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ISSUES RELATED TO LOCAL TSUNAMIS IN HAWAII

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ABSTRACT

A review of historical data for locally generated tsunamis suggests average recurrence intervals of about 20 years for destructive tsunamis, with the last such tsunami occurring in 1975. Also, preliminary modeling indicates that a large tsunami generated on the Kona Coast could have significant destructive potential on other islands, especially on the south shore of Oahu. Unfortunately, the recurrence interval for such large tsunamis on the Kona Coast is not known. In evaluating local warning system capabilities and limitations, it should be noted that warnings based only on earthquake magnitudes will have an unacceptably high failure rate. Incorporating conventional tide gauge readings into the decision making process with magnitude determinations may moderately reduce this failure rate. An acceptable warning system will require: (1) many more wave recorders than the three now present on the Big Island; (2) modeling studies of wave heights or runups at instrumented sites for a suite of possible tsunamigenic earthquakes along the Puna, Kau, and Kona coasts; (3) perhaps a new generation of tsunami detectors; and (4) automated warnings for highly localized tsunamis.

INTRODUCTION

Potentially destructive local tsunamis in Hawaii may range in their average recurrence rate from values for tsunamis generated by moderate earthquakes to values for tsunamis generated by massive submarine landslides. The focus of this discussion extends only from the most common local tsunamis to those with possible recurrence intervals of a few hundred years. All of the issues to be discussed relate to an evaluation of local hazards associated with these types of tsunamis and any identifiable improvements in local warning systems which could reduce the numbers of false warnings, yet provide valid warnings for many highly localized, but life threatening tsunamis.

HISTORICAL DATA

Data for locally generated tsunamis are given in Table 1. The largest amplitudes reported on islands other than the Big Island for these events were 0.6 m for Honolulu in 1868 and 0.4 m for Kahului in 1975. In addition to the 1868 tsunami, several suspected Big Island tsunamis in the 19th century may be found in the listings of Lander and Lockridge (1989). None of these had reported values on any other islands. Because of the absence of reliable data, it is not possible to confirm the actual origins of these suspected 19th century tsunamis. Nonetheless, the number likely to have been locally generated is not inconsistent with an estimated 20 year average recurrence interval based on 20th century data. Additional discussions of local tsunamis may be found in Cox and Morgan (1977).

Of the 19 earthquakes on or near the Big Island in this century which had surface wave magnitudes of 6.0 or more (Table 2 and Figure 1), only the 1908, 1951, and 1975 earthquakes (nos. 1, 11, and 17) were tsunamigenic . Of these 19 earthquakes, 7 were along the Kau and Puna coasts and 4 were along the Kona coast. Submarine landslides or small earthquakes in 1919 and 1952 generated significant local tsunamis (Table 1). [Although the Hawaiian Volcano Observatory was in operation in 1919, the tsunami triggering mechanism for the 1919 tsunami was so small that it escaped detection.] For the 1868 tsunami (Figure 2) and the five tsunamis in this century, significant runups (i.e., runups of 1 meter or more) were reported only in Hilo and in Puna, Kau, and Kona coastal areas from Cape Kumukahi to Honokohau. Remarkable similarities are found in runup values for the 1868 and 1975 (Figure 3) tsunamis.

DISCUSSION

With an estimated average recurrence interval of about 20 years and the last significant tsunami occurring in 1975, a locally generated Big Island tsunami could be considered to be overdue. Such a perspective encourages evaluations of local warning system capabilities and limitations.

Earthquake Magnitudes

The historical data indicates that a warning system based only on earthquake magnitudes could have some moderate success for only the largest earthquakes (i.e., Ms of 6.8 or greater) provided that improvements in the precision of immediate magnitude determinations could be achieved. [Recomputations of magnitudes for these large events often produces magnitudes which are higher or lower by a few tenths of a unit (e.g., “Big Islands Quake Size Recalculated”, Honolulu Advertiser, 5 July 1993, B2). A warning system with a lower threshold of 6.0 Ms would experience prohibitively large numbers of false warnings (Table 2), and would miss very localized, but significant, tsunamis generated by submarine landslides and moderate earthquakes (Table 1).

