up areas, designing sites within run-up areas to minimize loss, and recycling and retrofitting existing urbanized areas that are at risk.

LAND USE PLANNING MEASURES

Designate Tsunami Hazard Areas for Open-Space Uses

The designation and zoning of tsunami hazard areas for such open-space uses as agriculture, parks and recreation, or natural hazard areas is recommended as the first land use planning strategy to consider. This strategy is designed to keep development at a minimum in hazard areas. It is particularly effective in areas that have not yet experienced development pressure. It is obviously more difficult in areas that are already partially developed, and/or that have strong development pressure.

Park on the Hilo, Hawaii, waterfront. Open space uses such as parks can keep development at a minimum in hazard areas.
Credit: County of Hawaii

In areas where development pressures are stronger, transferable development rights (TDR) programs may be more feasible. Transferable development rights (TDRs) are "a device by which the development potential of a site is severed from its title and made available for transfer to another location. The owner of a site within a transfer area retains property ownership, but not the approval to develop. The owner of a site within a receiving area may purchase Transferable development credits, allowing a receptor site to be developed at greater density." (State of California, Office of Planning and Research, *General Plan Guidelines*, 1998). The term "transferable development credit" (TDC), used by some communities to describe their programs, is interchangeable with TDR.

A mandatory TDR program reduces the development potential in the sending district through some form of rezoning and effectively limits or prohibits development in that area. The advantage of a TDR program is that it provides a compensation mechanism for down-zoning property. The disadvantages are that it can be difficult to administer and often slow to take hold because of initial property owner reluctance and fear. Also, suitable locations into which the transfer of increased development can be made must be chosen carefully.

Acquire Tsunami Hazard Areas for Open-Space Uses

A second strategy is to acquire tsunami hazard areas for open-space uses. Open-space acquisition has several advantages over strictly regulatory approaches such as zoning. Acquisition ensures that the land will be controlled by a public agency or non-profit entity, and it removes any question about a regulatory taking. The primary disadvantage to acquisition is cost.

There are multiple approaches to acquisition. Since land ownership is in effect a bundle of rights, including the rights to sell, lease, and develop the property, some of these rights, such as the right to develop, can be sold separately from the rest of the property.

Fee-Simple Acquisition

Fee-simple acquisition consists of acquiring all of the real property interests associated with the land. The most effective and most costly way to keep development out of a risk area is to acquire the land and retain it in public ownership as open space. Fee-simple acquisition is particularly appropriate when the use of the land requires public access, as with recreation land. In situations where the primary goal is to limit development, ownership of a full fee-simple interest may be unnecessary.

Fee-simple property acquisition can often be accomplished after a disaster when there is significant money available for disaster-relief and prevention efforts. Sale of a fee-simple interest is usually voluntary but can also be accomplished by the exercise of the power of eminent domain by a public agency. Eminent domain is a compensated "taking" of land for public use.

Purchase of Development Rights (PDR)

A purchase of development rights (PDR) program is based on purchasing the right to develop land from the bundle of rights associated with the land. A PDR program involves the purchase of the development rights to a property, generally through the granting of a conservation, open-space, or scenic easement that restricts the uses to which the property owner may put the land. A PDR program can also be constructed to purchase a fee-simple interest in a property and then resell the property with an easement restricting future development. A similar result can be obtained through purchasing a fee-simple interest and then leasing the property with restrictions on use. PDR programs are more effective in preserving land from development where development pressure has not yet driven up land prices.

The advantages to a PDR program are that it can be less expensive than a fee-simple acquisition program (except in areas where development pressure is high), it provides a cash payment to landowners and reduces property and inheritance taxes, preserves land from development in perpetuity, and can be administered in conjunction with a non-profit agency so that a local jurisdiction does not have to assume the landlord responsibility. Disadvantages of PDR programs include the expense, and similar to TDR programs the slowness of establishing confidence and support of the program among landowners, and the damage that the program may cause to a community's ability to use regulations to limit development because of the perception that all development restrictions should be compensated.

Partial or Voluntary TDR Programs

A partial TDR program still allows some development potential in the sending area, while a complete TDR program proscribes development in the sending district. A voluntary TDR program leaves the existing zoning in place in the sending district, but allows the development rights to be transferred to the receiving district. A voluntary program could be structured so that density bonuses in the receiving districts are awarded in exchange for cash deposits into a dedicated fund that is used to purchase conservation easements from willing property owners in the sending area. In general, voluntary TDR programs are not very effective and a partial or mandatory TDR program (see above) is recommended.

Leasing or Lease-Purchase

As an alternative to purchasing a fee-simple or development right interest in a property, land can be leased to prevent development or to preserve it for open space uses. This technique can be useful to preserve land in the short-term to provide additional time to obtain acquisition capital or make a decision regarding purchase. Property can also be leased through a lease-purchase agreement. This option can spread payments out over time if a local jurisdiction does not have enough capital to purchase the land outright.

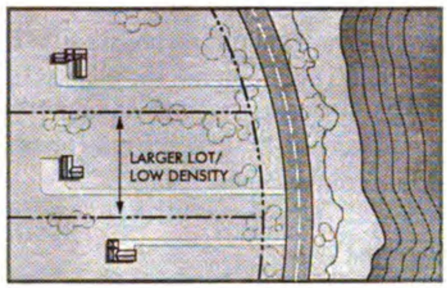
Land exchange

Local jurisdictions may exchange land that they own for land that they want to preserve from development.

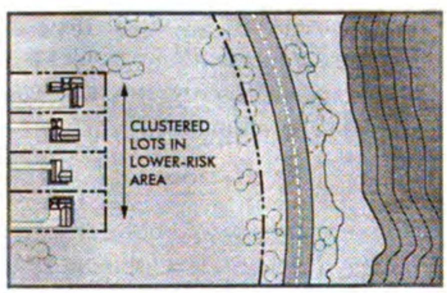
Restrict Development through Land Use Regulations

In areas where it is not feasible to restrict land uses to open-space uses, other land use planning measures can be used. These include strategically controlling the type of development and uses allowed in hazard areas, and avoiding high-value and high-occupancy uses to the greatest degree possible.

For example, plan designations and zoning districts can use density restrictions or large-lot zoning (e.g., 10-acre minimum) to ensure that only very low-density residential uses are allowed in hazard areas. Another technique is to require clustering of development on site areas where risks are the lowest. These site planning and design issues are addressed in more detail in Background Paper #4.



Large lot zoning can ensure that only very low density residential uses are allowed in hazard areas.



Development can be clustered on site areas where risks are the lowest.

Support Land Use Planning through Capital Improvement Planning and Budgeting

The capital improvement planning and budgeting process can be used to reinforce land use planning policies. A major factor in determining future development patterns is where a local jurisdiction chooses to extend sewer and water lines, roads, and other public facilities and services. These decisions can either discourage or encourage development in tsunami and other hazard areas.

It is important that capital improvement planning for public infrastructure is closely coordinated with land use planning programs to avoid hazard areas. Maximizing the safety of public infrastructure also increases a community's ability to recover from disaster and restore essential public services as quickly as possible. Natural hazard risk mitigation should be integrated into infrastructure policy. Infrastructure policies by themselves will not restrict development from certain areas, but they can reinforce existing land use plans, and they shape market forces to encourage development in less hazardous areas by not subsidizing infrastructure costs to serve high-risk hazardous areas.

Adapt Other Programs and Requirements

The safety element of a comprehensive plan and the zoning, subdivision, and other programs designed to implement the comprehensive plan may contain regulations that are applicable to tsunami risk mitigation even if tsunami hazards are not mentioned explicitly. Many of these programs and regulations can be adapted relatively easily to address tsunami hazards. For example, existing floodplain restrictions, hillside and landslide controls, and environmental, scenic, recreational, and wildlife-protection requirements can help address potential tsunami hazards and should be modified for that purpose.

Local jurisdictions should review these programs and requirements for their contribution to tsunami loss reduction and modify them, as necessary, to explicitly address tsunami hazards. Appendix 3-1 contains the Honolulu Flood Hazard District Ordinance as an example of an ordinance that addresses tsunami and flood hazards in an integrated manner.

APPENDIX 3-1:
HONOLULU FLOOD HAZARD DISTRICT ORDINANCE

Revised Ordinances of the City and County of Honolulu 1990, Chapter 21 - Land Use Ordinance, Article 9 - Special District Regulations

Sec. 21-9.10 Flood hazard districts. Purpose.

(a) Certain areas within the city are subject to periodic inundation by flooding and/or tsunami which may result in loss of life and property, creation of health and safety hazards, disruption of commerce and governmental services as well as extraordinary public expenditures for flood and tsunami protection and relief.

(b) The purposes of establishing flood hazard districts are to protect life and property and reduce public costs for flood control and rescue and relief efforts, thereby promoting the safety, health, convenience and general welfare of the community. (Added by Ord. 99-12)

Sec. 21-9.10-1 Authority.

This section is enacted pursuant to the U.S. National Flood Insurance Act of 1968 Public Laws 90-448 and 91-152), as amended, and the U.S. Flood Disaster Protection Act of 1973 (Public Law 93-234), as amended. (Added by Ord. 99-12)

Sec. 21-9.10-2 Establishment of districts.

(a) Flood Hazard Districts. This section shall apply to all lands within the flood hazard districts delineated on the flood insurance rate maps, as prepared by the Federal Insurance Administration, Federal Emergency Management Agency. The following flood hazard districts are established:

(1) Floodway district;
(2) Flood fringe district;
(3) Coastal high hazard district;
(4) General floodplain district.

(b) The flood hazard districts are delineated on the flood insurance rate maps and any amendments by the Federal Emergency Management Agency, on file with the department, and which hereinafter are called flood maps.

(c) The flood boundary and regulatory flood elevations shall be determined by the flood maps. Where interpretation is needed as to whether or not a project lies within a certain flood district, or interpretation is needed on the regulatory flood elevation in the floodway, flood fringe or coastal high hazard districts, a request for interpretation shall be submitted to the director for determination. The request shall include the project site and location plan, property lines and dimensions and tax map key.

(d) Where interpretation on the regulatory flood elevation or other data are needed, other than as stated in subsection (c), the director with the recommendation of the chief engineer shall make the determination. The request for interpretation under this section shall be submitted to the director and include three sets of documents, stamped and signed by a registered professional engineer, containing adequate information and substantiating data consistent with this part, such as flood study, flood data, project site and location plan, property lines and dimension, tax map key, and topographic data, contours or spot elevations based on reference marks on flood maps. Upon review by the director, other related information may be required to evaluate the request. (Added by Ord. 99-12)

Sec. 21-9.10-3 Warning and disclaimer of liability.

(a) The degree of flood and tsunami protection required by the flood hazard districts is considered reasonable for regulatory purposes and is based on standard engineering methods of study. Larger floods or tsunamis than the regulatory flood as designated on the flood maps may occur on occasions, or flood or tsunami elevations may be increased by man-made or natural causes. This section does not imply that areas outside the flood hazard area will be free from flooding or damage.

(b) This section shall not create liability on the part of the city or any officer, official or employee for any flood or tsunami damages that result from reliance on this part or any administrative decision lawfully made thereunder. (Added by Ord. 99-12)

Sec. 21-9.10-4 Development standards.

Developments within the flood hazard districts shall:

(a) Be designed and structures adequately anchored to resist flotation, collapse or lateral movement resulting from hydrodynamic and hydrostatic loads, including effects from buoyancy caused by the regulatory flood.

(b) Use construction materials and equipment that are resistant to flood damage caused by the regulatory flood elevation.

(c) Use construction methods and practices that will minimize damage caused by the regulatory flood.

(d) Be consistent with the need to minimize damage by the regulatory flood to the best available technological and practical design and construction.

(e) Provide utilities and facilities (including but not limited to sewers, water, electric, telephone and gas) to be designed, located and constructed to minimize or eliminate flood damage caused by the regulatory flood.

(f) Provide drainage to minimize damage by the regulatory flood in accordance with the storm drainage standards of the department.

(g) For new or replacement potable water system and facilities, be designed to minimize or eliminate infiltration of flood waters into the systems.

(h) For new or replacement sanitary sewer system and waste disposal system, be designed, located and constructed so as to minimize impairment to them or contamination from them during and subsequent to flooding by regulatory flood. (Added by Ord. 99-12)

Sec. 21-9.10-5 Floodway district.

(a) Within the floodway district, the following uses having a low flood damage potential and not obstructing the regulatory flood shall be permitted as under the underlying zoning district and which are not prohibited by any other laws or ordinances; and provided, they do not affect the capacity of the floodway or any tributary or any otherdrainage facility or system:

(1) Public and private outdoor recreational facilities, lawn, garden and play areas;
(2) Agricultural uses including farming, grazing, pasture and outdoor plant nurseries;
(3) Drainage improvements, such as dams, levees, channels and bridges.

(b) Temporary or permanent structures, fill, storage of material or equipment or other improvements which affect the capacity of the floodway or increase the regulatory flood elevations shall not be allowed. Construction and improvements shall be subject to documentation by studies and data by a registered professional engineer that, to the best available technical knowledge and information, encroachment shall not result in any increase in the regulatory flood elevations during occurrence of the regulatory flood. (Added by Ord. 99-12)

Sec. 21-9.10-6 Flood fringe district.

(a) Within the flood fringe district, the uses permitted in the underlying zoning district shall be permitted, provided such uses, improvements, structures and utilities are in compliance with the provisions of Sections 21-9.10 through 21-9.10-14.

(b) In addition to Section 21-9.10-4, the following standards shall be applicable in the flood fringe district:

(1) All construction and improvements of residential structures shall have the lowest floor including basements, but not including floors used for access purposes such as stairways, storage purposes, garages, carports and lanais, elevated to or above the regulatory flood elevation. Maximum height in country, agricultural or residential districts may be exceeded by no more than five feet, provided such additional height shall not be greater than 25 feet above the regulatory flood elevation. This provision shall also apply to detached dwellings and duplex units in apartment and apartment mixed use districts.

(2)(A) All construction and improvements of nonresidential structures shall have the lowest floor elevated to or above the regulatory flood elevation; or, together with attendant utility and sanitary facilities, be designed and constructed so that below the regulatory flood elevation, the structure is watertight with walls substantially impermeable to the passage of water and with structural components having the capability of resisting hydrostatic and hydrodynamic loads and effects of buoyancy due to the regulatory flood.

(B) A registered professional architect or engineer shall develop or review the design, specifications and plans and certify that the design and methods of construction are in accordance with accepted standards of practice for meeting the provisions of this section and include the specific elevation to which such structures are floodproof.

(3) The structure above the regulatory flood elevation shall be securely anchored to the foundation to resist movement and flotation due to the regulatory flood.

(4) All construction, improvements, portions of structures and foundations below the regulatory flood elevation shall be designed to be floodproof, anchored to resist movement and flotation and be able to resist the impact and calculated forces of the regulatory flood.

(5) (A) In areas of shallow flooding, as designated on the flood maps as AO zone, all construction and improvements of residential structures, including but not limited to dwelling or lodging units, shall have the lowest floor, including basements, elevated above the highest adjacent grade at least as high as the depth number specified on the flood maps. All new construction and improvements of nonresidential structures within the AO zone shall have the lowest floor elevated above the highest adjacent grade at least as high as the depth number specified on the flood maps; or, together with attendant utility and sanitary facilities, be completely floodproof to or above that level so that any space below that level is watertight with walls substantially impermeable to the passage of water and with structural components having the capacity of resisting hydrostatic and hydrodynamic loads and effects of buoyancy.

(B)A registered professional architect or engineer shall develop or review the design, specifications and plans and certify that the design and methods of construction are in accordance with accepted standards of practice for meeting the provisions of this section and include the specific elevation to which such structures are floodproof. Highest adjacent grade means the highest natural elevation of the ground surface prior to construction and measured next to the proposed walls of the structure.

(6) All construction of fully enclosed areas for access purposes, storage, garages and carports below the regulatory flood elevation shall be designed to automatically equalize hydrostatic flood forces on exterior walls by allowing for the entry and exit of floodwaters. Designs for meeting these criteria must be certified by a registered professional engineer or architect, or provide a minimum of two openings having a total net area of not less than one square inch for every square foot of enclosed area subject to flooding. The bottom of all openings shall be no higher than one foot above grade. Openings may be equipped with screens, louvers, valves or other coverings or devices provided that they permit the automatic entry and exit of floodwaters.

(7) Within the flood fringe district, the top of the lowest floor shall be at or above the regulatory flood, except for nonresidential floodproof structures. (Added by Ord. 99-12)

Sec. 21-9.10-7 Coastal high hazard district.

(a) Within the coastal high hazard district, the uses permitted in the underlying zoning district shall be permitted, provided such uses, improvements, structures and utilities are in compliance with the provisions of Sections 21-9.10 through 21-9.10-14.

(b) In addition to Section 21-9.10-4, the following standards shall be applicable in the coastal high hazard district:

(1)(A) All construction and improvements shall have the lowest floor, including basements, elevated to or above the regulatory flood elevation and securely anchored to piles or columns to resist movement and flotation and such foundation is able to resist the impact and calculated forces of the regulatory flood. Maximum height in agricultural, country or residential districts may be exceeded by no more than five feet, provided such additional height shall not be greater than 25 feet above the regulatory flood elevation. This provision shall also apply to detached dwellings and duplex units in apartment and apartment mixed use districts.

(B) Piles or column foundations and structures attached thereto shall be anchored to resist flotation, collapse and lateral movement due to the effects of wind and water loads acting simultaneously on all building components. Wind and water loading values shall each have a one percent chance of being equaled or exceeded in any given year.

(C) A registered professional architect or engineer shall develop or review the design, specifications and plans and certify that the design and methods of construction are in accordance with accepted standards of practice for meeting the provisions of Sections 21-9.10 through 21-9.10-14.

(2)(A) All construction and improvements shall have the space below the regulatory flood elevation reasonably free of obstruction or constructed with "breakaway walls," open wood latticework, or insect screening intended to collapse under wind and water loads without causing collapse, displacement or other structural damage to the elevated portion of the structure or supporting foundation.

(B) A breakaway wall shall have a design-safe loading resistance of not less than 10 and not more than 20 pounds per square foot, or a registered professional architect or engineer certifies that the breakaway wall shall collapse from a water load less than that which would occur during the regulatory flood. Such enclosed space shall be usable solely for parking of vehicles, building access or storage.

(3) The use of fill for structural support of buildings shall be prohibited.

(4) All new development shall be constructed landward of the reach of the mean high tide.

(5) Human alterations of sand dunes and mangrove stands which would increase potential flood damage shall be prohibited.

(6) Within the coastal high hazard district, the bottom of the lowest horizontal structural member of the lowest floor (excluding the pilings or columns) shall be at or above the regulatory flood. (Added by Ord. 99-12)

Sec. 21-9.10-8 General floodplain district.

(a) All proposed developments within the general floodplain district shall be subject to review and approval of the director. The application, signed and stamped by a registered professional engineer, shall include the following information to evaluate the flooding and to determine whether it is located on a floodway or flood fringe area:

(1) Project location and site plan showing dimensions, topographic data, contours or spot elevation based on reference marks on flood maps, relationship of project to floodway and flood fringe areas as determined by the flood study and existing and proposed control measures and requirements.

(2)(A) Flood study and drainage report, including cross section and profile of the area and the regulatory flood elevation and riverine flood velocities at the project.

(B) Upon review by the director, other information may be required to evaluate the flooding of the site.

(b) The director, with the recommendation of the chief engineer or other appropriate agency, shall evaluate and determine whether the proposed project is located within a floodway or flood fringe area and review the related flood data such as flood elevation, riverine flood velocities, boundaries, etc.

(c) If it is determined that the proposed project is within a floodway area, the project shall comply with the provisions and standards of the floodway district. If it is determined that the proposed project is within a flood fringe area, the project shall comply with the provisions and standards of the flood fringe district. Until a floodway or flood fringe district is designated, no development shall be allowed that would increase the water surface elevation of the regulatory flood more than one foot at any point.

(d) For developments in areas where the flood study and report have been previously reviewed and accepted by the city, the flood study and drainage report information may be waived by the director. (Added by Ord. 99-12)

Sec. 21-9.10-9 Developments adjacent to drainage facility outside the flood hazard district.

(a) Applications for building permits or development projects located on property encompassing or adjacent to a property with any stream, river or drainage facility shall be subject to review and approval of the chief engineer. Upon request by the chief engineer, the application shall include information signed and stamped by a registered professional engineer, in accordance with Section 21-9.10-10, to evaluate the potential flooding of the area.

(b) If it is determined that the proposed project is within a floodway area, the project shall comply with the provisions and standards of the floodway district. If it is determined that the proposed project is within a flood fringe area, the project shall comply with the provisions and standards of the flood fringe district.

(c) No drainage facility, river or stream shall be modified, constructed, lined or altered in any way unless approved by the chief engineer. (Added by Ord. 99-12)

Sec. 21-9.10-10 Application procedures.

(a) All permits required by this chapter regarding subdivisions and other projects within the flood hazard districts shall include the stamp, signature and the following statements of a registered professional engineer and/or architect that, to the best available technical knowledge and information:

(1) The studies, plans, specifications and other documents comply with the standards of the flood hazard district. The structural design, specifications and plans for the construction have been developed or reviewed, and the design and methods of construction to be used are in accordance with accepted standards of practice for meeting the provisions of the flood hazard district.

(2) The floodproofing measures are consistent with the regulatory flood elevation.

(3) The project is adequate to resist the regulatory flood forces.

(4)(A) Structures in the coastal high hazard district are securely anchored to adequately anchored pilings or columns in order to resist the forces of the regulatory flood and not adversely affect the regulatory flood on surrounding properties.

(B) Information shall also include the location of the flood hazard boundaries; location, dimensions and elevations of the property in relation to elevation reference marks on flood maps; regulatory flood elevations, velocity and data; location and elevations of existing and proposed structures, utilities, streets and improvements; and the existing and proposed floodproofing measures and improvements.

(C) Development applications within the general flood plain district shall include the flood documents which were reviewed and accepted by the director.

(D) Whenever applicable, the flood hazard district requirements of a development project shall be determined prior to processing for other approvals mandated by other laws and regulations. (Added by Ord. 99-12)

Sec. 21-9.10-11 Flood hazard variance.

(a) The following, as permitted by other ordinances and regulations, unless otherwise stated, may be permitted as a flood hazard variance from Sections 21-9.10 through 21-9.10-14 subject to review and approval of the director:

(1) New structures, except in the floodway district, which are to be erected on a lot of one-half acre or less in area, contiguous to and surrounded by lots with existing structures constructed below the regulatory flood elevation;

(2) Uses, structures and standards in the floodway district as permitted under the underlying zoning district, which do not result in any increase in the regulatory flood elevation;

(3) Standards in the flood fringe and coastal high hazard districts, except for height standards.

(b) The application shall be submitted to the director and signed and stamped by a registered professional architect or engineer, and shall include three sets of documents with the following information as may be applicable:

(1) Plans and specifications showing the site and location; dimensions of all property lines and topographic elevation of the zoning lot; existing and proposed structures and improvements, fill, storage areas; location and elevations of existing and proposed streets and utilities; floodproofing measures; relationship of the site to the location of the flood boundary; and the existing and proposed flood control measures and improvements.

(2) Cross sections and profile of the area and the regulatory flood elevations and profile based on elevation reference marks on flood maps.

(3) Flood study and drainage report in areas where study and report have not been reviewed and accepted by the city.

(4) Description of surrounding properties and existing structures and uses and the effect of the regulatory flood on them caused by the variance.

(5) Justification and reasons for the variance with consideration of the intent and provisions of this part and information as may be applicable on the following:

(A) The danger to life and property, including surrounding properties due to increased flood elevations or velocities caused by the variance.
(B) The danger that materials may be swept on to other lands or downstream to the injury of others.
(C) The proposed water supply and sanitation systems and the ability of these systems to prevent disease, contamination and unsanitary conditions.
(D) The susceptibility of the proposed facility and its contents to flood damage and the effect of such damage on the individual owners.
(E) The importance of the services provided by the proposed facility to the community.

(F) The availability of alternative locations not subject to flooding for the proposed use.
(G) The compatibility of the proposed use with existing development anticipated in the foreseeable future.
(H) The relationship of the proposed use to the flood plain management program for the area.
(I) The safety of access to the property in times of flood for ordinary and emergency vehicles.
(J) The expected elevations and velocity of the regulatory flood expected at the site due to the variance.
(K) That failure to grant the variance would result in exceptional hardship to the applicant.
(L) That the variance will not result in increase to the regulatory flood elevations, additional threat to surrounding properties and to public safety, extraordinary public expense or conflict with other laws or regulations.

(6) An agreement whereby a covenant will be inserted in the deeds and other conveyance documents of the property and filed with the bureau of conveyances of the State of Hawaii that the property is located in a flood hazard area and is subject to flooding and flood damage. The covenant shall contain a statement that a flood hazard variance to construct a structure below the regulatory flood elevation will result in increased premium rates for flood insurance and such construction below the regulatory flood elevation increases risks to life and property. The covenant shall also state that the property owner or owners will not file any lawsuit or action against the city for costs or damages or any claim, and shall indemnify and save harmless the city from any liability when such loss, damage, injury or death results due to the flood hazard variance and the flooding of the property. Upon approval of the flood hazard variance, such covenants shall be fully executed, and proof of filing with the bureau of conveyances shall be submitted to the director prior to issuance of any building permits.

(7) Such other factors which are relevant to the purposes of this section.

(c) The director shall refer the request to the chief engineer, building superintendent or other appropriate agency for their comments and recommendations. A flood hazard variance may be granted upon showing of good and sufficient cause, and determination that (1) failure to grant the variance would result in exceptional hardship to the applicant; (2) the variance will not result in increase to flood elevations, additional threat to public safety, extraordinary public expense or conflict with other laws or regulations, except as otherwise stated; and (3) a variance granted within a floodway district would not result in increase of the regulatory flood elevation. The director may approve, approve with conditions or deny the application. Such conditions may include:

(1) Modification of the project, including the sewer and water supply facilities.
(2) Limitations on periods of use and operation.
(3) Imposition of operational controls, sureties and deed restrictions.
(4) Requirements for construction of channels, dikes, levees and other flood-protective measures.

(5) Floodproofing measures designed consistent with the regulatory flood elevation, flood velocities, hydrostatic and hydrodynamic forces and other factors associated with the regulatory flood.
(6) Other conditions as may be required by the director. (Added by Ord. 99-12)

Sec. 21-9.10-12 Nonconforming structures within the flood hazard districts.

(a) Any nonconforming structures which were previously lawful prior to the effective date of the flood hazard districts but which are not in conformity with them, may be continued subject to the following conditions:

(1) Repairs and Maintenance. Exemption from the standards of the flood hazard districts shall be permitted for any repair and maintenance work done on any nonconforming structure; provided that the cost of the work done in any period of 12 consecutive months is less than 50 percent of the replacement value of the structure before the work is started, and, if the structure has been damaged and is being restored, that the cost of restoring the structure to its previous condition is less than 50 percent of the replacement value of the structure before the damage occurred.

(2) Damage, Destruction or Demolition. Reconstruction and improvements shall be permitted on any nonconforming structure that is damaged, destroyed, or demolished to the extent that the cost of restoring the structure to its before-damage condition equals or exceeds 50 percent of the replacement value of the structure before the damage or demolition occurred; provided:

(A) The entire structure is reconstructed in conformity with the standards and provisions of the flood hazard district in which it is located;
(B) The damage or demolition occurred within the previous 12 months; and
(C) Reconstruction and improvements within the floodway district shall comply with the standards and provisions of the flood fringe district, and a registered professional engineer shall submit documentation showing that to the best technical knowledge and information, the reconstruction will not increase the regulatory flood elevations that existed during existence of the nonconforming structure.

(3) Exterior Improvements to an Existing Structure. Exemption from the standards of the flood hazard district shall be permitted for any exterior alteration, addition, or remodeling to any nonconforming structure; provided that the cost of the work done in a period of 12 consecutive months is less than 50 percent of the replacement value of the existing structure before the work is started. This cost includes all work, including repairs and maintenance as stated above.

(4) Relocation. If a nonconforming structure is relocated, it shall thereafter conform to the applicable flood hazard district standards, except that any nonconforming structure relocated within the same floodway district shall be exempt from the floodway district standards, subject to the following requirements:

(A) The nonconforming structure is relocated within the same zoning lot within the floodway district;
(B) The relocated structure shall comply with the standards and provisions of the flood fringe district; and
(C) A registered professional engineer shall submit documentation showing that to the best technical knowledge and information, the relocation will not increase the regulatory flood elevations that existed prior to relocation of the nonconforming structure.

(b) Every application for an exemption involving repair, reconstruction, exterior improvements, or relocation for a nonconforming structure in the coastal high hazard or floodway districts, as provided in subsection (a), shall be subject to the following:

(1) Within the coastal high hazard district, a registered professional engineer or architect shall develop or review the design, specifications, and plans and certify that the design and methods of construction are in accordance with accepted standards of practice, and that the structures and improvements would not affect the regulatory flood nor aggravate existing flood-related erosion hazards; or

(2) Within the floodway district, a registered professional engineer or architect shall develop or review the design, specifications, and plans and certify that the design and methods of construction are in accordance with accepted standards of practice, and that the structures and improvements would not result in any increase of the regulatory flood levels. (Added by Ord. 99-12)

Sec. 21-9.10-13 Exemptions.

(a) The following structures and improvements shall be exempted:
(1) Structures listed on the national register of historic places or state inventory of historic places for reconstruction, rehabilitation, or restoration;
(2) Fences and retaining walls;
(3) Interior renovations and improvements;
(4) Repair and maintenance to strengthen or restore any existing building or structure to a safe condition, as declared to be unsafe by an official charged with protecting the public safety;
(5) Demolition;
(6) Outdoor swimming pools;
(7) Signs;
(8) Temporary structures and uses incidental to building construction or land development;
(9) Carnivals, circuses, luaus, and fairs, and camping tents of a temporary nature;
(10) Storage sheds for agricultural, lawn equipment, and other similar storage sheds, including garages and carports;
(11) Streets, roadways, off-street parking lots, including private driveways, bridges and walkways;
(12) Bathhouses, comfort stations, open park pavilions, boathouses, picnic tables and benches, playground equipment, recreational open play courts, and recreational outdoor lighting and landscaping;

(13) Seawalls, bulkheads, wharves, piers, and docks; and
(14) Other structures similar to those as stated above which meet the intent and purpose of this section as determined to be exempt by the director.

(b) Structures and improvements listed under subdivisions (2), (3), (8), and (10) through (14) of subsection (a) shall not be exempted in the coastal high hazard or floodway districts except as follows:

(1) Within the coastal high hazard district, a registered professional engineer or architect shall develop or review the design, specifications, and plans and certify that the design and methods of construction are in accordance with accepted standards of practice and that the structures and improvements would not affect the regulatory flood nor aggravate existing flood-related erosion hazards.

(2) Within the floodway district, a registered professional engineer or architect shall develop or review the design, specifications, and plans and certify that the design and methods of construction are in accordance with accepted standards of practice and that the structures and improvements would not result in any increase of the regulatory flood levels. (Added by Ord. 99-12)

Sec. 21-9.10-14 Other laws and regulations.

All construction and improvements subject to this section shall comply with other applicable laws and regulations including, but not limited to, the building, housing, plumbing and electrical codes, and grading ordinances. This section, designed to reduce flood losses, shall take precedence over any less restrictive, conflicting laws, ordinances or regulations. (Added by Ord. 99-12)

BACKGROUND PAPER #4: SITE PLANNING

INTRODUCTION

This paper examines site planning issues in coastal areas susceptible to tsunami events. It focuses on how to assess a site for hazards; establish a design review approach for new coastal investment; and develop mitigation strategies for various types of development.

The physical configuration of structures and uses on a site—including the siting of structures, location of open space areas, interaction of uses and landforms, design of landscaping, and erection of barriers—can reduce potential loss of life and property damage when development is to be sited within a tsunami hazard area. Within the broader framework of a comprehensive plan, site planning determines the location, configuration, and density of development on particular sites and is, therefore, an important tool in reducing tsunami risk.

Companion Background Paper #3 focuses on avoiding tsunami hazard areas through land use planning, while Background Paper #5 addresses reducing tsunami damage through building design.

KEY CONCEPTS AND FINDINGS

There are three key concepts that organize this background paper.

Concept 1: Create a Project Review Process that is Cooperative, Comprehensive, and Integrated

While Background Paper #2 summarizes the federal, state, and local regulatory context for coastal areas, Background Paper #4 focuses on how local planning officials or project sponsors can work with others to develop tsunami mitigation strategies. This includes:

- Agreeing on the level and nature of risk of the site;
- Exploring mitigation alternatives; and
- Integrating mitigation strategies in the development review process.

Concept 2: Understand Local Site Conditions

Background Paper #1 discusses the global and regional context and sources for understanding tsunami hazards. However, local planning officials and project sponsors have to be able to develop mitigation strategies reflecting the character of the site and immediate context. This includes understanding how tsunamis impact various types of:

- Site geography and configuration;
- Land uses and building types; and
- Development patterns.

Concept 3: Choose a Mitigation Strategy for the Site

This site planning paper provides a general set of methods and techniques that can be applied to projects. It applies four overall techniques to create site-specific mitigation strategies. These methods involve ways to:

- Avoid inundation areas;
- Slow water currents;
- Steer water forces; and
- Block water forces.

WORKING WITH PROJECT SPONSORS

Local planning officials and project sponsors must work with others to develop tsunami mitigation strategies. This requires that project participants:

- Agree on the level and nature of risk on the site;
- Explore mitigation alternatives; and
- Maintain mitigation strategies in the development review process.

This section of Background Paper #4 focuses on understanding the regulatory context, basic steps in the site design process, and how to include tsunami mitigation in the planning process.

Understanding the Context: Federal, State and Local Regulations

Every project has a set of federal, state, regional, and local policies and regulations that have to be satisfied. Understanding the regulatory context is critical in the site planning process.

State and Federal Policy and Regulatory Context

Every coastal community in the five Pacific states has a land use planning and regulation process that responds to state mandates or guidelines. Most states have statewide planning guidelines, require local plans to be consistent with state policies, and require hazard mitigation in local comprehensive plans and environmental review (see Background Papers #2 and #3). Federal Flood Insurance mandates projects be located above the 100-year flood or inundation areas.

Many states require public access or use of waterfront areas as well. These regulations limit the location, uses, and character of development and become part of the equation for new coastal investment.

Local Regulations

At the top of the local land use planning/regulatory process hierarchy is the community's comprehensive plan. The comprehensive plan is implemented day-to-day through "current planning" project review and permitting. Local governments typically require formal approvals for land divisions, the establishment of certain new uses ("conditional uses"), and the physical layout of new development. At the site planning level in the planning/regulatory hierarchy, the focus typically is on a single parcel or collection of parcels of land two to 200 acres in size, under the control of a single owner. This scale of planning provides limited opportunities for avoiding the tsunami hazard entirely, but can still provide a broad range of opportunities to design a project to minimize tsunami damage.

Site Planning and Review Process

The most effective site planning in coastal areas includes a project review process that reflects the area's vulnerability and exposure to tsunami hazards, considers the larger policy and regulatory context, and is a part of a larger mitigation strategy. An interactive and informed site planning and review process can save time for project sponsors and provide better mitigation solutions.

Communities interact with project proponents at various levels in the preparation and review of site plans. The level of review relates to the scale and context of a project. Some projects require site and concept review, while others require a review of fully developed designs. Community-level project review can take place parallel to the design process in an interactive fashion. Alternatively, project site review can be more reactive based on predetermined criteria or plans.

Some communities have adopted comprehensive development policies for waterfront areas to ensure that site planning is part of a review process that implements a larger mitigation plan, economic objectives, and community design concepts. Without this broader framework, community-wide mitigation objectives can be overlooked in a site plan review process that involves different disciplines and multiple departments and decision-making bodies.

Site Analysis: Setting the Mitigation Framework

The site analysis phase can be used to establish site plan parameters for tsunami hazard mitigation. Many communities have already mapped hazard areas (although these maps are not always reliable at the scale of a single site). Within these areas, communities may also have area plans that have included site analysis. The analysis typically includes geographic conditions, landscape, critical infrastructure (see Background Paper #6), area access and egress (see Background Paper #7), and existing and future development patterns. Experts should be consulted to accurately define the hazard area. Other considerations include economic feasibility and community design objectives.

UNDERSTANDING LOCAL SITE CONDITIONS

Local planning officials and project sponsors must develop mitigation strategies reflecting the character of the site and immediate context. This includes understanding how tsunamis impact various types of site geography, land uses and building types, and development patterns. The depth of tsunami inundation, speed of currents, presence of breaking wave or bore conditions, debris load, and warning time can vary greatly from site to site.

Understanding the Context: Regional Geography and Multiple-Hazards

At the local level, the geographic context has an important bearing on the amount of risk exposure in an area. In all five Pacific coastal states, hazards maps are available, being updated, or underway that define elevations and locations susceptible to tsunamis. However, not all coastal areas are covered by these maps. In addition, most communities that have experienced tsunamis have historic and geologic records that indicate high-risk areas. Most of this experience has been with distant-source tsunamis, not the rare local source tsunamis. For rare tsunami events, very few coastal communities have any records at all.

The site analysis phase can be used to establish site plan parameters for tsunami mitigation. Many communities have mapped hazard areas. Within these areas, communities may also have more detailed plans that include site analysis. The analysis typically includes geographic conditions, critical infrastructure (see Background Paper #6), area access and egress (see Background Paper #7), and existing and future development patterns. Other considerations include economic feasibility and community design objectives.

Regional hazard maps can identify many of these at-risk areas, but typically they do not reflect the catastrophic potential of a tsunami that is accompanied by other disasters. Besides inundation, near-source earthquakes can cause damage and possibly lower the elevation of the entire region, causing flooding. Fires, broken infrastructure, liquefaction, mudslides, erosion, and other hazardous conditions can create scenarios that make communities even more vulnerable to tsunami waves. Therefore, each site assessment should identify other hazardous conditions besides elevation and shoreline configuration.