Tide Gauge Readings and Numerical Modeling

A local warning system based on earthquake magnitudes and tide gauge readings could be more reliable than a system based only on earthquake magnitudes. However, numerical modeling studies indicate that bathymetric focusing and defocusing of tsunamigenic energy can make gauge readings very unreliable indicators of tsunamigenesis (e.g., Mader, 1991). Although sufficient tide gauge data is unavailable for local tsunamis to demonstrate this point, tide gauge data related to this issue for Pacific-wide tsunamis is substantial and convincing (Tables 3 and 4). Therefore, improvements to local warnings based on earthquake magnitudes and tide gauge readings could only be made by matching real-time gauge readings with precomputed, numerically modeled gauge readings for a variety of earthquake epicenters and source mechanisms. This would be similar to what has been done on a much larger scale for portions of the North Pacific by Whitmore and Sokolowski (1996).

Existing Gauges

At present there are three tide gauges on the Big Island from Cape Kumukahi to Honokohau. These are at Kapoho (near Cape Kumukahi), Honuapo, and Honokohau. One or two additional gauges may be installed by the Pacific Tsunami Warning Center in the next year or two. Obviously four or five gauges will not be enough to provide adequate early warnings for all of the coastal areas extending from Hilo to Honokohau. Another problem is that with the current absence of modeling studies, it is not possible to reliably estimate wave heights at other locations adjacent to those gauges first to record a local tsunami.

Improvements

Some practical considerations in improving the existing system are costs and the nature of the environment in which conventional gauges would have to be placed. Much of the all important Kau coast is accessible only by foot or helicopter. It is characterized mostly by sea cliffs and a few small shallow natural bays. These environments are very unsuited to tide gauges which are normally mounted on pilings and docks in sheltered developed harbors. Another problem is that in such remote areas the instrumentation may be subjected to a high degree of vandalism for such petty reasons as the acquisition of stainless steel nuts and bolts. At costs of approximately $25 K per unit, this is a serious consideration. Some of the installations on the Kona coasts would also have to be made in similar environments. The importance of having instruments along the Kau coast, especially in the area of Halape and Keauhou Landing, cannot be overstated. The largest values in 1868 and 1975 were reported at those sites, and data from these locations for Kau and Puna generated tsunamis could provide early life-saving warnings for other portions of the Big Island. Two people were killed at Halape in 1975 and many more in other coastal areas could have died if this tsunami occurred during prime time daylight hours (look at the runup values from Hilo to Honokohau in Fig. 3). Another practical consideration is whether bathymetric data for the coastal areas of the Big Island are of sufficient accuracy and resolution to permit reliable modeling. All of the above suggest that the establishment of a reliable conventional local warning system could be an expensive and difficult task. With this realization it may be worthwhile to consider other options.

Other Options

In the absence of modeling studies, and until such time as modeling results become available, comparisons of real-time runup values to historical runup values for those sites first struck by a tsunami could be used to estimate runups in other coastal areas. For example, it might be reasonable to estimate that for tsunamis originating along the Kau coastline: (1) runups along the Kona coast will generally be less than one-half of the runups at Punaluu, Honuapo, and Kaalualu; and (2) the runups in Hilo could be comparable to those observed at Kaimu, Opihikao, and Cape Kumukahi. For tsunamis originating along the Kau Coast, it might be reasonable to estimate that runups might have to exceed values for 1868 and 1975 to represent any possible risk to other islands. One way of acquiring comparative runup data would be with water level or pressure level switches in historically important coastal areas. The switches could be banded to trees at heights above sea level considered to be significant, and coupled into existing dc powered cellular alarm systems recently developed by the security industry for remote sites as a back-up when phone lines are cut by would- be burglars. These items are off-the-shelf, commercially available. The water level switches are used to detect flooding in basements and cost about $40. The cellular telephone alarms cost about $250. Monthly subscription charges could be provided as a public service by local cellular phone companies. [Aside from testing, the phones would be used on an average of once every twenty years!] With a waterproof case, a battery pack, and some wiring, the costs of cellular runup detectors (CRD's) could be less than $500. Also, by banding the instruments in inconspicuous plastic tubes up in trees, vandalism could be minimized. Cellular phone service now covers nearly all of the sites on the Big Island for which historical runup data are available (based on site surveys from 15 through 28 March 1999). For less than the cost of a single tide gauge, CRD's could be placed at every site on the Big Island for which historical runup values are available (i.e., 16 sites).