Designing for Specific Site Conditions

Communities and project sponsors need to assess the types of shoreline conditions of the site in order to identify a mitigation strategy. The following summarizes various types of shoreline conditions and related site planning considerations.

Beach Communities

Many cottages and homes located along beaches are susceptible to tsunami damage. Numerous tsunami deaths have occurred in these small rural communities. Existing access roads and lot patterns have been developed without considering potential tsunami inundation. Over time these areas have been subdivided and more individual homes added.

In larger resorts, hotels have been located parallel or diagonal to the shore to capture views with recreational facilities in between the shoreline and buildings. Unless designed to withstand a tsunami, these structures are vulnerable.

Beach communities exist because of the lifestyle and visitor industry opportunities created by the water. Therefore, adjacency and views of the beach are at a premium. Many beach communities have to balance their economic dependence on the ocean setting and their tsunami risk.

There are also large regional-serving facilities located in low-lying shoreline areas. Older sewage treatment facilities, power plants, and industrial uses may be located within inundation areas. Inundation of these facilities can cause severe environmental damage from chemicals and bacteria.

Bays

Bays, coves, and river inlets are especially susceptible to tsunami run-up. Their morphology can funnel water into rural delta and valley communities, inundate harbors and town centers, and knock out bridges. Tsunami damage can increase in a scenario that includes high tides, storm surge, or liquefaction from an earthquake.

Harbors

"Tsunami" means "harbor wave" in Japanese. Harbor towns provide the best-known case studies of tsunami disasters. They are susceptible for many of the reasons mentioned previously. They are in coves, may have rivers, and are developed close to the water's edge. Small shipyards, fishing fleets, marinas, and commercial activities ring harbors. One of the things most notable about tsunami aftermath mapping of harbor towns is where all the boats end up.

Ports

In the past 30 years, commercial maritime facilities have shifted to containerization, which requires large paved yards. These slick surfaces can spread wave damage and float trailer-sized debris.

MITIGATION STRATEGIES

Many communities work with project sponsors to select a mitigation approach during the site planning process. Generally, this includes siting solutions that avoid, slow, steer or block inundation. These can be blended with building design and engineering that provides hardened or passive ways of handling the force of a tsunami (see Background Paper #5). Depending on the land uses and site characteristics, a single or hybrid mitigation approach could be used.

There are four basic site planning techniques that can be applied to projects to reduce tsunami risk:

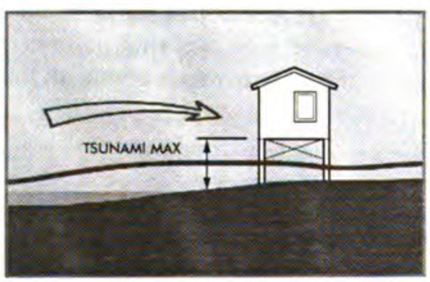
- Avoid inundation areas;
- Slow water currents;
- Steer water forces; and
- Block water forces.

These basic strategies can be used as separate mitigation approaches or be combined into a broader strategy. These include passive methods to allow tsunamis to pass through an area without causing major damage, and methods to harden structures and sites to withstand the force of a tsunami. The efficacy of these techniques depends on the intensity of the tsunami event. If the tsunami hazard is underestimated, development in the area may still be vulnerable to a larger event.

The techniques can be studied both in plan and site sections to reveal vertical stratification of uses, avoidance, and barriers; and in the plan view to understand where water is steered by development, egress routes, and the potential distribution of debris.

Avoiding

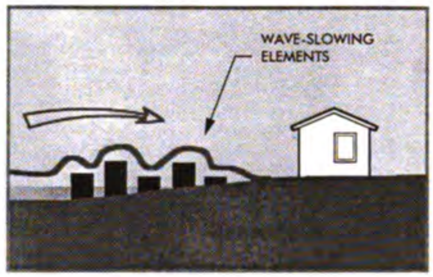
Avoiding a tsunami hazard area is, of course, the most effective mitigation method. At the site planning level, this can include siting buildings and infrastructure on the high side of a lot or elevating structures above tsunami inundation levels on piers or hardened podiums.



Avoiding

Slowing

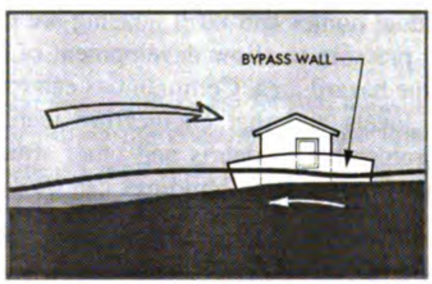
Slowing techniques involve creating friction that reduces the destructive power of waves. Specially designed forests, ditches, slopes, and berms can slow and strain debris from waves. To work effectively, these techniques are dependent on correctly estimating the inundation that could occur.



Slowing

Steering

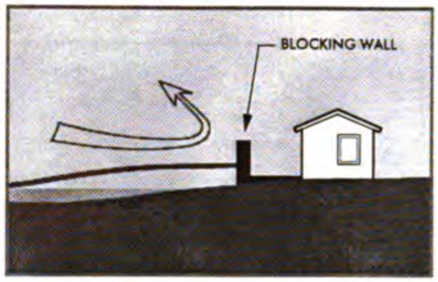
Steering techniques guide the force of tsunamis away from vulnerable structures and people by strategically spacing structures, using angled walls and ditches, and using paved surfaces that create a low-friction path for water to follow.



Steering

Blocking

Hardened structures such as walls, compacted terraces and berms, parking structures, and other rigid construction can block the force of waves. Blocking, however, may result in amplifying wave height in reflection or in redirecting wave energy to other areas.



Blocking

Mitigation Strategies for Various Types of Development

The following describes various types of new development that may be exposed to tsunami damage and identifies possible mitigation strategies for these different types of development.

Infill Housing

In small communities, individual homes and infill housing are the most common development. Often, there is great political pressure to allow development of smaller sites that do not permit locating development out of the hazard area. Communities can require that these smaller projects be raised above inundation levels and that engineering features be added to their design. However, they can still be vulnerable to debris and other structures that may break free and collide with them. In some cases, new infill buildings can be sited on the high side of a lot to avoid being hit by another structure.

New Neighborhoods and Subdivisions

To reduce tsunami damage, the layout of new subdivisions in shoreline areas can include:

- providing maximum spacing between buildings;
- elevating buildings above inundation levels;
- placing houses behind a tsunami control forest or larger hardened buildings; and
- siting primary access roads outside inundation areas and secondary access roads perpendicular to the shore.

High-Rise Hotels

New hotels in coastal areas are typically multi-level concrete frame structures. The lower levels of these buildings can be designed for public areas such as lobbies and support uses (such as parking) for upper level rooms. In Hawaii, for example, lower levels of hotels have been designed to allow waves to pass through the ground floor parking, lobby, and service spaces leaving upper level rooms and meeting spaces undamaged. These buildings must be designed to withstand both tsunami and earthquake forces.

Elevated restaurant in Hilo, Hawaii. Lower level is designed to allow waves to pass through.
Credit: Mintier & Associates

Resorts

Resorts can include a broad range of facilities and services, including small-scale cottages, large hotels, tennis facilities, swimming pools, golf, and beach-related recreation. Resort planning can draw on a variety of mitigation methods, including open space and tsunami forests, elevating or locating structures above estimated inundation levels, and buffering smaller buildings with larger hotels and waterfront structures.

Community Commercial

The downtowns of most coastal communities are located adjacent to piers and beach areas. The primary access roads typically follow the coastline and are lined with commercial enterprises. Both of these development patterns are susceptible to damage by tsunamis. Strengthening and expanding harbor structures can help protect adjacent commercial areas. Depending on the tsunami, however, breakwaters can be swamped by the rising tide and be ineffective. New buildings can be elevated above inundation levels and hardened and designed to withstand tsunami forces.

Industrial

Dry docks, refineries, power plants, and other shoreline industrial facilities are of special concern. In large tsunamis, damaged oil facilities and shoreline industry can wreak havoc in harbors and bays. Destruction or flooding of industrial facilities can add another environmental dimension to a tsunami disaster with burning oil, toxic chemicals, and other hazardous materials. Floating buildings, debris, and boats can crush pipes and tanks. Protecting industrial facilities with walls and stronger anchoring can help; however, locating these types of uses outside inundation zones is the most effective mitigation technique.

Damage to port facilities in Seward, Alaska, from the 1964 tsunami.
Locating industrial facilities outside inundation zones is the most effective mitigation technique.
Credit: U.S. Army Corps of Engineers

Essential and Critical Facilities

Fire stations, power substations, hospitals, sewage treatment facilities, and other critical infrastructure generally should not be located in inundation zones. Relocation of these types of facilities out of inundation areas should be an integral part of any tsunami mitigation plan. Where essential service facilities such as fire stations or permanent lifeguard stations must be located in tsunami hazard areas, they should be designed or retrofitted to survive tsunami damage. This topic is discussed in more detail in Background Paper #6.

Table 4-1 identifies possible mitigation methods for these different types of development.

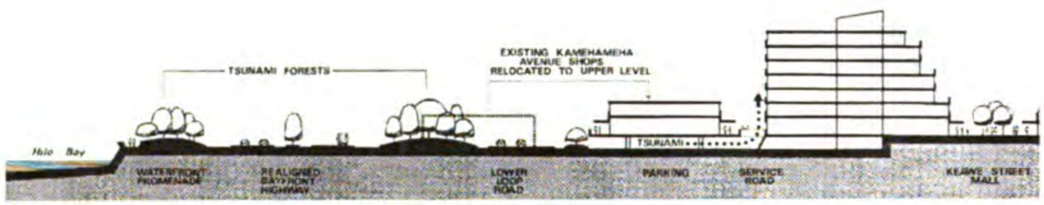
Table 4-1. Mitigation Methods for Selected Types of Development

	Avoidance Methods	Steering Methods	Slowing Methods	Blocking Methods
Infill Housing	• Locate on high side of lot • Elevate above inundation levels on piles or fill	• Maximum spacing between buildings	• Plant tsunami forest in front of single family neighborhoods	• Place larger structures in front of single family structures
New Neighborhoods and Subdivisions	• Locate on high side of lot • Elevate above inundation levels on piles or fill • Locate access roads outside inundation areas	• Maximum spacing between buildings • Place buildings to steer water and floating debris and structures away • Walls and ditches	• Plant tsunami forest in front of single family neighborhoods • Walls and ditches	• Place larger structures in front of single family structures
High-rise Hotels	• Locate rooms above inundation levels on a parking podium • Orient narrow face of the building towards tsunami	• Place buildings to steer water and floating debris and structures away • Walls and ditches	• Place buildings to slow water and floating debris • Walls and ditches • Plant tsunami forest	• Walls • Hardened building design
Resorts	• Locate smaller buildings on the high portions of the site • Elevate structures above inundation levels on piles or fill • Orient narrow face of the building towards tsunami • Locate access roads outside inundation areas	• Maximum spacing between buildings • Place buildings to steer water and floating debris and structures away • Walls and ditches • Grade and pave surfaces	• Place buildings to slow water and floating debris • Walls and ditches • Grading • Plant tsunami forest	• Place larger structures in front of smaller structures • Walls • Hardened building design • Breakwaters for marinas
Community Commercial	• Elevate structures above inundation levels on piles or fill • Orient narrow face of the building towards tsunami • Locate access roads outside inundation areas	• Walls and ditches • Grade and pave surfaces	• Place buildings to slow water and floating debris • Walls and ditches • Grading • Plant tsunami forest	• Walls • Hardened building design
Industrial	• Elevate structures above inundation levels on piles or fill • Locate hazardous and critical operations on high side of lot or relocate • Orient narrow face of the building towards tsunami • Locate access roads outside inundation areas	• Place buildings to steer water and floating debris and structures away • Walls and ditches • Grade and pave surfaces	• Place buildings to slow water and floating debris • Walls and ditches • Grading • Plant tsunami forest	• Place larger structures in front of smaller structures • Walls • Hardened building design • Breakwaters for docks
Critical Facilities	• Relocate facilities to areas outside inundation zone	NA	NA	NA

CASE STUDY: HILO DOWNTOWN DEVELOPMENT PLAN

The Hilo Downtown Development Plan was adopted in 1974 to guide efforts to revitalize the downtown core of Hilo, Hawaii. The Plan established a Safety District based on the 1946 and 1960 inundation experience lines. All redevelopment in the Safety District was subject to urban design and building design standards. Any structure below the 20-foot elevation contour line was required to be designed to withstand the force of a major tsunami. A Parking District was also designated in the Plan to provide parking for downtown businesses and to use parking structures as a protective barrier for inland structures from a tsunami. Parking facilities have been constructed in accordance with the Plan.

In 1985, the Hilo Downtown Development Plan was superceded by the Downtown Hilo Redevelopment Plan under the authority of Chapter 27, Flood Control, of the Hawaii County Code.



A section through the lower downtown area from the *Hilo Downtown Development Plan. Credit: County of Hawaii*

BACKGROUND PAPER #5: BUILDING DESIGN

INTRODUCTION

This paper describes how tsunami risk can be mitigated through building design and construction. It describes considerations that affect the design and construction of buildings in tsunami hazard areas, describes available building codes and guidelines relating to tsunami-generated forces, and provides general advice on an approach to the design of new and the retrofit of existing buildings. Companion Background Paper #3 focuses on avoiding tsunami hazard areas through land use planning, and Background Paper #4 addresses reducing tsunami damage through site planning.

Damage to buildings in Hilo, Hawaii, from the 1946 tsunami.
Credit: Pacific Tsunami Museum

KEY CONCEPTS AND FINDINGS

This background paper presents five key concepts. Essentially, these are an extension of those presented in Background Papers #3 and #4, which deal with planning decisions and site considerations. Assuming planning and zoning requirements are met and that the site is or can be made usable, the design and construction process can begin. The best time to consider preventing tsunami losses to buildings is during the earliest project design stage where the performance objectives and standards are set. These decisions govern the final design and eventual construction.

Concept 1: Understand and Describe the Nature and Extent of Tsunami and Other Hazards Affecting the Building Site

Background Paper #1 provides background information needed to conduct local tsunami risk studies, and Background Papers #3 and #4 focus on planning and siting considerations. While general "rules" exist to prevent losses to buildings, they have to be applied on a building-by-building basis because of differences in uses, sizes, configurations, materials, site characteristics, and other factors. Mitigation considerations include:

- Working in advance with the project's sponsors/owners to ensure an understanding of the risk and general strategies for preventing future losses;
- Adapting and applying appropriate codes and standards to the building design;
- Ensuring site characteristics and mitigation measures are considered in the design; and
- Enforcing design and construction requirements through adequate and independent plan checking and construction inspection procedures.

Concept 2: Determine the Performance Objective for the Building or Structure and the Uses it Will Provide

For many reasons, some buildings are more important than others. This may be due to their function, nature of their occupancy, or activities included in them. For example, hospitals and schools may be assigned higher performance objectives than those given to tourist accommodations. Regardless, every building in a tsunami-hazard area should be constructed to at least meet the minimum tsunami-resistant building code requirements. Several activities include:

- Ensuring the community has adequately enforced minimum code requirements appropriate for the tsunami hazard and for other local hazards;
- Determining which buildings, because of their higher relative importance, should be governed by higher-than-minimum codes, standards, and approval and inspection processes; and
- Requiring through the plan review and construction inspection processes that the importance of the building is recognized and adhered to in construction.

Concept 3: Avoid Constructing New Buildings in High Tsunami Hazard Areas

Insofar as practical, siting new buildings in high hazard areas should be avoided. This reduces community vulnerability by limiting exposure in high hazard areas. Key strategies include:

- Examining proposals and plans for new buildings to see if equally efficient alternative locations can be used;
- Determining if incentives, such as transferring development rights, are available and can be used to promote development in less hazardous areas; and
- Enacting controls to prevent the construction of new buildings—and possibly requiring the removal of many existing ones—in the high hazard areas.

Concept 4: Require Buildings to be Elevated Above the Expected High Water Elevation

As in other flood hazard management programs, buildings can be required to be elevated above the expected tsunami inundation level. This would mean having open ground floors with restricted uses. Key considerations could include:

- Requiring similar elevated design requirements of buildings in tsunami areas as are required in flood prone locations;
- Ensuring that design standards exist that account for tsunami forces and earthquake ground motions; and
- That construction requirements account for water borne debris impact in addition to the tsunami force itself.

Concept 5: Use Qualified Coastal and Structural Engineers and Architects Experienced in Designing (or Retrofitting) Buildings to Resist Tsunami Forces and the Effects of Inundation

Good design and engineering can greatly minimize the effects of tsunamis on buildings. Communities should ensure that design professionals qualified in structural, coastal, and geotechnical engineering are used on projects in high hazard areas. Communities should:

- Identify proposed projects that should involve specially qualified professionals;
- Ensure that project sponsors secure the specialized assistance as early as possible in their project planning; and
- Locate both local and distant sources of qualified assistance that can be contacted when needed.

OVERVIEW OF EXISTING REGULATIONS AND PROGRAMS

Although good engineering techniques and materials will help a building resist tsunami forces and inundation, in cases of intense tsunamis, they only will reduce losses but not prevent severe damage. The best approach to minimizing or avoiding tsunami losses is to locate buildings beyond the reach of run-up.

The design of a building to achieve a particular performance level following tsunamis—that is, the amount of damage the owner can tolerate and the ability of the building to support its intended uses after tsunamis strike—depends on an integrated set of decisions that begin with determining the importance of the building, understanding the consequences of damage, and deciding how much damage can be tolerated. A performance objective expresses this tolerance. Performance depends on the intensity of the tsunami hazard; the location of the building and its configuration (size, shape, elevations, orientation); building codes and standards; choice of structural and finish materials; reliability of utilities; the professional abilities of designers; and the quality of construction. Building codes and standards are but one aspect of an integrated set of planning and design decisions that affect the construction cost, day-to-day functionality, the value of facilities, and their susceptibility to damage. Achieving the desired performance requires that all who participate in decisions affecting these factors agree on performance expectations, understand how their decisions affect performance, and are able to do the work. Ultimately, the owner is responsible for defining acceptable performance and for ensuring the entire design and construction team follows through.

Damage to building in Hilo, Hawaii, from the 1960 tsunami.
Although there are engineering techniques and materials that can be used to resist tsunami forces and inundation, in cases of intense tsunamis, they will only reduce losses but not prevent severe damage.
Credit: Pacific Tsunami Museum

Building design is governed by engineering principles and practices and building codes that establish minimum standards relating to public health and safety. However, codes are not a substitute for competent engineering and design or construction and quality assurance. The circumstances applicable to each building differ, and thorough and independent consideration must be given to each building to be sure the approach and results are appropriate. Each design professional must maintain expertise in this rapidly advancing area of specialization and exercise independent judgement. Knowledge regarding tsunamis and building performance is constantly changing and improvements should be anticipated.

Building Codes

Building construction in the United States is governed at the local level by building codes. Building codes establish minimum acceptable requirements for protecting life, addressing property damage, and preserving the public health, safety, and welfare in the built environment. Building codes are applied to new construction as well as existing buildings undergoing reconstruction, repair, rehabilitation or alteration, or when the nature of the use is changed to a new occupancy that increases the risk or exceeds the structural capability of the building.