As an example of how such a system might work, the recording of 10 ft runups at two sites could automatically (without human intervention) trigger warning sirens for the Big Island. [The "two site" trigger would eliminate false alarms produced by instrumental malfunctions, vandals, animals, insects, or falling trees.] Larger values or continuing large values on other gauges could require the consideration of warnings for other areas of the State.

State-Wide Destruction from a Kona Coast Tsunami?

It may be a comforting thought for the rest of the State that the largest local earthquakes and largest local tsunamis in recorded history (1868, 7.5 Ms, 45 feet/13.7 m at Keauhou Landing; 1975, 7.2 Ms, 47 feet/14.3 m at Keauhou Landing) did not produce any significant reported runups on islands other than the Big Island. However, an important and disturbing question which must be asked is whether a 1975 type tsunami could occur on the Kona coast; and, if so, what runups would be observed on other islands. The question seems reasonable because large earthquakes occur along the Kona Coast (e.g., a 6.5 in 1929 and a 6.9 in 1951), and bottom conditions (large volumes of loose volcanic sands and debris) and slopes in many areas of Kau and Kona are similar. Two of the five Big Island tsunamis in the 20th century were along the Kona coast; and the source area for the proposed giant tsunami which is believed by some to have deposited limestones at elevations of up to 1,000 feet on the island of Lanai is off the Kona coast (Moore and Moore, 1984). The central issue is not whether a 1975 type event could occur off the Kona coast. With this region's recorded history of earthquakes and tsunamis, and the long history of massive submarine landslides in the Hawaiian Islands (Moore et al., 1994; Lockridge, 1998), it seems likely that such an event could occur. The central issue is the recurrence rate for such events. Is it once every 100,000 years or once every 200 years? From historically reported data it is not possible to answer this question. However, if the recurrence interval is on the order of a few hundred years, field investigations combined with numerical modeling studies could provide evidence for such an event. Remote regions in the Kau district of the Big Island may still be found which show clear evidence of the 1868, 1946, 1960, or 1975 tsunamis in the form of wave strewn rounded ocean boulders and isolated 2 to 3 foot diameter logs deposited on grassy slopes of Pahala ash or on barren lava flows - all at elevations corresponding to historical runup values for those areas. Detailed numerical modeling could tell us where to look in other remote and undisturbed areas of the State for evidence of a large Kona tsunami. This is an important consideration because preliminary modeling studies suggest that such an event could, in fact, produce runups of 10- to 20-feet along Oahu's south shore (Mader; personal communication). Travel times to Honolulu for such a tsunami would be about 35 minutes.

Pending evidence to the contrary, and in the interest of public safety, it would be appropriate to consider that a large Kona tsunami could occur sometime in the next 100 years. Because of the State-wide implications of such an event, numerical modeling studies could tell us what tide gauge or runup values along the Kona coast could indicate destructive potentials on other islands. Without such information, false State-wide warnings for large Kona earthquakes would destroy credibility in the State's warning system. Along with this modeling effort, more tide gauges or runup detectors would have to be placed along the Kona Coast. Until such time as modeling studies become available, data from runup detectors could be matched to historical runup values so as to reduce false warnings, and to provide valid State-wide warnings for large Kona Coast tsunamis, as well as some warnings for much smaller local tsunamis. Again we note that insufficient historical data from tide gauges are available for comparisons to future gauge recordings. Also, there is at present only one tide gauge along the Kona Coast - at Honokohau, well within a man-made sheltered harbor.

In the absence of modeling studies and more tide gauges or runup detectors, a State-wide warning might be issued for a 6.8 Ms Kona earthquake which generates a 2 or 3 meter reading on the Honokohau tide gauge and readings of less than 0.3 m on other islands. On the other hand, a State-wide warning might not be issued for a 6.7 Ms Kona earthquake at a different location which generates a 1 meter tsunami at Honokohau and a 3 meter tsunami in Waikiki. Such scenarios should only be dismissed when they can be proven false by modeling studies. In both scenarios people may die on the Kona Coast and certainly more may die along that coast as time passes during the human decision making process. This argues for a totally automated warning system for all, or part of, the Big Island.