Most local building codes used in the Pacific states are modified or unmodified versions of the Uniform Building Code (UBC) prepared by the International Conference of Building Officials. In California, Oregon, and Washington, the state governments mandate code adoption and enforcement at the local level. Alaska only mandates adoption of a fire code and Hawaii does not have a state-mandated building code (see Background Paper #2). However, all the counties in Hawaii and the larger cities in Alaska have adopted a version of the UBC. The three Pacific States mandating the use of the UBC allow local government amendments that are more stringent than the state-mandated code.

The UBC includes design requirements and standards for fire, wind, floods, and earthquakes, but it does not contain requirements for tsunami-resistant design. Appendix Chapter 31, Division I, contains provisions for flood-resistant construction consistent with the requirements of the FEMA Flood Insurance Program. These requirements apply to buildings or structures in flood hazard zones and coastal high hazard zone (V zones). According to these provisions, buildings and structures are to be located at an elevation above the base flood elevation. Portions of the structure below this elevation have use limitations and must either be designed to break away or be impermeable to water. Structural members and impermeable walls are to be designed for flood water forces and scour. Specific rules are not given, but a licensed architect or engineer must be responsible for the design and provide calculations supporting the design to the building official.

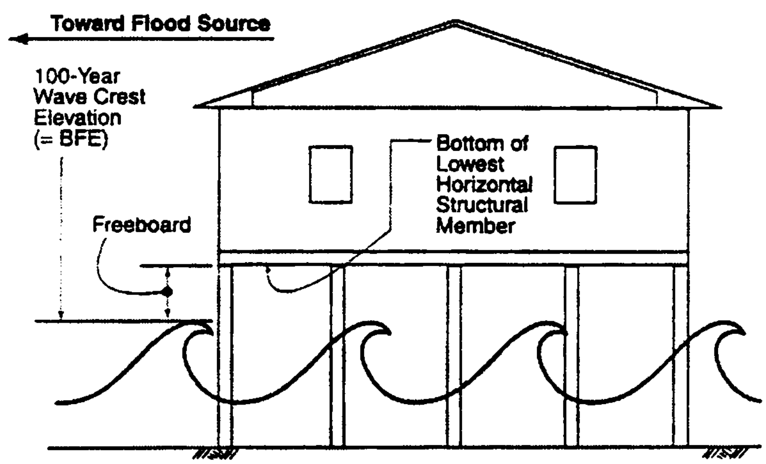
The City and County of Honolulu enforces the Uniform Building Code and special requirements for flood and tsunami adopted as Article 11, *Regulations Within Flood Hazard Districts and Developments Adjacent to Drainage Facilities*, as part of its Revised Ordinances. It applies to the design and construction of all new buildings and structures, relocation and major alterations, and additions to or reconstruction of existing buildings lying within the flood hazard and coastal high-hazard districts as delineated on the flood boundary and floodway maps and flood insurance rate maps published by the Federal Emergency Management Agency. Article 11 includes provisions for structural design of buildings and structures subject to coastal flooding specifically addressing hydrostatic loads, hydrodynamic loads, impulsive loads, soil loads, and tsunami loads. The tsunami loads include buoyant forces, surge forces, drag forces, impulse (impact) forces, and hydrostatic forces. Article 11 serves as a general model regarding how a municipality might address tsunami forces through its building code. However, the technical provisions of the ordinance are not recommended because of significant differences in the design forces derived in Article 11 compared to the forces derived by application of the FEMA *Coastal Engineering Manual*. Consensus values, or values based on the latest research, should be used in calculating dynamic and impulsive forces and other factors used in building design. The text of Article 11 is included in Appendix 5-1 and can be found at:
(http://www.co.honolulu.hi.us/refs/roh/16a11.htm).

Relationship to Other Hazards

Tsunamis are only one of several hazards affecting development located along the coastal margins of the states bordering the Pacific Ocean. The key components of resistance to tsunami, earthquake, flood, fire, erosion, and other hazard-induced forces are: competent designs prescribing continuous and well-connected structural systems, and proper construction using quality materials and skilled workers. While force levels and conditions during different types of hazard events vary considerably, there are common factors. Following code requirements for these other hazards will improve tsunami resistance of buildings, especially those located in areas where large hydrodynamic and impact forces are not expected. Because of these common factors, a fundamental measure to improve the performance of buildings in tsunamis is to enforce building codes and standards addressing all of the hazards at a site.

Coastal Engineering Guidelines

Guidance for architects and engineers in the design for tsunami forces is included in the revised version of FEMA's *Coastal Construction Manual,* also known as FEMA 55. The manual deals with tsunamis in a manner similar to the Honolulu ordinance, but there are significant differences. The *Coastal Construction Manual* refers to many newer documents and is more timely than the Honolulu ordinance, which appears to have been amended last in 1987. Appendix 5-2 consists of a comparison of Section 16-11.5 of Article 11 of the City and County of Honolulu code with Chapter 11 of Volume II of the revised FEMA *Coastal Construction Manual.*



b. Exceeding NFIP Elevation Requirement in V Zones and Coastal A Zones

Flood Zone V requirements in the *Coastal Construction Manual.*

The Coastal and Hydraulics Laboratory (CHL), a part of the US Army Corps of Engineers Research and Development Center, publishes two relevant documents. The *Shore Protection Manual,* 4th edition, published in 1984, is readily available. However, the manual is undergoing an extensive revision and will be published under a new name, the *Coastal Engineering Manual.* Parts of the new manual are available for review at the CHL web site:
(http://chl.wes.army.mil/library/publications).

A second Corps of Engineers reference, *Coastal Engineering Technical Notes,* is available on the same web site. Technical notes are short descriptions that identify problem areas and provide techniques or data for solutions to engineering problems. The notes promote discussion regarding changing information and are issued as new information becomes available. For example, CETN-III-38 provides a method to compute wave forces on walls. The two manuals and technical notes provide the methods and values needed by engineers to determine force levels and design tsunami-resistant structures.

BUILDING DESIGN PROCESS

The following describes the considerations that should be addressed in the design of new—or the retrofit of existing—buildings in tsunami hazard areas.

Understand the Hazard

The intensity and frequency of tsunami events vary greatly along the Pacific Ocean shoreline and at each locality based on site specific and on-land conditions (see Background Paper #1). Intense tsunami forces associated with wave surge can inundate two- and three-story buildings, create currents in excess of 50 feet per second, propel debris weighing tons, and scour sand from beaches and undermine foundations. In the same event, sites only hundreds of yards away, or nearby sites at higher elevations may only experience the wetting effects of a few feet of slow moving water. Differences in the hazard are critical to design, but they are subject to a great deal of uncertainty. The challenge is defining the hazard in terms relevant to building design.

Define Performance Levels

How a building should perform in a tsunami depends on the uses supported by the building during and after the event and the needs and expectations of the owner and occupants. "Performance levels" describe these expectations in terms of damage and the building's ability to support occupant activities after a hazard event. The desired performance level combined with the probability and intensity of the event, and the level of confidence that the performance will be achieved are combined to express a "performance objective." Although statistically valid quantitative data do not exist to compute structural reliability for tsunami conditions, a qualitative consideration of these factors will give the building owner and design professionals useful information. An owner could consider the following goals:

- Protect the public from harm
- Protect public health (releases of contaminates and toxic and flammable materials)
- Provide essential public emergency services (police, fire, and emergency management)
- Provide the infrastructure needed for commerce (access, utilities)
- Prevent environmental degradation (release of pollutants)

Four performance levels are suggested:

Minimum Level—Buildings located, designed, and constructed to this level can withstand hydrostatic and hydrodynamic forces without being moved off their foundation or off site. Buildings might suffer extensive damage from flooding and may not resist the impact of debris, wave break forces, scour, or ground failure. These buildings would meet the minimum standards for other hazards. Occupants of these buildings must be prepared to evacuate off site to be safe.

Safety Level—Buildings located, designed, and constructed to this level should withstand forces from hydrostatic and hydrodynamic (pushing and drag) pressures and debris and wave-break impact (see Table 5-2 below). They should have foundations designed in anticipation of scour erosion and saturation. People can evacuate vertically to floors above the level of wave action. Extensive damage could be expected to parts of the building affected by flooding and hydrodynamic and debris impact forces, but structural integrity would be maintained. These buildings would be designed to withstand earthquake shaking, induced ground failure, and fire without significant structural damage. Depending on a building's height and location, it could serve as a refuge from near source tsunamis.

Reoccupancy Level—Buildings located, designed, and constructed to this level can withstand the same forces as safety level buildings and be occupied and functional within a few weeks after clean up, minor repairs, and restoration of utilities. Meeting this standard would require more stringent location restrictions and choice of flood-resistant materials. Building location and the elevation of the lower floors are critical considerations.

Operational Level—Buildings located, designed, and constructed to this level can withstand the same forces and effects as in the Reoccupancy Level, but must have back-up emergency systems (utilities, etc.) needed to support use of the building immediately after the tsunami. These buildings preferably would be located outside of the tsunami hazard area.

Select the Intensity of Design Events

Small tsunamis are less damaging, but are more frequent than more intense events. Very large events may be extremely rare and might not be considered except for critical facilities. The probability of occurrence—or the return interval—describes the frequency and intensity of events. Guidance on selecting event frequency and intensity can be taken from the way other hazards are addressed. Design should consider a tsunami with a recurrence of once every 500 years. Buildings with essential uses and large numbers of hard-to-evacuate-people in areas threatened by near-shore-generated tsunamis should consider larger events that recur once every 2,500 years. By designing for a larger event with a longer recurrence interval, the design will consider higher water levels and greater forces. Table 5-1 provides exceedance levels—that is the chance a level will be met or exceeded within a selected time span for different hazards.

Table 5-1. Event Frequency and Design

Hazard Event	Being Exceeded	Return Interval (years)	Design Application
Earthquake			
Design Basis Earthquake (DBE)	10 percent in 50 years	475	Used to determine the design shaking levels for construction under the Uniform Building Code.
Upper Bound Earthquake (UBE)	10 percent in 100 years		Used for design of hospitals, schools, and essential facilities in California.
Maximum Considered Earthquake (MCE) [1]	2 percent in 50 years	2,500 +/-	
Maximum Credible Earthquake			
Flood			
Base Flood	1 percent in one year	100	Defines the Base Flood as the elevation of the crest of the flood. New buildings and substantial improvements to existing buildings must be elevated or "flood-proofed," and manufactured homes raised above this elevation. In Coastal High Hazard Areas[2], the building can be elevated only on a foundation of piers, piles, or columns.
Zone B		500	An area of moderate flood hazard depicted on Flood Insurance Rate Maps as the area lying between the limits of the base and 500-year flood elevations.
Wind			
Normal buildings	2 percent in one year	50	The basic wind speed for buildings if it exceeds the minimum velocity of 70 mph.
Important buildings	~1 percent in one year	~100	An importance factor of 1.15 is used to increase the force from the basic wind speed.

[1] In California where large earthquakes are frequent, the MCE for coastal areas generally has a return period of once per thousand years.

[2] Coastal high hazard flood areas are subject to high velocity water and waves of greater than three feet in height. These areas include hurricane wave wash and tsunamis and are mapped as Zone V. Areas without high velocity are mapped as Zone A. In Zone V areas, all new buildings must be elevated on pilings and columns so: 1) The lowest horizontal structural member is elevated above the base flood level; 2) An engineer or architect certifies the foundation anchoring; and 3) Areas below elevated buildings are open or enclosed using breakaway walls.

Modify Building Codes and Design Standards

Codes, standards, and other requirements currently governing coastal construction should be modified to address tsunami hazards for new buildings and structures. Local jurisdictions should require a minimum performance objective, and encourage owners to decide on higher performance objective(s) if needed. Building code requirements should be enforced for all hazards, especially for earthquakes in areas where local tsunamis may originate. Codes and standards alone do not guarantee buildings capable of withstanding tsunami forces. Engineering judgment, site specific analysis, and good construction are all essential to meeting desired performance objectives. Experienced coastal and structural engineers should be engaged to design important buildings located within tsunami hazard zones. Moreover, all substantial developments should be designed based on a tsunami hazard study completed by a qualified coastal expert.

Recommendations should be coordinated with practices for other hazards, since they share the same principles of resistance and performance (e.g., in Hawaii, tsunami requirements are tied to flood zones determined by FEMA to be coastal flooding zones). In areas where locally-generated earthquakes will cause groundshaking and failure, building code provisions for earthquakes must be enforced.

Anchor bolts. Measures to resist earthquake shaking, such as anchoring and bracing buildings, can also help to reduce tsunami damages.
Credit: Northridge Collection, Earthquake Engineering Research Center, University of California, Berkeley

Adopt and Enforce Special Provisions Governing Removal, Relocation, or Retrofit of Existing Buildings

Retrofit of existing buildings should be encouraged when the effort will improve tsunami resistance to a level capable of meeting identified performance objectives of owners and occupants, or minimize floating debris that can damage nearby buildings. However, relocating buildings to less hazardous locations and considering certain buildings to be expendable are techniques to manage tsunami risk.

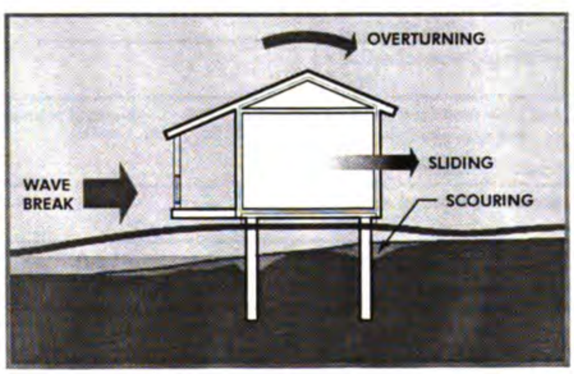
The standards for upgrading buildings involve the same factors as constructing new buildings, but upgrading to achieve a selected performance objective is more expensive to implement after initial construction is completed. Dealing with the vulnerability of existing buildings is difficult because of the limited number of alternatives and cost of remedial activities that will withstand hydrodynamic and impact loads.

Astoria, Oregon, at the mouth of the Columbia River.
Many of the tsunami risk mitigation techniques used for new development can be applied to existing development, but their application will be limited by site constraints and building conditions.
Credit: Army Corps of Engineers

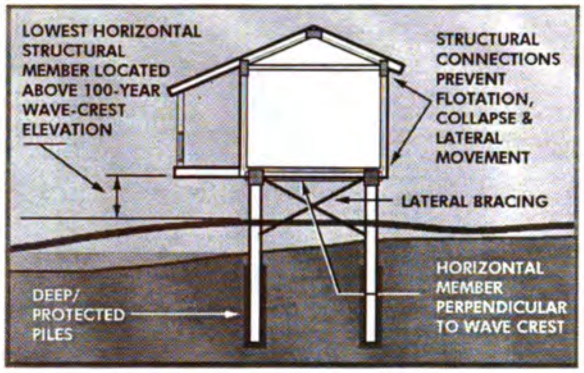
An owner should, in determining the desired performance level, consider the frequency and intensity of the tsunami hazard, the desired level of reliability, and the vulnerability of the building. If the expected performance is unacceptable, various remedial alternatives to improve the performance of the building can be considered. Measures that improve resistance to tsunamis in combination with other more-frequently occurring hazards are more likely to be feasible. These include raising buildings above the base flood elevation, improving foundations to resist scour and erosion, and anchoring and bracing the buildings to resist earthquake shaking. Although these measures will reduce tsunami damages, especially in the statistically-more-frequent small tsunamis, they will not ensure that a building will withstand the intense conditions associated with larger events.

BUILDING CONSTRUCTION MEASURES

Design and construction of new buildings and the retrofitting of existing buildings should address forces associated with water pressure, buoyancy, currents and waves, debris impact, scour, and fire.



Forces on structures created by tsunamis



Design solutions to tsunami effects

Substantially-built buildings of concrete, masonry, and heavy steel frames are likely to do fairly well in a tsunami unless compromised by earthquake shaking. Woodframe buildings, manufactured housing, and light steel frame structures at lower elevations close to the shoreline are likely to fare poorly. However, not every area affected by tsunami run-up will experience damaging forces. Buildings in these less hazardous areas affected by shallow run-up water depths should survive with repairable damage if well designed and constructed. The force of currents and breaking waves, fast-moving waterborne debris, and scouring currents will exceed the resisting capabilities of most buildings unless the building is built with specific design elements and materials.

Table 5-2 describes tsunami effects and possible design solutions.

Table 5-2. Tsunami Effects and Design Solutions

Phenomenon	Effect	Design Solution
Inundation	• Flooded basements • Flooding of lower floors • Fouling of mechanical, electrical, and communication systems and equipment • Damage to building materials, furnishings, and contents (supplies, inventories, personal property) • Contamination of affected area with waterborne pollutants	• Choose sites at higher elevations • Raise the building above the flood elevation • Do not store or install vital material and equipment on floors or basements lying below tsunami inundation levels • Protect hazardous material storage facilities that must remain in tsunami hazard areas • Locate mechanical systems and equipment at higher locations in the building • Use concrete and steel for portions of the building subject to inundation • Evaluate bearing capacity of soil in a saturated condition
	• Hydrostatic forces (pressure on walls caused by variations in water depth on opposite sides)	• Elevate buildings above flood level • Anchor buildings to foundations • Provide adequate openings to allow water to reach equal heights inside and outside of buildings • Design for static water pressure on walls
	• Buoyancy (flotation or uplift forces caused by buoyancy)	• Elevate buildings • Anchor buildings to foundations
	• Saturation of soil causing slope instability and/or loss of bearing capacity	• Evaluate bearing capacity and shear strength of soils that support building foundations and embankment slopes under conditions of saturation • Avoid slopes or provide setback from slopes that may be destabilized when inundated
Currents	• Hydrodynamic forces (pushing forces caused by the leading edge of the wave on the building and the drag caused by flow around the building and overturning forces that result)	• Elevate buildings • Design for dynamic water forces on walls and building elements • Anchor building to foundations
	• Debris impact	• Elevate buildings • Design for impact loads
	• Scour	• Use deep piles or piers • Protect against scour around foundations
Wave break and bore	• Hydrodynamic forces	• Design for breaking wave forces
	• Debris impact	• Elevate buildings • Design for impact loads
	• Scour	• Design for scour and erosion of the soil around foundations and piles
Drawdown	• Embankment instability	• Design waterfront walls and bulkheads to resist saturated soils without water in front • Provide adequate drainage
	• Scour	• Design for scour and erosion of the soil around foundations and piles
Fire	• Waterborne flammable materials and ignition sources in buildings	• Use fire-resistant materials • Locate flammable material storage outside of high-hazard areas

APPENDIX 5-1: CITY AND COUNTY OF HONOLULU, ARTICLE 11. REGULATIONS WITHIN FLOOD HAZARD DISTRICTS AND DEVELOPMENTS ADJACENT TO DRAINAGE FACILITIES

Revised Ordinances of the City and County of Honolulu 1990[1, 2]

Article 11. Regulations Within Flood Hazard Districts and Developments Adjacent to Drainage Facilities

Sections:

Sec. 16-11.1 Applicability.