Other Earthquakes and Tsunamis

Other historical earthquakes with magnitudes in excess of 6.0 in the Hawaiian Islands occurred in 1871 (a 7.0 at about 20.8°N and 157.0°W between Lanai and Molokai), 1885 (a 6.0 at about 21.0°N and 156.0°W north of Hana, Maui), and 1938 (a 6.75 at about 21.0N and 156.0°W, again north of Hana). In spite of the disturbingly large sizes of the 1871 and 1938 events, none of the three earthquakes have any reported tsunamis. Also, the recent historical record contains no evidence of confirmed, or even highly suspicious, tsunamis generated near any islands other than the

Big Island. Again it should be cautioned that such tsunamis could have escaped detection in the limited historical record, and future field investigations in remote areas could provide evidence for such tsunamis. These regions are obviously far less active than the Big Island, and have generally more compacted sediments and more stable sedimentary slopes than are present near the Big Island. Therefore, there can be no doubt that the most frequent local tsunamis will continue to originate along the coastal regions of the Big Island.

CONCLUSIONS

In recent years the limitations of the State's warning capabilities for local tsunamis has been a frequent topic of discussion in private scientific meetings and in conferences sponsored by State and County Civil Defense agencies. To formalize the concerns of the local scientific community, written recommendations for more instrumentation on the Big Island as well as local modeling studies have been distributed to State and County Civil Defense Agencies (letter of 4 August 1998 to State Civil Defense; and in "Executive Summary and Position Paper on Recent Discussions Related to Tsunamis Issues.", 20 October 1997).

Therefore, on the issue of locally generated tsunamis, the scientific community has, at this time, fulfilled its responsibility to the State in identifying possible limitations of the warning system. It is now the responsibility of the State to decide whether the injuries, fatalities, false warnings, and damage to tourism inevitable with the existing system are acceptable given their limited budgets and other options for reducing fatalities and injuries from other natural, as well as man-made, hazards; or whether the recommended improvements would be an efficient use of hazard mitigation funds. If the improvements recommended by the scientific community are adopted, the State should formulate a plan and invite the continued support of its science advisors, as well as formally request the support of appropriate federal agencies, including the National Weather Service and the Pacific Tsunami Warning Center, in those efforts.

Acknowledgments. I wish to thank all of my colleagues in Hawaii whose comments at recent Civil Defense meetings has helped to identify local tsunami issues, and all those whose research and field investigations have provided the data on which our current knowledge is based. Finally, I would like to acknowledge Evelyn Norris for her assistance with the preparation of this manuscript, as well as with earlier tsunami publications. School of Ocean and Earth Science and Technology Contribution 4792 and Hawaii Institute of Geophysics and Planetology Contribution 1045.

TABLE 1

All Reported and Confirmed Locally Generated Tsunamis in the Hawaiian Islands*

Yr	Mo	Day	Ms	Runups or Tide Gauge Readings
1868	04	03	7.5	45 ft (13.7 m) Keauhou Landing; 2 ft (0.6 m) Honolulu; observed Lahaina; many other runups on the Big Island.
1908	09	21	6.8	4 ft (1.2 m) Hilo; no other observations.
1919	10	02	- -	14 ft (4.3 m) Hoopuloa; 8 ft (2.4 m) Keauhou; 3 ft (0.9 m) Kailua-Kona; no other observations.
1951	08	21	6.9	4 ft (1.2 m) Hookena; 3 ft (0.9 m) Kailua-Kona, Napoopoo, Milolii; < 0.1 m Hilo, Honolulu, Port Allen.
1952	03	17	4.5	10 ft (3.0 m) Kalapana; no other observations.
1975	11	29	7.2	47 ft (14.3 m) Keauhou Landing; 1 ft (0.4 m) Kahului; 0.1 m Nawiliwili; < 0.1 Coconut Island on Oahu, Honolulu; observed Lahaina, Hana; many other runups on the Big Island.

* All data are taken from Lander and Lockridge (1989). All available data are given unless otherwise indicated. Maui sites are Lahaina, Kahului, and Hana. Kauai sites are Port Allen and Nawiliwili.