(a) General. The provisions contained herein are applicable to the construction of all new buildings and structures, relocation and major alterations, additions or reconstruction of existing buildings within the flood hazard districts as delineated on the flood boundary and floodway maps and flood insurance rate maps, and any amendments by the Federal Emergency Management Agency, on file with the department of land utilization, City and County of Honolulu.

These provisions shall also apply to developments adjacent to drainage facilities outside the flood hazard district which are determined to be within a floodway area or a flood fringe area in accordance with Section 21-7.10-9.

(b) Nonconforming Buildings. Any building or structure which was previously lawful prior to the effective date of this article but which is not in conformity with this article may be continued subject to the provisions of Section 21-7.10-12.

(c) Exemptions. The provisions contained herein shall not apply:

(1) To buildings and structures exempted from the flood hazard district provisions under Section 7.10-13;

(2) To buildings and structures which have been granted a flood hazard variance under provisions of Section 21-7.10-11.

(Sec 16-7.1, R.O. 1978 (1983 Ed.); Sec. 16-5.1, R.O. 1978 (1987 Supp. to 1983 Ed.); Am. Ord. 90-57)

Sec. 16-11.2 Definitions.

For the purpose of this article, the following terms are defined in Article 9 of Chapter 21:

Coastal high hazard district;
Flood elevation;
Flood fringe;
Flood hazard district;
Floodproof;
Floodway;
Regulatory flood.

(Sec. 16-7.2, R.O. 1978 (1983 Ed.); Sec. 16-5.2, R.O. 1978 (1987 Supp. to 1983 Ed.); Am. Ord. 90-57)

(1) The ordinance uses the letter "p" to represent the density of water although common usage in engineering is the Greek letter "rho".

(2) The ordinance uses the term "impact force" to describe the force caused by the collision of a body carried by currents with the structure in question. However, the force is more properly an "impulsive force" because it is related to a change in momentum.

Sec. 16-11.3 Floodproofing requirements in certain areas.

(a) General. Building permit applications for structures which are required to be floodproofed under the provisions of Section 21-7.10 and this article shall be accompanied by a statement of a registered professional engineer or architect that to the best of such person's knowledge, information and belief, the floodproofing methods are adequate to resist the flood depths, pressures, velocities, impact and uplift forces, and other factors associated with the flood, including flood waters due to tsunamis in coastal high hazard districts.

(b) Floodproofing of Buildings above Regulatory Flood Elevation. All buildings and structures which are required to be elevated above the regulatory flood elevation shall be floodproofed by building on natural terrain above the regulatory flood elevation on natural undisturbed ground or by building on stilts or by building on fill (unless fill is specifically prohibited by Section 21-7.10, in the particular flood hazard district) or by other approved methods.

(c) Waterproofing of Buildings Below Regulatory Flood Elevation. Any building or portion thereof, not used for human habitation, and which is permitted to be below the regulatory flood elevation shall either have the space below the regulatory flood elevation free of obstructions or shall be designed and constructed so that below the regulatory flood elevation, the structure is watertight with walls substantially impermeable to the passage of water and with structural components having the capability of resisting hydrostatic and hydrodynamic loads and effects of buoyancy due to the regulatory flood. Compliance with the waterproofing provisions of the "Flood-Proofing Regulations," pamphlet No. EP1165 2 314, published for the Office of the Chief Engineers, U.S. Army, Washington, D.C., shall be deemed to be in compliance with this section. Within coastal high hazard districts, however, any usable enclosed space below the regulatory flood elevation shall be constructed with breakaway walls intended to collapse under stress without jeopardizing the structural support of the building. Areas enclosed by such breakaway walls shall not be used for human habitation.

(Sec. 16-7.3, R.O. 1978 (1983 Ed.); Sec. 16-5.3 R.O. 1978 (1987 Supp. to 1983 Ed.); Am. Ord. 90-57)

Sec. 16-11.4 Floodproofing methods.

(a) Natural Terrain. The following shall be applicable to buildings on natural terrain:

(1) Foundation design shall take into consideration the effects of soil saturation on the performance of the foundation.

(2) The effects of floodwaters on slope stability and erosion shall be investigated.

(3) All utility service lines shall be designed and constructed as provided in the plumbing and electrical codes.

(b) Building on Stilts. Where a building is to be constructed so that the lowest floor is to be elevated above the regulatory flood elevation, the building may be supported on columnar type members, such as columns, piers and in certain cases, walls. Clear spacing of support members, measured perpendicular to the general direction of flood flow shall not be less than eight feet apart at the closest point. The stilts shall, as far as practicable, be compact and free from unnecessary appendages which would tend to trap or restrict free passage of debris during a flood. Solid walls or walled-in columns are permissible if oriented with the longest dimension of the member parallel to the flow. Stilts shall be capable of resisting all applied loads as required by this code and all applicable flood-related loads as required herein. Bracing, where used to provide lateral stability, shall be of a type that causes the least obstruction to the flow and the least potential for trapping floating debris. Foundation supports for the stilts may be of any approved type capable of resisting all applied loads, such as spread footings, mats, piles and similar types. In all cases, the effect of submergence of the soil and additional floodwater-related loads shall be recognized. The potential of surface scour around the stilts shall be recognized and protective measures provided, as required.

(c) Building on Fill.

(1) Except in districts where fill is specifically prohibited as structural support for buildings by Section 21-7.10, as amended, buildings may be constructed on fill material.

(2) The fill shall not adversely affect the capacity of the floodway or any tributary or any other drainage facility or system, and shall be performed in accordance with Chapter 14, ROH 1990, as amended.

(Sec. 16-7.4, R.O. 1978 (1983 Ed.); Sec. 16-5.4, R.O. 1978 (1987 Supp. to 1983 Ed.); Am. Ord. 90-57)

Sec. 16-11.5 Structural requirements.

(a) General. All buildings and structures to be constructed under the provisions of this article shall be capable of resisting all loads required under this chapter and, in addition, all loads prescribed in this section.

(b) Stability.

(1) Overturning or Sliding. All buildings and structures to be constructed under the provisions of this article shall be designed and constructed to provide a minimum factor of safety of 1.50 against failure by sliding or overturning when subjected to combined loads as specified in subsection (d) of this section.

(2) Flotation. All buildings and structures to be constructed under the provisions of this article shall be designed and constructed to resist flotation from floodwater at the regulatory flood elevation with a safety factor of 1.33.

(c) Loads. The following loads shall be considered in the design and construction of buildings and structures subject to the provisions of this article:

(1) Hydrostatic loads;

(2) Hydrodynamic loads;

(3) Impact Loads. Assume concentrated load acting horizontally at the regulatory flood elevation or at any point below it, equal to the impact force produced by a 1,000-pound mass traveling at the velocity of the flood water and acting on a one-square-foot surface of the structure;

(4) Soil Loads. Consideration shall be given to loads or pressures resulting from soils against or over the structure. Computation shall be in accordance with accepted engineering practice with proper consideration for effect of water on the soil. Special consideration shall be given in the design of structures when expansive soils are present;

(5) Tsunami. Structural design of buildings and structures subject to tsunamis shall be in accordance with subsection (f) of this section.

(d) Combined Loads. All loads stipulated in this chapter and all flood-related loads specified under subsection (c) of this section shall be applied on the structure and on structural components, alone and in combination, in such manner that the combined effect will result in maximum loads and stresses on the structure and members. Application of these loads shall be as follows:

(1) Dead Loads. Use at full intensity.

(2) Live Loads. Use at reduced intensity as provided in this chapter for design of columns, piers, walls, foundation, trusses, beams and flat slabs. Live loads on floors at or below the regulatory flood elevation and particularly in basement slabs, shall not be used if their omission results in greater loading or stresses on such floors. Similarly, for storage tanks, pools and other similar structures designed to contain and store materials, which may be full or empty when a flood occurs, both conditions shall be investigated in combination with flood-related loads of the containing structure being full or empty.

(3) Wind Load. Use at full intensity as required in this chapter on areas of the building and structure above the regulatory flood elevation.

(4) Earthquake Load. Combined earthquake and flood-related loads need not be considered.

(e) Allowable Soil Pressures. Under flood conditions, the bearing capacity of submerged soils is affected and reduced by the buoyancy effect of the water on the soil. For foundations of buildings and structures covered by this article, the bearing capacity of soils shall be evaluated by a recognized acceptable method. Expansive soils should be investigated with special care. Soils which lose all bearing capacity when saturated, or become "liquefied" shall not be used for supporting foundations.

(f) Coastal Flood Water Design.[a]

(1) Buildings or structures shall be designed to resist the effects of coastal floodwaters due to tsunamis. The regulatory flood elevation due to tsunamis is considered to result from a non-bore condition, except where a bore condition is shown on the flood insurance maps or in the flood study adopted for the county.

(2) Habitable space in building structures must be elevated above the regulatory flood elevation by such means as posts, piles, piers or shear walls parallel to the expected direction of flow of the tsunami wave. The forces and effects of floodwaters on the structure shall be fully considered in the design.

(3) Allowable stresses (or load factors in the case of ultimate strength or limit design) for the building materials used shall be the same as the building code provides for wind or earthquake loads combined with gravity loads, i.e., treat loads and stresses due to tsunamis in the same fashion as for earthquake loadings.

(4) The main building structure shall be adequately anchored and connected to the elevating substructure system to resist all lateral, uplift and downward forces. In wood construction, toenailing is not allowed.

(5) Scour of soil from around individual piles and piers shall be provided for in the design in the coastal flood hazard district. Shallow foundation types are not permitted unless the natural supporting soils are protected on all sides against scour by a shore protection structure, preferably a bulkhead. Shallow foundations may be permitted beyond 300 feet from the shoreline, provided they are founded on natural soil and at least two feet below the anticipated depth of scour, and provided not more than three feet of scour is expected at the structure. The table below gives estimated minimum depths of soil scour below existing grade as a percentage of the depth (h) of water at the location.

[a] Reference is made to the January 31, 1980, report by Dames & Moore entitled "Design and Construction Standards for Residential Construction in Tsunami-Prone Areas in Hawaii" prepared for the Federal Emergency Management Agency for a more detailed study and analysis of tsunami wave forces.

Estimated Minimum Scour

	Distance from Shoreline	
	Up to 300 Feet[1]	Greater than 300[2] Feet
Loose sand	80% h	60% h
Dense sand	50% h	35% h
Soft silt	50% h	25% h
Stiff silt	25% h	15% h
Soft clay	25% h	15% h
Stiff clay	10% h	5% h

[1] Values may be reduced by 40% if a substantial dune or berm higher than the regulatory flood elevation protects the building site.
[2] Values may be reduced 50% if the entire region is essentially flat.

(6) Forces which must be considered in the design of structures elevated to resist floodwaters include:

(A) Buoyant forces - uplift caused by partial or total submergence of a structure.
(B) Surge forces - caused by the leading edge of a surge of water impinging on a structure.
(C) Drag forces - caused by velocity of flow around an object.
(D) Impact forces - caused by debris such as driftwood, small boats, portions of houses, etc., carried in the flood currents and colliding with a structure.
(E) Hydrostatic forces - caused by an imbalance of pressure due to a differential water depth on opposite sides of a structure or structural member.

(7) Buoyant Force. The buoyant force on a structure or structural member subject to partial or total submergence will act vertically through the center of mass of the displaced volume and is calculated from the following equation:

$$F_B = pgV$$

where F_B = buoyant force acting vertically
p = density of water (2.0 $lb\text{-}s^2/ft^4$ for salt water)
g = gravitational acceleration (32.2 ft/s^2)
V = displaced volume of water (ft^3)

(8) Surge Force. The total force per unit width on a vertical wall subjected to a surge from the leading edge of a tsunami which approaches the structure as a bore or bore-like wave is calculated from the equation below. The resultant force acts at a distance approximately h above the base of the wall. (Note: This equation is applicable for walls with heights equal to or greater than 3h. Walls whose heights are less than 3h require surge forces to be calculated using the appropriate combination of hydrostatic and drag force equations for the given situation.)

$$F_S = 4.5\ pgh^2$$

where F_S = total force per unit width of wall
p = density of water (2.0 lb-s^2/ft^4 for salt water)
g = gravitational acceleration (32.2 ft/s^2)
h = surge height (ft)

(9) Drag Force.

$$F_D = \frac{pC_D A u^2}{2}$$

where F_D = total drag force (lbs) acting in the direction of flow
p = density of water (2.0 lb-s^2/ft^4 for salt water)
C_D = drag coefficient (nondimensional) (1.0 for circular piles, 2.0 for square piles, 1.5 for wall sections)
A = projected area of the body normal to the direction of flow (ft^2)
u = velocity of flow relative to body (ft/s) (estimated as equal in magnitude to depth in feet of water at the structure)

The flow is assumed to be uniform, so the resultant force will act at the centroid of the projected area immersed in the flow.

(10) Impact Force.

$$F_I = m\frac{\Delta U_b}{\Delta t}$$

where F_I = impact force (lb)
m = mass of the water displaced by the body impacting the structure (slugs)
$\frac{\Delta U}{\Delta t}$ = acceleration (deceleration) of the body at (ft/s2)
U_b = velocity of the body (ft/s) (estimated as equal in magnitude to depth in feet of water at the structure)
t = time (s)

This single concentrated load acts horizontally at the regulatory flood elevation or at any point below it and is equal to the impact force produced by a 1000-pound weight of debris traveling at the velocity of the flood water and acting on a one square-foot surface of the structural material where impact is postulated to occur. The impact force is to be applied to the structural material at a most critical or vulnerable location determined by the designer. It is assumed that the velocity of the body goes from U_b to zero over some small finite time interval (Δt) so the following approximation can be made:

$$F_I = \frac{31U}{\Delta t}$$

For structural material of wood construction, assume Δt, the time interval over which impact occurs, is one second. For structural material of reinforced concrete construction, use Δt of 0.1 second and for structural material of steel construction, use Δt = 0.5 second.

(11) Hydrostatic Force.

$$F_H = \frac{1}{2} pg \left\{ h + \frac{u_P^2}{2g} \right\}^2$$

Where F_H = hydrostatic force (lb/ft) on a wall, per unit width of wall
p = density of water (2.0 $lb\text{-}s^2/ft^4$ for salt water)
g = gravitational acceleration (32.2 ft/s^2)
h = water depth (ft)
u_p = component of velocity of flood flow perpendicular to the wall (ft/s) (total velocity, u, estimated as equal in magnitude to depth in feet of water at the structure)

The resultant force will act horizontally at a distance of

$$\frac{1}{3} \left\{ h + \frac{u_p^2}{2g} \right\}^2$$

above the base of the wall.

(Sec. 16-7.5, R.O. 1978 (1983 Ed.); Sec. 16-5.5, R.O. 1978 (1987 Supp. to 1983 Ed.); Am. Ord. 90-57)

Sec. 16-11.6 Violations--Penalty.

For violation and penalty provisions of this article, see Article 10 of this chapter. (Added by Ord. 90-57)

APPENDIX 5-2:
COMMENTARY BY JAMES RUSSELL REGARDING HONOLULU FLOOD HAZARD ORDINANCE PROVISIONS

The structural requirements in section 16-11.5 of Article 11 of the Honolulu Code are in general agreement with the provisions contained in Chapter 11 of Volume II of the revised *FEMA Coastal Construction Manual*. However, there are some significant technical differences as noted below.

The Honolulu code is apparently based on the Dames and Moore report *Design and Construction Standards for Residential Construction in Tsunami-Prone Areas of Hawaii* (1980). The FEMA manual also references that report, but also refers to many more recent documents including: *Introduction to Fluid Mechanics* (Fox & McDonald 1985), *Criteria for Evaluating Flood-Protection Structures* (Walton, 1989), *Wave Forces on Inclined and Vertical Wall Surfaces (ASCE 1995), US Army Corps of Engineering Shore Protection Manual, Volume II* (USACE 1984), *Minimum Design Loads for Building and other Structures* (ASCE 7-98), ASCE 24-98 and *Engineering Principles and Practices for Retrofitting Flood Prone Residential Buildings*, FEMA 259, (1995).

Provisions for "breakaway walls" in any enclosed usable space below the flood elevation are required in the Honolulu ordinance for Coastal High Hazard Districts, which includes tsunami-prone locations. This provision is consistent with NFIP regulatory requirements for Coastal V Zones; however, the specific provisions of 44CFR 60.3(e)(5) and those of FEMA Technical Bulletin 9, regarding design loading and construction details for breakaway walls, are not included.

The effects of five types of structural loading required by the Honolulu ordinance are the same type of loads considered in the FEMA Coastal Design Manual. These include the following:

- Hydrostatic loads;
- Hydrodynamic loads;
- Impact loads;
- Soil loads; and
- Tsunami loads.

A small difference does exist between the Honolulu code and the 1997 UBC regarding the load factor used when applying strength design methods for tsunami loads. The Honolulu code specifies the same factor as for earthquake loads, which is a factor of 1.0 in the 1997 UBC. In contrast, the 1997 UBC specifies a load factor of 1.3 when applying fluid loads in a strength design analysis. Therefore, the Honolulu code is less restrictive in the application of fluid loads.

The effect of scour of soil from around building foundation piles or piers is required in both the ordinance and the FEMA manual. The values for estimating the depth of scour are reasonably consistent between the two documents with the exception that the Honolulu ordinance has reduced scour depths at distances greater than 300 feet from the shoreline, or when a dune or berm higher than the regulatory flood height protects the building site. The FEMA manual reproduces the Honolulu ordinance table on scour depth without using these reductions. The FEMA manual also provides design guidance on the scour produced in non-tsunami conditions along walls.

Design consideration for five types of tsunami forces are required in the Honolulu ordinance and these are consistent with the types of forces considered in the FEMA manual. The five forces in the ordinance include: 1) Buoyant forces, 2) Surge forces (e.g., breaking wave forces), 3) Drag forces (e.g., hydrodynamic forces), 4) Impact forces, and 5) Hydrostatic forces. However, there are differences in the magnitude of those forces between the two documents, the most significant of which occurs in those forces dependent on water velocity (e.g., drag and impulsive forces).

The equation used to determine surge force in the Honolulu ordinance is predicated on a tsunami bore wave. However, the force is smaller than that determined using equation 11.6 in the FEMA manual for a breaking wave in shallow water, typical of coastal flood and storm events. The forces determined for a breaking wave of a given height in the FEMA manual would be 22 percent greater than the surge force from a bore wave of equal height as determined by the Honolulu ordinance. The FEMA document does not specifically address a tsunami bore type wave.

The equation for determining hydrodynamic drag forces in the Honolulu ordinance contains different letters representing certain components of forces than the formula 11-8 in the FEMA manual, but it does contain all of the same elements as in the FEMA document. However, a <u>major</u> difference occurs in the numerical result of the two equations because of the way the water velocity is determined. In the Honolulu ordinance, velocity in feet per second is estimated to equal the depth of the water at the building. Therefore, for a depth of 3 feet, the velocity is assumed to be 3 feet per second. In the FEMA manual, for a 3-foot depth, a 3 feet per second velocity only results when computing the lower bound velocity from formula 11.2.

Three velocity estimates are given in the FEMA manual, lower bound, upper bound and extreme (tsunami), each of which is dependent on the assumed water depth. At an assumed water depth of 3 feet, the upper bound design velocity in feet per second, determined by formula 11.2 in the FEMA manual, would be approximately 3 times greater (10 fps) and result in forces that are 10-1/2 times greater because the drag force is a function of the velocity squared. At this same 3 foot depth, the tsunami design velocity in the FEMA manual would be 6.5 times greater, and result in forces that are 43 times greater than assumed for this depth by the Honolulu ordinance. Ironically, smaller water depths actually result in larger differences between the water velocity that would be determined in the Honolulu ordinance and those determined using the FEMA upper bound or tsunami velocities. The result is that the method used to determine water velocity has a profound effect on the drag loads to be used in a design.

Impact forces also are dependent on water velocity as determined by both the Honolulu ordinance and FEMA formula 11.9. Once again the letters used to designate the individual components of the equations differ between the two documents but the resulting formulas are the same. For impact loads the velocity term is not squared, therefore the difference in forces is directly proportional to any difference in velocity. However, in the FEMA document, the water velocity for impulsive forces is estimated to be one-half of the upper bound velocity as determined by Formula 11.2. Using a 3 foot high water depth example, and assuming a wood post is being impacted by a 1,000 pound object as the Honolulu code would require, the 3 foot per second velocity results in a 3,000 pound force. In the FEMA document, assuming this same water depth and mass of object, the velocity is 4.9 feet per second and results in a 4,900-pound force, or an increase of nearly 65 percent.

Another variable that must be established when determining impulsive forces is the duration of the impact. The Honolulu ordinance gives specific time intervals for the duration of impulsive forces to wood (1.0 second), reinforced concrete (0.1 second) and steel (0.5 second) members. These are also quoted in the text of the FEMA document. However, the FEMA document also provides a Table 11.3 wherein ranges of impact duration are given for walls and piles (columns) of wood, steel, reinforced concrete and concrete masonry. These duration of impact ranges differ from the single values given in the Honolulu ordinance with steel being shorter (0.2- 0.4 sec), concrete being longer (0.2 – 0.6 sec), and wood being slightly shorter (0.5 –1.0 sec) duration.

In conclusion, there is a substantial difference in the magnitude of drag forces, and significant differences in impulsive forces between the two documents, with the Honolulu code providing less resistance to these types of tsunami generated forces.

BACKGROUND PAPER #6: INFRASTRUCTURE AND CRITICAL FACILITIES

INTRODUCTION

Infrastructure and critical facilities are often located on the coast within tsunami hazard areas. Because of the services these facilities provide—or the harm they can cause—to the community, their performance during natural hazard events is a community-wide concern and needs to be considered as part of a tsunami risk management effort. Managing the tsunami risk is a responsibility shared by the government and private sectors. Ownership and regulatory control over some infrastructure and critical facilities rests with special districts, state and federal government agencies, and largely autonomous investor-owned utility companies rather than local government.

This paper discusses critical facilities and infrastructure and the issues associated with locating, siting, designing, or constructing new critical facilities and infrastructure and protecting existing facilities in tsunami hazard areas.

Damage to the Washington State Highway 109 bridge over the Copalis River from the 1964 tsunami.
Credit: Army Corps of Engineers

Proposals for new critical facilities and infrastructure located in tsunami hazard areas should be considered carefully to determine whether the performance expected is acceptable once feasible design measures are implemented. Proposals for new infrastructure should be evaluated in terms of the increased risk because of "induced growth." For example, construction of new buildings and facilities may be facilitated by the availability of new services in the hazard area. Existing infrastructure and critical facilities present vexing issues. It is difficult and expensive to improve the tsunami performance of existing facilities and infrastructure, and relocation is usually impractical, especially in the short term. However, understanding the risk to these existing facilities and anticipating the consequences of tsunami events can lead to long-term risk-reducing strategies.

KEY CONCEPTS AND FINDINGS

There are four key concepts presented in this background paper. Fundamental to all of them is the need to understand that tsunami hazard mitigation responsibilities can be very diffuse.

Depending on the community, infrastructure systems and critical facilities may be owned and managed by local and state agencies, special districts, private companies, non-profit organizations, federal departments and agencies, joint powers authorities, and others.

Concept 1: Understand and describe the nature and extent of tsunami and other hazards affecting the community

Background Paper #1 provides background information needed to conduct local tsunami risk studies. It is important to include in such studies data about infrastructure and critical facilities and to identify who is responsible for their location, design, construction, operation, and maintenance. This work would include:

- Inventorying and gathering data about infrastructure elements and critical facilities in the potential damage area; and

- Identifying the responsible organizations and including their representatives in the mitigation process.

Concept 2: To describe the performance objectives appropriate to utility and transportation systems and critical facilities

Because of the varied nature and differing importance of infrastructure systems and critical facilities, an effort must be made to "rank" their relative importance to the community and to establish performance objectives to help guide mitigation actions. This work involves several items:

- Determine how each has addressed tsunami and earthquake mitigation, plus any important site hazards such as potential landslides or soil failures;

- Establish a scale of relative importance to help focus mitigation efforts (e.g., preventing losses to the potable water system may be more important than preventing losses to the wastewater system); and

- Set acceptable outage intervals for each element (e.g., the community hospital must be minimally functional within one hour of the event, but a major street could be bypassed for two weeks).

Bore advancing through the railroad bridge at the Wailuku River in Hilo, Hawaii, during the 1946 tsunami.
Credit: Pacific Tsunami Museum

Concept 3: Avoid locating new infrastructure elements and critical facilities in high tsunami hazard areas

While it may be difficult for many reasons, the siting of new elements and facilities in high hazard areas should be avoided whenever practical. This practice reduces community vulnerability, and by limiting services, this practice also may contribute to reduced growth in such areas. Key strategies include:

- Examine plans for such systems and facilities to see if equally efficient alternative locations, alignments, and routes can be used;
- Determine if redundancies exist or can be provided where elements and facilities must serve high-hazard areas; and
- Where it is impractical to locate them elsewhere, ensure that adequate mechanisms exist to isolate the damaged area, such as shutoff valves, detours, and others.

Concept 4: Use professional coastal and structural engineers and architects experienced in designing (or retrofitting) buildings to resist tsunami forces and resist the effects of inundation

Effective design and engineering can greatly minimize the effects of tsunamis on infrastructure and critical facilities. Communities should ensure that design professionals qualified in coastal, earthquake, and geotechnical engineering are used regularly on projects in high hazard areas. Communities should:

- Identify proposed projects that should involve specially qualified professionals;

- See that the owning organizations secure the specialized assistance as early as possible in the project planning; and

- Locate both local and distant sources of qualified assistance that can be contacted when needed.

A boat washed up over 400 feet onshore from the wharf by the 1946 tsunami in Hilo, Hawaii.
Credit: Pacific Tsunami Museum

DEFINITIONS

Table 6-1 provides examples of structures and uses typical to the following definitions:

Critical Facilities—Critical facilities are "critical" because of their occupants or the functions they contain. These facilities serve important public purposes, house large numbers of persons or special populations, or may threaten the community if their contents are released. Critical facilities include *essential service facilities*, *hazardous facilities*, and *special occupancy structures* with uses such as government activities important to sustaining a community, buildings with large numbers of occupants, or buildings with occupants who cannot evacuate the premises readily.

Essential Services Facilities—Essential services facilities include hospitals with surgery and emergency medical treatment areas, fire and police stations, garages and shelters for emergency vehicles and aircraft, structures and shelters in emergency operations and communications centers and other facilities required for emergency response, standby power generating equipment and fuel storage for essential facilities, tanks or other structures containing housing or supporting water or other fire-suppression material or equipment required for the protection of other critical facilities. Private businesses may consider some facilities as essential to their business. For example, computer facilities, communications hubs, or record storage locations may be essential to the existence of some companies.

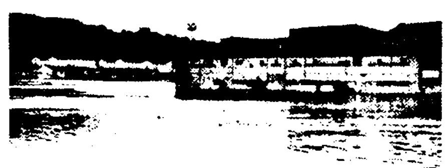
Hazardous Facilities—Hazardous facilities include buildings and non-building structures that house or support or contain acutely and chronically toxic substances, explosive or flammable chemicals. Uncontrolled release of hazardous materials to the air or water can harm people, contaminate the environment and feed fires on land and on the water.

Hazardous facilities should safely contain their contents following a disaster. The Uniform Building Code includes requirements for the use of enhanced wind and earthquake forces in the design of hazardous facilities.

Special Occupancy Structures—Special occupancy structures include schools, colleges, large occupancy buildings, buildings and facilities with resident incapacitated patients and elder care, jails and structures, and equipment in power-generating stations and other public utility facilities. Special occupancy structures should resist hazard events without endangering the occupants. Life safety systems in these structures must be designed for forces 50 percent greater than normal.

Infrastructure—Infrastructure includes the facilities needed by the community to function and to recover after a disaster, such as transportation systems for people and goods and utility systems such as communications, natural gas, water supply, and power generation and transmission/distribution systems. The elements that compose infrastructure should be functional—or easily and rapidly repairable—following a disaster.

Waterfront-dependent Facilities—Some facilities require a location on or adjacent to the water to function as intended. They gain a significant economic advantage from a waterfront location because they receive raw materials or distribute finished products by ship, use significant quantities of seawater, or support water-related recreational and commercial uses. Ports and harbor facilities are examples. Some waterfront-dependent uses may also be essential services facilities, (e.g., a Coast Guard installation and oil spill response and cleanup facilities); some special occupancy structures, (e.g., nuclear and fossil fuel power generation stations; and some hazardous facilities, (e.g., a fuel handling and storage facility). However, most of these facilities are not dependent on a waterfront location and only need to be close—not on the water.



Tsunami inundation at the Kodiak Naval Station airstrip from the 1964 tsunami.
Credit: USGS

Table 6-1. Examples of Infrastructure and Critical Facilities

INFRASTRUCTURE
Transportation Systems ▪ Roads, highways, bridges, parking lots and structures, and traffic control systems ▪ Railroad-track beds, bridges, and rail and switching yards for freight and passengers ▪ Transit systems (rail, trolley, tram, and motor coach), storage and maintenance facilities, power systems and substations, control systems, bridges, tunnels, and tubes ▪ Airports and control towers ▪ Maritime ports and maritime traffic control systems, marine terminals, loading/unloading facilities, storage facilities (including tank farms), docks, and ship moorings, piers, seawalls, and bulkheads
Utility Systems ▪ Electrical generation, transmission, substations, and distribution systems ▪ Natural gas production, processing, storage, transmission, pump, and distribution systems ▪ Landline communication systems: switching stations, trunk lines, and data lines ▪ Cellular systems, switching stations, antenna, and towers ▪ Cable systems for television, radio, and data ▪ Satellite systems for television and data ▪ Potable water systems: wells, water supply sources, storage, pumps, and treatment and distribution systems ▪ Sewerage collection, mains, pumps, treatment facilities, and outfalls ▪ Pipelines that transport oil, fuels, and other petroleum products ▪ Storm water runoff facilities, drainage, and pipelines
CRITICAL FACILITIES
Essential Services ▪ Police stations ▪ Firehouses ▪ Hospitals with surgery, acute care, or emergency rooms ▪ Emergency operations and communications facilities and equipment ▪ Garages and shelters for emergency vehicles and aircraft ▪ Standby power-generating equipment for essential services ▪ Tanks or other structures containing water or other fire-suppression material or equipment required to protect essential, hazardous, or special occupancy facilities ▪ Permanent lifeguard stations
Special Occupancy Structures ▪ Schools ▪ Universities and colleges ▪ Residential treatment centers and nursing and convalescent homes ▪ Retirement communities ▪ Large-occupancy structures ▪ Power-generating stations and other utility facilities needed for continuous operations
Hazardous Facilities ▪ Fuel docks and storage ▪ Spent nuclear fuel storage ▪ Chemical storage facilities ▪ Rail tank cars and trucks with chemicals ▪ Munitions storage, loading docks, and harbors

Table 6-2. Acceptable Use Matrix

Use	Tsunami Hazard[1]		
	High	**Moderate**	**Low**
Essential Facility	NO[2]	NO[2]	OK[3]
Hazardous Facility	OK[2,3]	OK[2,3]	OK[2,3]
Special Occupancy Structure	NO	NO	OK[3]
Maritime Infrastructure	OK[3]	OK[3]	OK[3]
Non-maritime Infrastructure	NO	NO	OK

[1]. See Background Paper #5, "*Building Design,*" for a description of the tsunami hazard

[2]. Only if dependent on a waterfront location

[3]. Only if risk reduced to the maximum extent feasible

MANAGING TSUNAMI RISK INVOLVING INFRASTRUCTURE AND CRITICAL FACILITIES

Planning Process

A planning process for new and existing infrastructure and critical facilities should involve the individuals and agencies and companies responsible for critical facilities and infrastructure. Knowledge of the nature and extent of tsunami hazard, the causes of vulnerability, and the consequences of damage are essential ingredients for risk management. These factors should be quantified to an appropriate extent and then be considered in normal decisionmaking processes such as environmental review, land use and community planning, coastal program planning, subdividing land, redevelopment of existing areas, capital outlay, and in the regulation of design and construction of structures. Studies of the hazard, vulnerability, risk, and consequences will help facility managers understand community concerns as well as the threat to their own interests.

- Define the tsunami hazard (see Background Paper #1) and describe it by intensity (expected effects) and probability of occurrence.
- Identify infrastructure and critical facilities within the tsunami hazard area and describe why their functions make tsunami resistance an important issue for the community.
- Describe what makes each facility vulnerable to damage from tsunami forces.
- Determine what appropriate performance objectives are desired (i.e., acceptable damage condition for a given tsunami intensity and probability). See Background Paper #5 for a discussion on performance objectives.
- For new infrastructure and critical facilities, determine appropriate performance objectives and whether their use is dependent on a waterfront location.

- For existing infrastructure and critical facilities, determine which mitigation options and combinations of options can reduce the risk and whether the remaining risk would be acceptable.

- Adopt policies to manage the tsunami risk and integrate them into coastal management programs, land use plans, capital outlay plans, building regulation programs, and other procedures used to control the use and safety of facilities near the ocean shoreline.

- Prepare and adopt long-term loss reduction plans with strategies that include relocating or, if possible, strengthening existing infrastructure and critical facilities against tsunami forces, and that provide redundant facilities and emergency response measures to lessen the impact of losing infrastructure and critical facilities that remain at risk.

General Principles

- Enforce zoning ordinances and building codes that address tsunamis and all other hazard conditions (seismic, fire, wind, flood inundation, erosion and scour, hazardous materials).

- Undertake community-wide studies to define the tsunami hazard by intensity, recurrence, and location.

- Essential services facilities should be operational following a hazard event. This concept already is contained in the Uniform Building Code (UBC). The UBC requires the use of enhanced seismic and winds forces for design, and enhanced structural observation during construction for essential services facilities. The UBC uses an "Importance Factor" to increase the force levels by 15 to 50 percent over those calculated for other occupancy categories to provide stronger structures.

- Prepare for the inevitable destruction of infrastructure and critical facilities located in tsunami hazard areas that cannot be newly constructed or retrofitted to withstand tsunami forces.

- When waterfront-dependent infrastructure and critical facilities cannot be newly designed or retrofitted to resist a tsunami event, they should be considered "expendable" and appropriate steps taken for evacuation, emergency response, recovery, and replacement.

- Certain types of infrastructure can affect the extent and intensity of the tsunami hazard (breakwaters, seawalls, roadway fills).

- Provide redundant facilities and infrastructure.

- Each coastal management program should provide guidance for revising or adopting measures that deal with existing and new infrastructure, critical facilities, waterfront-dependent uses, and tsunami hazards. State planning and permit jurisdiction and federal consistency requirements should incorporate these measures.

Specific Principles for Existing Infrastructure and Critical Facilities

- Strengthen or phase out existing facilities.
- Relocate portions of at-risk facilities.
- Raise existing facilities above the inundation elevation, and protect against impact forces (reinforce walls and columns) and scour.
- Construct barriers.
- Provide redundant facilities.
- Take advantage of the eventual obsolescence of existing infrastructure and critical facilities as opportunities to relocate the facility or to incorporate design standards that will allow for acceptable performance following tsunamis.
- Do not allow expansion or renovation of existing facilities in tsunami hazard areas without requiring measures to reduce the risk.
- Prepare emergency plans to cope with the emergency situation and expedite recovery.

Petroleum tank on fire due to damage from the 1964 tsunami
on Highway 101 near Crescent City, California.
Credit: Del Norte Historical Society

Principles for New Infrastructure and Critical Facilities

- Do not allow construction of new infrastructure and critical facilities in tsunami hazard areas or fail to enforce current codes and standards.
- Prohibit new critical facilities in tsunami hazard areas unless: 1) they are waterfront-dependent; 2) risk is reduced through mitigation and emergency planning measures to such an extent that the resulting facility will perform as needed; or 3) the need for the facility outweighs the consequences of loss during a tsunami (e.g., a small hospital in a remote,

tsunami-prone area may be justified because it needs to be close to the population for routine emergencies).

- Reserve sites for infrastructure and critical facilities either outside of the tsunami hazard area or in areas where the risk can be reduced through feasible measures.

- Most critical facilities need not be located in a tsunami hazard area to serve their intended purpose. Some essential facilities may need to be located in a tsunami hazard area because alternative locations will not serve the day-to-day needs of the community.

- Do not allow infrastructure improvements that will encourage construction of other facilities that cannot withstand the tsunami hazard.

- Consider the impact of new infrastructure on hazard intensity and distribution. Does it change drainage patterns, decrease exposure to inundation, or channel currents in a way that will increase the hazard?

See Appendix 6-1 for the text of provisions in the State of Oregon's statutes related to tsunami hazards that serve to illustrate acceptable use decisions.

APPENDIX 6-1: TSUNAMI PROVISIONS IN STATE OF OREGON REVISED STATUTES

Chapter 455
1999 EDITION

455.446 Construction of certain facilities and structures in tsunami inundation zone prohibited; establishment of zone; exceptions.

(1)(a) New essential facilities described in ORS 455.447 (1)(a)(A), (B) and (G) and new special occupancy structures described in ORS 455.447(1)(e)(B), (C) and (E) shall not be constructed in the tsunami inundation zone established under paragraph (c) of this subsection. The provisions of this paragraph apply to buildings with a capacity greater than 50 individuals for every public, private or parochial school through secondary level and child care centers.

(b) The State Department of Geology and Mineral Industries shall establish the parameters of the area of expected tsunami inundation based on scientific evidence that may include geologic field data and tsunami modeling.

(c) The governing board of the State Department of Geology and Mineral Industries, by rule, shall determine the tsunami inundation zone based on the parameters established by the department. The board shall adopt the zone as determined by the department under paragraph (b) of this subsection except as modified by the board under paragraph (d) of this subsection.

(d) The board may grant exceptions to restrictions in the tsunami inundation zone established under paragraph (c) of this subsection after public hearing and a determination by the board that the applicant has demonstrated that the safety of building occupants will be ensured to the maximum reasonable extent:

(A) By addressing the relative risks within the zone.