TABLE 2.							
Large (Ms ≥ 6.0) 20th Century Big Island Earthquakes*							
				Coordinates			
No.	**Yr**	**Mo**	**Day**	**°N**	**°W**	**Ms**	**Tsunamigenic**
1	08	09	21	19.00	155.00	6.8	Yes
2	18	11	02	19.40	155.30	6.2	No
3	19	09	15	19.00	155.50	6.1	No
4	26	03	20	20.50	155.50	6.0	No
5	27	03	20	20.50	155.25	6.0	No
6	29	10	06	19.75	156.00	6.5	No
7	40	06	17	20.40	154.70	6.0	No
8	41	09	25	19.50	155.50	6.0	No
9	50	05	30	19.50	156.00	6.2	No
10	51	04	23	19.20	155.50	6.5	No
11	51	08	21	19.48	155.97	6.9	Yes
12	52	05	23	19.48	155.98	6.0	No
13	54	03	30	19.38	155.02	6.0	No
14	54	03	30	19.35	155.02	6.5	No
15	62	06	28	19.40	155.45	6.1	No
16	73	04	26	19.90	155.13	6.1	No
17	75	11	29	19.34	155.00	7.1	Yes
18	83	11	16	19.43	155.45	6.7	No
19	89	06	26	19.36	155.08	6.1	No

* Data taken from U.S. Geological Survey listings. Surface wave values are U.S.G.S. values when available. The 7.1 Ms for the 1975 earthquake is a U.S.G.S. value whereas the Pasadena value in Table 1 is 7.2.

TABLE 3.

Tide Gauge Readings and Runups from North Pacific Earthquakes with Runups of 9 Meters (30 Feet) or More in Hawaii*

Station	**Year**		
	1946 (m)	**1952 (m)**	**1957 (m)**
At Source	**35.0**	**18.4**	**15.0**
Japan	1.1	1.0	**3.0****
Adak	--	1.1	4.0
Attu	--	1.5	0.6
Kodiak	--	0.2	0.2
Seward	--	0.1	0.2
Sitka	0.4	0.3	0.4
Unalaska	--	0.6	0.7
Yakutat	0.3	0.3	0.3
Canada	0.3	0.3	--
Washington	0.2	0.2	0.2
Oregon	**3.0****	0.1	<0.1
Crescent City	0.9	1.0	0.7
San Francisco	0.3	0.5	0.3
Los Angeles	0.4	0.5	0.5
San Diego	0.2	0.4	0.2
Midway	--	**1.9****	0.5
Wake	--	0.3	0.4
Hawaii	**16.4**	**9.1**	**16.1**

* Source areas for the '46, '52, and '57 earthquakes were Eastern Aleutians, Kamchatka, and Central Aleutians, respectively. Values for Japan and Canada are taken from Iida et al. (1967). All other values are from Lander and Lockridge (1989). Values include the largest reported in each country, state, or territory indicated, as well as the largest value (**) reported in the Pacific outside of the Hawaiian Island and the source area of the tsunami.

TABLE 4.

Tide Gauge Readings at Midway and Reported Tsunami Runups in Hawaii*

Earthquake	Location	Runup in Hawaii (ft)	Tide Gauge Reading or Runups at Midway (ft)
4 Nov. 1952	Kamchatka	29.8	6.2
9 March 1957	Aleutians	**52.8**	**1.6**
6 Nov. 1958	Kurils	1.0	0.7
13 Oct. 1963	S. Kurils	1.3	1.0
20 Oct. 1963	S. Kurils	1.3	0.7
28 March 1964	Alaska	**16.1**	**0.3**
4 Feb. 1965	Aleutians	3.6	0.7
16 May 1968	Japan	1.6	0.7
7 May 1986	Aleutians	2.0	1.0
4 Oct. 1994	S. Kurils	**1.6**	**1.6**
10 June 1996	Aleutians	1.8	1.5

* For earthquakes in this century located in the North Pacific which had readings at Midway and runups of 1 foot or more in Hawaii. Data for the 1994 and 1996 tsunamis were taken from listings published by the National Earthquake Information Center of the U.S. Geological Survey. Data for other tsunamis are taken from Lander and Lockridge (1989). The unreliability of gauge data as an exclusive predictor of tsunamis in the Hawaiian Islands is best indicated by the values in bold type.