(B) By balancing competing interests and other considerations.

(C) By considering mitigative construction strategies.

(D) By considering mitigative terrain modification.

(e) The provisions of paragraph (a) of this subsection do not apply:

(A) To fire or police stations where there is a need for strategic location; and

(B) To public schools if there is a need for the school to be within the boundaries of a school district and this cannot otherwise be accomplished.

(f) All materials supporting an application for an exception to the tsunami inundation zone are public records under ORS 192.005 to 192.170 and shall be retained in the library of the department for periods of time determined by its governing board.

(g) The applicant for an exception to the tsunami inundation zone established under paragraph (c) of this subsection shall pay any costs for department review of the application and the costs, if any, of the approval process.

(2) The definitions in ORS 455.447 apply to this section.

(3) The provisions of this section do not apply to water-dependent and water-related facilities, including but not limited to docks, wharves, piers and marinas.

(4) Decisions made under this section are not land use decisions under ORS 197.015 (10). [1995 c.617 s.2]

Note: 455.446 was enacted into law by the Legislative Assembly but was not added to or made a part of ORS chapter 455 or any series therein by legislative action. See Preface to Oregon Revised Statutes for further explanation.

455.447 Regulation of certain structures vulnerable to earthquakes and tsunamis. (1) As used in this section, unless the context requires otherwise:

(a) "Essential facility," means:

(A) Hospitals and other medical facilities having surgery and emergency treatment areas;

(B) Fire and police stations;

(C) Tanks or other structures containing, housing or supporting water or fire-suppression materials or equipment required for the protection of essential or hazardous facilities or special occupancy structures;

(D) Emergency vehicle shelters and garages;

(E) Structures and equipment in emergency-preparedness centers;

(F) Standby power generating equipment for essential facilities; and

(G) Structures and equipment in government communication centers and other facilities required for emergency response.

(b) "Hazardous facility," means structures housing, supporting or containing sufficient quantities of toxic or explosive substances to be of danger to the safety of the public if released.

(c) "Major structure," means a building over six stories in height with an aggregate floor area of 60,000 square feet or more, every building over 10 stories in height and parking structures as determined by Department of Consumer and Business Services rule.

(d) "Seismic hazard," means a geologic condition that is a potential danger to life and property which includes but is not limited to earthquake, landslide, liquefaction, tsunami inundation, fault displacement, and subsidence.

(e) "Special occupancy structure," means:

(A) Covered structures whose primary occupancy is public assembly with a capacity greater than 300 persons;

(B) Buildings with a capacity greater than 250 individuals for every public, private or parochial school through secondary level or child care centers;

(C) Buildings for colleges or adult education schools with a capacity greater than 500 persons;

(D) Medical facilities with 50 or more resident, incapacitated patients not included in subparagraphs (A) to (C) of this paragraph;

(E) Jails and detention facilities; and

(F) All structures and occupancies with a capacity greater than 5,000 persons.

(2) The Department of Consumer and Business Services shall consult with the Seismic Safety Policy Advisory Commission and the State Department of Geology and Mineral Industries prior to adopting rules. Thereafter, the Department of Consumer and Business Services may adopt rules as set forth in ORS 183.325 to 183.410 to amend the state building code to:

(a) Require new building sites for essential facilities, hazardous facilities, major structures and special occupancy structures to be evaluated on a site specific basis for vulnerability to seismic geologic hazards.

(b) Require a program for the installation of strong motions accelerographs in or near selected major buildings.

(c) Provide for the review of geologic and engineering reports for seismic design of new buildings of large size, high occupancy or critical use.

(d) Provide for filing of noninterpretive seismic data from site evaluation in a manner accessible to the public.

(3) For the purpose of defraying the cost of applying the regulations in subsection (2) of this section, there is hereby imposed a surcharge in the amount of one percent of the total fees collected under the structural and mechanical specialty codes for essential facilities, hazardous facilities, major structures and special occupancy structures, which fees shall be retained by the jurisdiction enforcing the particular specialty code as provided in ORS 455.150.

(4) Developers of new essential facilities, hazardous facilities and major structures described in subsection (1)(a)(E), (b) and (c) of this section and new special occupancy structures described in subsection (1)(e)(A), (D) and (F) of this section that are located in an identified tsunami inundation zone shall consult with the State Department of Geology and Mineral Industries for assistance in determining the impact of possible tsunamis on the proposed development and for assistance in preparing methods to mitigate risk at the site of a potential tsunami. Consultation shall take place prior to submittal of design plans to the building official for final approval. [1991 c.956 s.12; 1995 c.79 s.229; 1995 c.617 s.1]

Note: 455.447 was added to and made a part of 455.010 to 455.740 by legislative action but was not added to any smaller series therein. See Preface to Oregon Revised Statutes for further explanation.

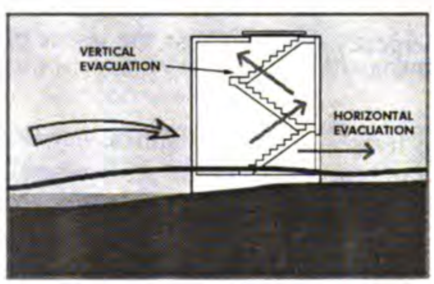
BACKGROUND PAPER #7: VERTICAL EVACUATION

INTRODUCTION

This background paper discusses the concept of vertical evacuation as it relates to the siting and design of buildings in tsunami-threatened coastal communities.

The concept of vertical evacuation originated as a hurricane emergency preparedness and response measure. Consideration of its feasibility likely began with intense development of the coastal barrier islands, often served by only one bridge. A literature search and interview results indicate that vertical evacuation may be more complicated to use in tsunami-threatened areas because of the differing hazard characteristics, such as strong groundshaking and potential ground failures, and their implications for siting, design, and construction. Other planning issues relate to managing the number of occupants, providing in-building security, compensating building owners, and addressing liability issues associated with vertical evacuation.

The primary strategy for saving lives immediately before tsunami waves arrive is to evacuate people from the hazard zone either horizontally or vertically. In some areas, vertical evacuation may be the only feasible means of evacuation for local tsunamis with short warning times. Horizontal evacuation (having people move to more distant locations when tsunamis, hurricanes or floods threaten, for example) is the most commonly used method of the two. Vertical evacuation, much less common and still in an experimental mode in some areas, helps eliminate potential congestion and travel delays by having people move to the upper stories of relatively tall, well-designed, and well-constructed buildings.



Horizontal and vertical evacuation

Whether vertical or horizontal evacuation, effective warning systems and public information, notification, and training programs are critical to the success of all evacuation measures. In addition, both methods require that reasonably close "safe buildings" be identified for rapid use, especially for locally-generated tsunamis, and that evacuation centers be designated in local emergency plans for both distant and local tsunamis. Tsunami warning systems are discussed in more detail below. Emergency service officials are responsible for general evacuation plans and procedures.

KEY CONCEPTS

This background paper focuses on four key concepts. The information in this paper has been derived from a variety of sources discussed below, but primarily from recent research on evacuation, especially vertical evacuation, in hurricane-prone areas. Tsunami-threatened communities may find it useful to consider vertical evacuation measures, especially when neither time nor adequate routes are likely to be available for people to move inland (horizontally) away from the vulnerable area.

Concept 1: Understand Vertical Evacuation

Vertical evacuation uses existing multiple story buildings as places of refuge for evacuees. While the evacuation process is an emergency preparedness and response measure, the important mitigation consideration is that buildings must be located, designed, and constructed to withstand the expected tsunami forces—and earthquake forces if the tsunami is local—so the occupants are protected. Background Papers #1, #4, and #5 address key topics related to vertical evacuation. Properly implemented vertical evacuation measures require an understanding of:

- How tsunamis may affect your community;
- The nature of the current building stock and its ability to withstand tsunami and earthquake forces;
- Which siting, design, and construction requirements should govern new buildings that are to be designated as vertical shelters; and
- How current local emergency plans address the issues of warning, public education, and response operations.

Evacuating people can save lives and reduce injuries, but it will have little, if any, effect on reducing property and economic losses. In coastal areas where building and population densities are high, where roads, bridges, and other horizontal evacuation methods are limited, or where warning time may be insufficient, vertical evacuation may be needed as an alternative or supplement to horizontal evacuation. Land use planning, site planning, and building design issues discussed in the previous background papers determine a community's ability to rely, at least partially, on vertical evacuation to protect people.

Concept 2: Ensure Adequate Standards Apply to New Buildings

It is easier to design and construct a new building to follow prescribed standards than it is to retrofit an existing one. New buildings to be designated as vertical evacuation shelters must have sufficient structural integrity to resist expected tsunami forces and earthquake groundshaking for tsunamis originating locally. Building codes and other applicable standards should ensure the tsunami and earthquake resistance of new buildings. These standards should go beyond the minimum life-safety requirements of most locally-adopted codes. Background Paper #5 addresses the need for adequate standards.

Communities and building owners should also seek additional technical information and secure the assistance of qualified professionals in the fields of coastal, geotechnical, and structural engineering.

Concept 3: Inventory Existing Buildings

The building stock for vertical evacuation varies greatly across communities. Thus, it is critical that a community inventory and assess buildings that could serve as vertical evacuation shelters. This may be difficult because important information about existing buildings, such as drawings and calculations, may not be available. Professional engineers play a key role in evaluating the capacity of structures to resist expected forces and motions, and their reports often lead to rehabilitation and retrofit work designed to strengthen the buildings.

Depending on the nature of the existing building stock, some structures may be capable of sheltering people for a limited amount of time. In general, they should be at least two stories tall, with the first being left open to inundation. Some may have to be strengthened to serve this purpose. Designating existing buildings as vertical evacuation shelters includes the following:

- Conducting an engineering survey of existing buildings that could be candidate shelters;
- Working with the owners and others involved to have such buildings retrofitted, if needed, and designated as shelters; and
- Posting or otherwise notifying people which buildings have been designated to serve as shelters following tsunami warnings or strong groundshaking due to local earthquakes.

Concept 4: Ensure Emergency Plans and Information Programs Address Evacuation

Vertical evacuation, while dependent on structures for its success, primarily is an emergency preparedness and response measure. It is important, therefore, that those community officials responsible for planning and managing emergency programs and operations have lead responsibility for vertical evacuation planning. In addition, it is extremely important to involve building owners and others in the process of establishing a vertical evacuation program.

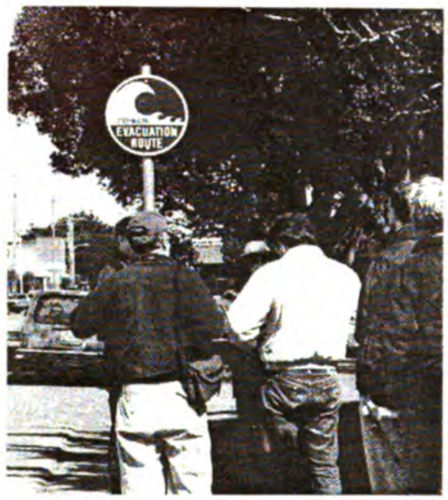
Evacuating people from threatened areas may have to be done on very short notice. Local emergency plans and preparedness programs should contain procedures for receiving and disseminating warnings, facilitating the movement of people, and regularly providing residents and especially seasonal visitors with warning and evacuation information. This includes:

- Reviewing the nature and density of regular and seasonal occupants in the potential inundation areas;

- Ensuring informational, local warning, and public announcement systems are regularly tested and capable of informing occupants;

- Addressing and resolving any legal or regulatory issues associated with implementing vertical evacuation procedures; and

- Including appropriate evacuation measures in local emergency operations plans, including procedures for early post-tsunami/local earthquake evacuee care and damage evaluations.



Tsunami evacuation route sign in Crescent City, California.
Credit: FEMA

DIFFERING HAZARD CHARACTERISTICS

While creating similar types of damage, tsunamis and hurricanes are different in many respects. Because hurricanes are generated at some distance, they can be tracked with some precision, and timely warnings can be issued, even if the hurricanes change their course. Advance warning allows the public to take precautionary actions, such as evacuating the area to more distant locations. The wind-driven water (storm surge) that creates coastal flooding also is predictable, moves relatively slowly, only batters shoreline structures, and inundates only the lower levels of buildings, such as basements and ground floors.

Tsunamis, on the other hand, can be generated at great distances or locally, and each type may be accompanied by multiple waves. Tsunami waves can move at great speeds, can be, but are not always, very high (50 feet or more), and can carry extensive amounts of debris that act as battering rams, such as trees, boulders, building wreckage, cars, shipping containers, and boats.

Where they exist, warning systems can notify people of distant tsunamis, providing them with up to several hours to take protective actions. These warnings can provide sufficient time to shut down critical activities and to evacuate low lying areas for higher or more distant locations. On the other hand, locally-generated tsunamis provide almost no warning time (5-30 minutes), and they may be accompanied by strong earthquake groundshaking, landslides, and other on-shore effects. Problems may be exacerbated by building damage, utility system failures, and transportation system outages, especially in areas subject to ground failure, such as liquefaction, lateral spreading, and slumping.

Thus, the siting and design considerations for hurricanes and both local and distant tsunamis are substantially different. Tsunami mitigation guidelines have to address the peculiarities associated especially with locally-generated tsunamis accompanied by other earthquake effects.

TSUNAMI WARNING PROGRAMS

The following is a description of tsunami warning programs. This topic is not directly related to the building issues involved in vertical evacuation, but provides helpful background information.

As part of an international cooperative effort to save lives and protect property, the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service operates two tsunami warning centers. The West Coast and Alaska Tsunami Warning Center (WCATWC) in Palmer, Alaska, serves as the regional tsunami warning center for Alaska, British Columbia, Washington, Oregon, and California.

Tsunami hazard zone logo

The Pacific Tsunami Warning Center (PTWC) in Ewa Beach, Hawaii, serves as the regional tsunami warning center for Hawaii and as a national/international warning center for tsunamis that pose a Pacific-wide threat. This international warning effort became a formal arrangement in 1965 when PTWC assumed the international warning responsibilities of the Pacific Tsunami Warning System (PTWS). The PTWS is composed of 26 international member states that are organized as the International Coordination Group for the Tsunami Warning System in the Pacific.

The objective of the tsunami warning centers is to detect, locate, and determine the magnitude of potentially tsunamigenic earthquakes. Earthquake information is provided by seismic stations. If the location and magnitude of an earthquake meet the known criteria for generation of a tsunami, a tsunami warning is issued to warn of an imminent tsunami hazard. The warning includes predicted tsunami arrival times at selected coastal communities within the geographic area defined by the maximum distance the tsunami could travel in a few hours. A tsunami watch with additional predicted tsunami arrival times is issued for a geographic area defined by the distance the tsunami could travel in a subsequent time period.

If a significant tsunami is detected by sea-level monitoring instrumentation, the tsunami warning is extended to the entire Pacific Basin. Sea-level (or tidal) information is provided by NOAA's National Ocean Service, PTWC, WCATWC, university monitoring networks, and other participating nations of the PTWS.

Tsunami watch, warning, and information bulletins are disseminated to appropriate emergency officials and the general public by a variety of communication methods:

- Tsunami watch, warning, and information bulletins issued by PTWC and WCATWC are disseminated to local, state, national, and international users as well as the media. These users, in turn, disseminate the tsunami information to the public, generally over commercial radio and television channels.

- The NOAA Weather Radio System, based on a large number of VHF transmitter sites, provides direct broadcast of tsunami information to the public.

- The U.S. Coast Guard also broadcasts urgent marine warnings and related tsunami information to coastal users equipped with medium frequency (MF) and very-high-frequency (VHF) marine radios.

- Local authorities and emergency managers are responsible for formulating and executing evacuation plans for areas under a tsunami warning. The public should stay tuned to the local media for evacuation orders should a tsunami warning be issued. And, the public should not return to low-lying areas until the tsunami threat has passed and the local authorities announce the "all clear."

Earthquakes with preliminary magnitudes of 7.0 are used to trigger warning systems because that is a threshold magnitude where tsunami generation is more likely to occur, with sufficient displacement and fault area. Of course, smaller earthquakes may generate tsunamis, or more likely, trigger submarine landslides that generate tsunamis. These would probably be missed by the warning center, and the tsunami would more likely be a local event.

GENERAL CONSIDERATIONS

It appears from recent research that residents of densely populated metropolitan areas are more supportive of vertical evacuation compared to those people in the smaller urban (or largely rural) areas. A study of the feasibility of vertical evacuation noted that "Smaller urban areas generally do not have the large populations and the accompanying traffic problems found in metropolitan areas. Therefore, vertical evacuation incorporated into horizontal evacuation is not a pressing issue." (Ruch, et al., xi)

Further information from this and two other related studies noted below provide additional insights into the issues associated with the potential use of vertical evacuation in tsunami hazard areas:

(1) The evacuation feasibility study notes that "In some coastal areas, the time needed to achieve successful inland evacuation already exceeds the maximum possible advance warning time. As traditional "horizontal" evacuation plans become less feasible, "vertical" evacuation into properly designed high-rise buildings capable of riding out hurricane stresses is becoming an appealing alternative. The six authors of this anthology considered the behavioral and logistical feasibility of vertical evacuation, ramifications of public tort liability in evacuation situations, legal authority and liability concerns in Texas and Florida, political problems that emerge with vertical evacuation policies, and the structural viability of large buildings to survive hurricane phenomena. Some of the findings reported include: 1) government intervention or regulation will be required to achieve vertical refuge; 2) the majority of respondents to a survey indicated that they would use vertical shelter; and 3) Florida, and to a lesser extent Texas, has started the process to implement vertical evacuation as a public policy alternative." (Ruch, et al.)

(2) An article on the experience of two states notes that "With growing coastal populations expected to compound problems associated with hurricane evacuation planning, some authorities are paying more attention to the possibility of vertical sheltering. This article discusses the pros and cons of vertical sheltering, presents the findings of a case study that compares hurricane awareness and risk perception among residents of Texas and Florida, and considers the viability of implementing vertical sheltering policies in both states. Three major conclusions are reached: 1) a tangible hurricane safety situation must be identified as a precondition to discussing policies involving vertical shelter; 2) a fortuitous "window of opportunity" does not necessarily lead to the adoption of a hurricane safety policy; and 3) the conditions of acceptance of a vertical shelter policy depends on the presence of an advocate, communication among key participants, linkage to other issues, and the presence of an acceptable solution." (Berke)

(3) An evaluation of hurricane shelters describes "a procedure for evaluating the storm resistance of buildings in low-lying coastal areas that have been, or may

be, designated as hurricane shelters. Developed during a study of hurricane shelters in the Florida Keys, the report reviews building plans, examines potential problems due to site location, and analyzes the resistance of shelters to wind, water, and storm-driven debris. The method used to analyze resistance incorporates design data pertaining to footings, columns, soil bearing capacity, floors, roofs, exterior and interior bearing walls, interior shelter potential, and mechanical/structural projections such as canopies or air conditioning units. Two detailed case studies illustrate this analytical method. The authors suggest that vertical evacuation should be used only as a last resort. The designation of vertical evacuation shelters may encourage people not to physically leave an area when extreme hurricane conditions are forecast." (Spangler, et al.)