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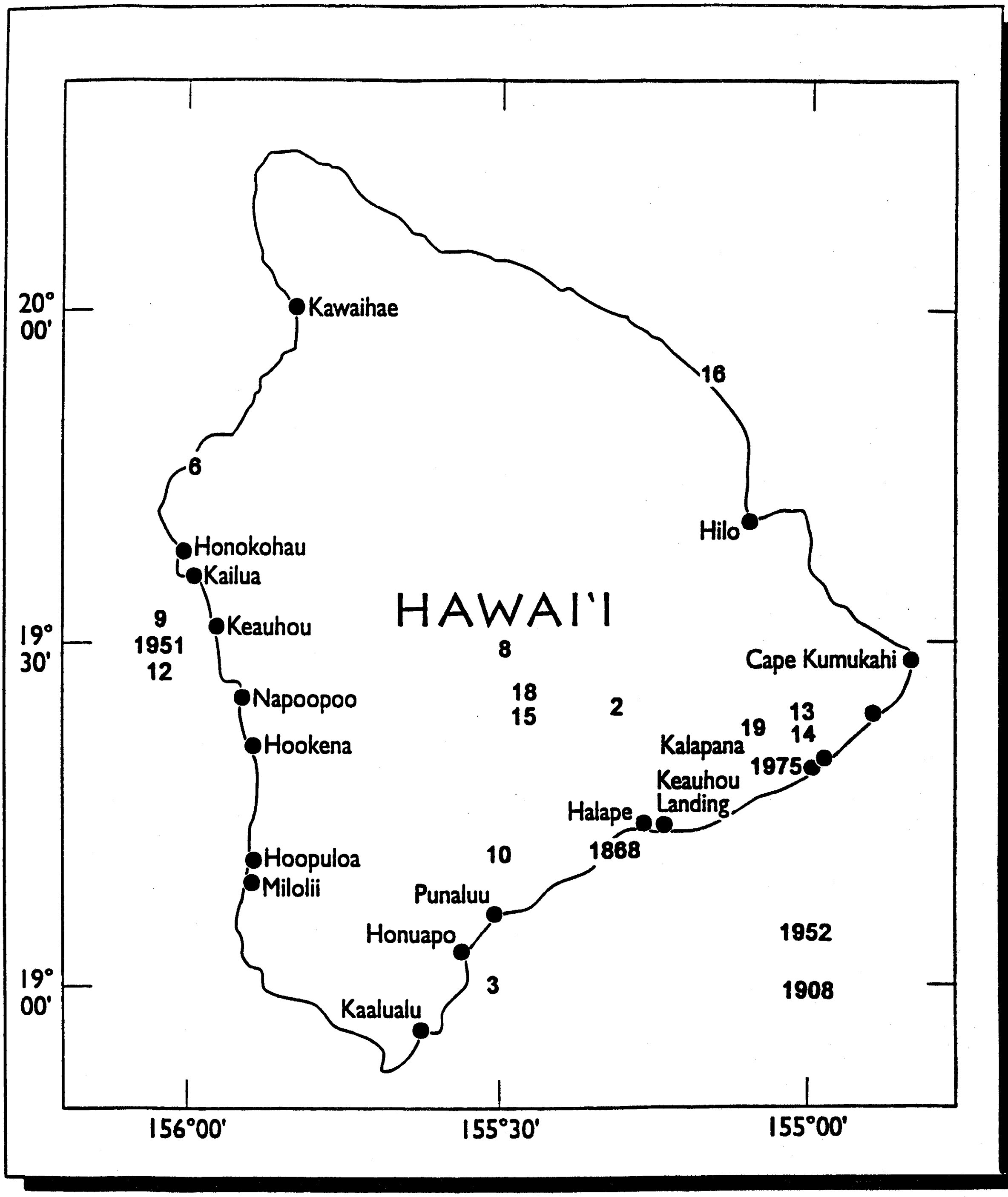

Figure 1. Estimated epicenters for 20th century earthquakes on or near the Big Island with surface wave magnitudes of 6.0 or more. Single and two digit numbers are the earthquake identifying numbers for non-tsunamigenic earthquakes given in Table 2. Also shown are the estimated epicenters for tsunamigenic earthquakes given in Table 1. Four digit numbers used to identify these earthquakes indicate the years in which they occurred. All numbers are approximately centered over their respective epicenters. Three earthquakes occurred just north of the Big Island outside of the area of the map. None of these earthquakes (nos. 4, 5, and 7 in Table 2) were tsunamigenic.