Finally, the evacuation feasibility study states that "The technical feasibility of vertical evacuation has its basis in the historically superior performance of engineered structures in wind hazards. In the United States, no multistory structure designed by professional architects and engineers and subjected to wind forces primarily generated by hurricane or tornado has been observed to collapse...Vertical evacuation may therefore be considered structurally feasible in a particular situation if...[its] use leads to a saving of lives. For a given scenario, the level of risk at which the use of vertical evacuation begins to result in a net saving of lives may be defined as the level of risk at which a building may be considered safe." (Ruch, et al., xv-xvi)

Occupancy, Security, and Liability

It is relatively easy to move owners and tenants higher in buildings to avoid the flooding of lower floors. This can be done via building safety plans, and all occupants can be notified about this procedure and provided with instructions about what to do. The principal questions to be resolved are: How long will they be there, and what kinds of support will the people need for the duration of their stay, such as food, water, power, and sanitary services?

Vertical evacuation becomes far more complicated if the building is designated or assumed to be a public shelter. Many newer buildings have sophisticated security systems effectively limiting access to the public. Even if a building is publicly accessible, capacity issues can be a problem. For example, it may be a recipe for a riot if 1,000 people are allowed to use the building as a shelter and 5,000 appear in response to an approaching tsunami.

In addition to those issues to resolve above, others relate to supporting strangers, such as providing sufficient space, anticipating the acceptance or resistance by the tenants of outsiders, ensuring the security of tenants' space and property, and paying the extra costs to care for the non-tenants. A particular concern may be the number of elderly people who may have problems climbing stairs (Ruch, et al., xi).

There could be liability problems in both public and non-public shelters. One problem could be determining the presumed standard of care under these conditions. Another could be determining who is responsible for ensuring that it is provided. A third liability issue could be determining who, if anyone, is at fault if the building is damaged or destroyed resulting in fatalities and injuries, possibly creating a mass casualty incident. The following excerpts from the evacuation feasibility study offers insights into liability issues:

- *Is governmental intervention or regulation required to achieve vertical refuge?* ...There are currently no market incentives inducing private owners to assume the additional costs of strengthening, outfitting, or retrofitting their buildings for vertical refuge, must less the potential additional liability inherent in such refuge.

- *If state or local governments decided not to provide for vertical refuge, would they be held liable if people were injured or killed because they were unable to evacuate a vulnerable coastal area?* No...Absent a constitutional or statutory requirement, courts will not substitute their judgment for that of the legislature, under the doctrine of separation of powers. [Where there is no mandate] no state or local government would be held liable for failure to enact such legislation.

- *Can regulations require owners to retrofit existing buildings or design new buildings for vertical refuge?* Yes. Legislatures have the power to enact both prospective and retrospective building regulations in all jurisdictions, subject to a number of constitutional safeguards.

- *If states or local governments enacted regulations governing vertical refuge in privately owned buildings, could they be liable for money damages 1) if they failed to enforce the regulations? Or 2) if they were negligent in the course of their enforcement?* There are no clear-cut answers to these questions [because] the determination of governmental liability varies from state to state according to constitutional, legislative, or judicial determinations of sovereign immunity.

  However, if any governmental unit should choose to implement VR (Vertical Refuge), legal duties of care would arise (under the doctrine of sovereign immunity). Depending on each state's torts claims act, the state would be immune from liability for injury or death arising from certain executive branch actions implementing established policy while other implementing actions would subject the state to liability if it failed to meet the applicable duty of care. . . .Under Texas common law, the duty owed would depend on whether those entrants are classified as invitees, licensees, or trespassers. . . .In Florida, persons volunteering buildings for use as emergency shelters without compensation can not [sic] be held liable for injury to or death of shelterees, unless they act with gross negligence or willful and wanton misconduct...Under Florida common law, the duty owed would depend on whether the entrant is an invited or uninvited visitor.

  If action is brought within the statute of limitations, architects, engineers, and builders of buildings used as VR shelters would be highly vulnerable to liability if their errors caused injury to those taking VR (Ruch, et al., xi-xiv).

VERTICAL EVACUATION MEASURES

The use of a building for vertical evacuation implies that the building is expected to be damaged only to the extent that it is not a threat to life and that it could continue to serve as a temporary safe shelter. Life safety is a governmental objective, and for normal structures, it is provided by the adoption and effective enforcement of building codes, which commonly allow for substantial damage as long as few casualties result from it.

Moreover, building codes usually address only new buildings or substantial modifications to existing buildings. Very few, or only special codes, laws, or ordinances, address the complexities associated with rehabilitating or retrofitting existing buildings to meet life safety threats posed by expected hazards.

Local governments should consider vertical evacuation in the design of new buildings or the rehabilitation of existing buildings to support emergency evacuation activities, especially those taken in response to local tsunamis. In addition to applying the information spatially from the hazard study to locate candidate "safe buildings," this will require that all of them be evaluated to determine their individual survivability from both direct tsunami impacts and those associated with local earthquakes, such as groundshaking, liquefaction, and other potential ground failures. Other background papers suggest appropriate siting, design, and construction measures to help ensure the survivability of existing and future buildings.

Near-shore coastal tsunami barriers, breakwaters, and sea walls may be ways of reducing the impacts of tsunamis. By helping to absorb the impacts of tsunamis, some buildings closer to the shore could serve as shelters and would be more immediately accessible. This would require both the proper design (including height) of the barriers and the buildings.

While many of the general principles governing liability are common, the specifics in each state can be quite different. It is, therefore, important that the liability implications of evacuation be examined by representatives of each state.

It is equally important that local emergency managers address the subject of evacuation in their emergency operations plans, including providing adequate warning, communications, public education, and training programs.

Listed below are specific vertical evacuation plan strategies to reduce tsunami exposure for people.

Identify Specific Buildings to Serve as Vertical Shelters

Some existing buildings can serve as vertical shelters and newer ones can be located, designed, and constructed with that use in mind. Local building officials and consulting engineers can help inventory the community's stock of candidate buildings, evaluate the buildings' tsunami- and earthquake-resistant capabilities, and establish criteria and standards for rehabilitation or new construction that meet the expected hazard forces so the buildings will be able to serve as shelters.

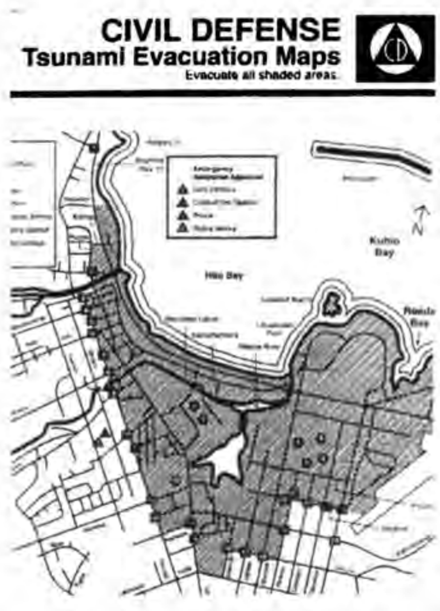
Factors to be considered in determining building suitability include size, number of stories, access, contents, and available services. Only those buildings that are judged able to withstand the potential tsunami and earthquake forces and that meet other occupancy criteria should be designated as shelters. For example, if expected tsunami wave heights will not exceed one story (about ten feet), then open-floor designs can be used to allow the waves to pass through with minimal impact on the building. Further information about evaluating the tsunami resistance of existing buildings is discussed under Background Paper #5.

Work Out Agreements and Procedures with Building Owners

To a large extent, vertical evacuation shelters will be designated in privately owned buildings. For a program to be effective, therefore, appropriate agreements should be negotiated with the owners, and the owners or their representatives should be involved in the creation and maintenance of the program. While they will vary among communities and states, issues related to notification, standards of care, compensation, duration of occupancy, security, and liability will be important to the owners.

Ensure Procedures Exist to Receive and Disseminate Warnings

It is very important that tsunami-vulnerable communities ensure that procedures and systems exist for notification by official warnings so appropriate actions can be taken, sometimes many hours in advance for distant tsunamis. Local tsunamis pose special problems because insufficient time might preclude official warnings. Some communities are advising and training their residents and visitors to evacuate immediately whenever earthquake shaking is felt. If no tsunami warning is issued, people can return after a short time.



Tsunami evacuation route map from the civil defense section of the Hilo, Hawaii, telephone book.

Implement Effective Information and Education Programs

Communities can use brochures, single-page instructions, periodic warning system tests, electronic and print media information, signs, and emergency response exercises to maintain awareness and instill effective response behavior. Some of this information will be directed towards special institutions, such as schools, hospitals, and convalescent-care facilities, and non-English speaking community members. Because of seasonal tourism in many coastal communities, some provide information especially for tourists. Depending on the community's needs, it is important that information and education efforts be routine, comprehensive, and directed toward special facilities and populations.

Maintain the Program Over the Long Term

Tsunamis are rare events, but their impacts on coastal communities can be devastating. It is a challenge to maintain emergency preparedness programs and procedures when the threat is perceived as remote. It is, therefore, important that vertical evacuation measures not only be integrated into community response plans, but that they be reviewed and revised regularly. Since cooperation is essential, these reviews should include building owners and others involved in the program. Periodic simulations are a valuable learning exercise, and regular informational and instructional materials should be provided to those occupying potential tsunami damage areas.

APPENDICES

GLOSSARY

Amplitude:
The tsunami's rise above or drop below the ambient water level as read on a tide gauge.

Bore:
Traveling wave with an abrupt vertical front or wall of water. Under certain conditions, the leading edge of a tsunami wave may form a bore as it approaches and runs onshore. A bore may also be formed when a tsunami wave enters a river channel, and may travel upstream penetrating to a greater distance inland than the general inundation.

Harbor Resonance:
The continued reflection and interference of waves from the edge of a harbor or narrow bay. This interference can cause amplification of the wave heights and extend the duration of wave activity from a tsunami.

Horizontal Inundation Distance:
The distance that a tsunami wave penetrates onto the shore. Measured horizontally from the mean sea level position of the water's edge, it is usually measured as the maximum distance for a particular segment of the coast.

Inundation:
The depth, relative to a stated reference level, to which a particular location is covered by water.

Inundation Area:
An area that is flooded with water.

Inundation Line (limit):
The inland limit of wetting, measured horizontally from the edge of the coast, defined by mean sea level.

Local/Regional Tsunami:
Source of the tsunami is within 1000 km of the area of interest. Local or near-field tsunami has a very short travel time (30 minutes or less), mid-field or regional tsunami waves have times on the order of 30 minutes to 2 hours. Note: "local" tsunami is sometimes used to refer to a tsunami of landslide origin.

Period:
The length of time between two successive peaks or troughs. May vary due to complex interference of waves. Tsunami periods generally range from 5 to 60 minutes.

Run-up:
Maximum height of the water onshore observed above a reference sea level. Usually measured at the horizontal inundation limit.

Seiche:
An oscillating wave in a partially or fully enclosed body of water. May be initiated by long period seismic waves, wind and water waves, or a tsunami.

Tidal Wave:
Common term for tsunami used in older literature, historical descriptions, and popular accounts. Tides, caused by the gravitational attractions of the sun and moon, may increase or decrease the impact of a tsunami, but have nothing to do with their generation or propagation. However, most tsunamis (initially) give the appearance of a fast-rising or fast-ebbing tide as they approach shore, and only rarely appear as a near-vertical wall of water.

Travel Time:
Time (usually measured in hours and tenths of hours) that it took the tsunami to travel from the source to a particular location.

Tsunami:
A Japanese term derived from the characters "tsu" meaning harbor and "nami" meaning wave. Now generally accepted by the international scientific community to describe a series of traveling waves in water produced by the displacement of the sea floor associated with submarine earthquakes, volcanic eruptions, or landslides.

RESOURCES FOR LOCAL GOVERNMENT OFFICIALS AND THE PUBLIC

Compiled by Lee Walkling, Library Information Specialist, Washington Department of Natural Resources, Division of Geology and Earth Resources

BOOKS

American Institute of Professional Geologists, 1993. *The Citizens' Guide to Geologic Hazards—A Guide to Understanding Geologic Hazards, Including Asbestos, Radon, Swelling Soils, Earthquakes, Volcanoes, Landslides, Subsidence, Floods, and Coastal Hazards.* Arvada, CO: American Institute of Professional Geologists. (Good overview and easy -to-understand explanations)

Myles, Douglas, 1985. *The Great Waves.* New York: McGraw-Hill Book Company. (For the general public)

Mileti, Dennis S., 1999. *Disasters by Design—A Reassessment of Natural Hazards in the United States.* Washington, D.C.: John Henry Press. (Preparedness and mitigation)

Atwater, Brian F.; Marco V. Cisternas; Joanne Bourgeois; Walter C. Dudley; James W. Hendley, II; Peter H. Stauffer, compilers, 1999. *Surviving a Tsunami—Lessons from Chile, Hawaii, and Japan.* U.S. Geological Survey Circular 1187.

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U.S. Federal Emergency Management Agency, 2000. *Coastal Construction Manual—Principles and Practices of Planning, Siting, Designing, Constructing, and Maintaining Residential Buildings in Coastal Areas.* 3rd. ed., 3 vol. (FEMA 55) Washington, D.C.: U.S. Federal Emergency Management Agency. (For more information: http://www.fema.gov/MIT/bpat/bpn0600e.htm)

PERIODICALS

Natural Hazards Observer (print and online versions)
(http://www.colorado.edu/IBS/hazards/o/o.html)
The bi-monthly newsletter of the Natural Hazards Center. It covers current disaster issues; new international, national, and local disaster management, mitigation, and education programs; hazards research; political and policy developments; new information sources; upcoming conferences; and recent publications.

TsuInfo Alert Newsletter
The bi-monthly newsletter of the National Tsunami Hazards Mitigation Program is distributed to approximately 250 emergency managers of the five Pacific coastal states. Back issues are online: http://www.wa.gov/dnr/htdocs/ger/tsuinfo/index.html

WEBSITES

http://www.geophys.washington.edu/tsunami/intro.html
University of Washington Geophysics Program - many links to other tsunami sites

http://www.fema.gov/library/tsunamif.htm
FEMA tsunami fact sheet and links

http://www.pmel.noaa.gov/tsunami/
NOAA/PMEL Web site, with links to inundation mapping, modeling, events, forecasting and the National Tsunami Hazards Mitigation Program sites

http://www.pmel.noaa.gov/tsunami-hazard/links.html
Important links to major tsunami sites

http://www.redcross.org/disaster/safety/guide/tsunami.html
Red Cross tsunami site, with overview, discussion of warning systems, and good preparedness information

http://www.geocities.com/CapeCanaveral/Lab/1029/
The Tsunami Page of Dr. George P.C. (Pararas-Carayannis)
Just about everything you'd need to know about tsunamis!

http://www.fema.gov/mit/handbook
Property Acquisition Handbook for Local Communities (FEMA 317)

VIDEOS

Forum: Earthquakes and Tsunamis (2 hrs.)
CVTV-23, Vancouver, WA (January 24, 2000)
Two lectures: Brian Atwater describes the detective work and sources of information about the January 1700 Cascadia earthquake and tsunami; Walter C. Dudley talks about Hawaiian tsunamis and the development of warning systems.

Tsunami: Killer Wave, Born of Fire (10 min.)
NOAA/PMEL
Features tsunami destruction and fires on Okushiri Island, Japan; good graphics, explanations, and safety information. Narrated by Dr. Eddie Bernard (with Japanese subtitles).

Waves of Destruction (60 min.)
WNET Video Distribution
An episode of the "Savage Earth" series. Tsunamis around the Pacific Rim.

Disasters Are Preventable (22 min.)
USAID
Ways to reduce losses from various kinds of disasters through preparedness and prevention.

Tsunami: Surviving the Killer Waves (13 min.)
DOGAMI
Two versions, one with breaks inserted for discussion time.

Raging Planet; Tidal Wave (50 min.)
Produced for the Discovery Channel in 1997, this video shows a Japanese city that builds walls against tsunamis, talks with scientists about tsunami prediction, and has incredible survival stories.

CONTACTS: STATE LAND USE PLANNING AND COASTAL PLANNING OFFICES

Alaska

Municipal and Regional Assistance Division (MRAD)
Mr. Pat Poland, Director (e-mail: Pat_Poland@dced.state.ak.us)
Alaska Department of Community and Economic Development (DCED)
333 W 4th Ave. Suite 220
Anchorage, Alaska 99501-2341
(907) 269-4580
fax: (907) 269-4539
home page: *http://www.dced.state.ak.us/mra/Home.htm*

Division of Governmental Coordination (DGC)
Gabrielle LaRoche, Coastal Program Coordinator (e-mail: Gabrielle_LaRoche@gov.state.ak.us)
Office of the Governor
P.O. Box 110030, Juneau, AK 99811-0030
907) 465-3562
fax: (907) 465-3075
Alaska Coastal Program homepage: *http://www.alaskacoast.state.ak.us/*

California

Governor's Office of Planning and Research
Steve Nissen, Acting Director
1400 Tenth Street
P.O. Box 3044
Sacramento, CA 95812-3044
(916) 322-2318
fax: (916) 322-3785
e-mail: opr.webmaster@opr.ca.gov
home page: *http://www.opr.ca.gov/*

California Coastal Commission
Peter Douglas, Executive Director
45 Fremont Street, Suite 2000
San Francisco, CA 94105-2219
(415) 904-5200
fax: (415) 904-5400
home page: *http://www.ceres.ca.gov/coastalcomm/web/*

Hawaii

Land Use Program and Hawaii Coastal Zone Management Program
Hawaii Office of Planning
David W. Blane, Director (e-mail: dblane@dbedt.hawaii.gov)
Dept. of Business, Economic Development & Tourism
P.O. Box 2359
Honolulu, Hawaii 96804
(808) 587-2809
fax: (808) 587-2899
home page: *http://www.hawaii.gov/dbedt/op.html*

Oregon

Department of Land Conservation and Development
Richard Benner, Director (e-mail: Dick.Benner@State.OR.US)
635 Capitol Street NE, Suite 150
Salem, OR 97301
(503) 373-0050
fax: (503) 378-6033
home page: *http://www.lcd.state.or.us/*

Oregon Coastal Management Program
Eldon Hout, Coastal Program Manager
Department of Land Conservation and Development
(503) 731-4065, Ext. 28
e-mail: eldon.hout@state.or.us

Washington

Growth Management Program
Shane Hope, Managing Director (e-mail: shaneh@cted.wa.gov)
Department of Community, Trade and Economic Development (CTED)
906 Columbia St. S.W.
P.O. Box 48300, Olympia, WA 98504-8300
(360) 753-2222
fax: (360) 753-2950
home page: *http://www.cted.wa.gov/info/lgd/growth/index.html*

Shorelands & Environmental Assistance Program
Gordon White, Manager (e-mail: gwhi461@ecy.wa.gov)
Department of Ecology
PO Box 47600, Olympia, WA 98504-7600
(360) 407-6000
home page: *http://www.wa.gov/ecology/sea/shorelan.html*

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Department of Community, Trade, and Economic Development, State of Washington (http://www.cted.wa.gov)

Department of Land Conservation and Development (DLCD), State of Oregon (http://www.lcd.state.or.us)

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