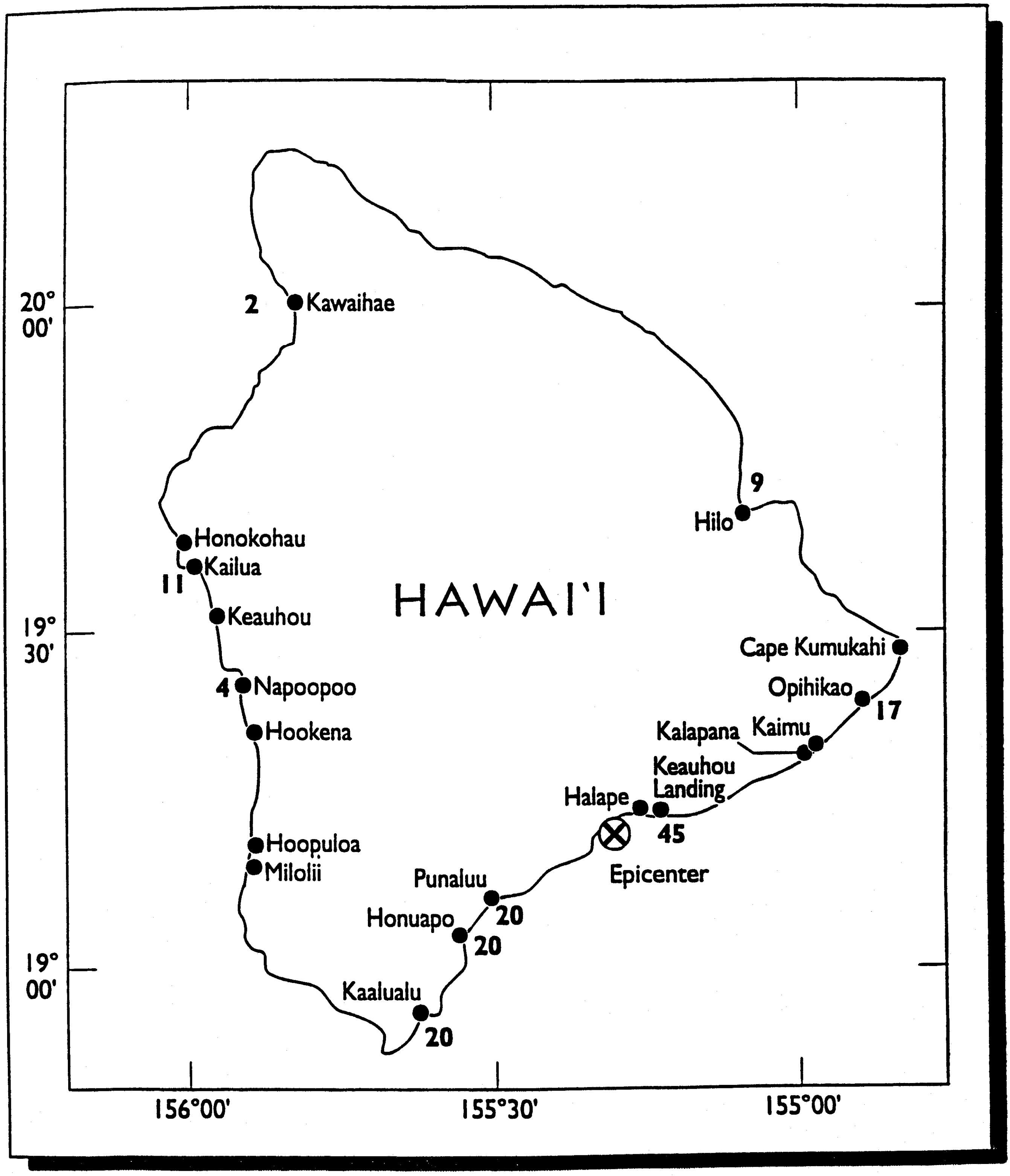

Figure 2. Estimated runups for the 1868 tsunami.

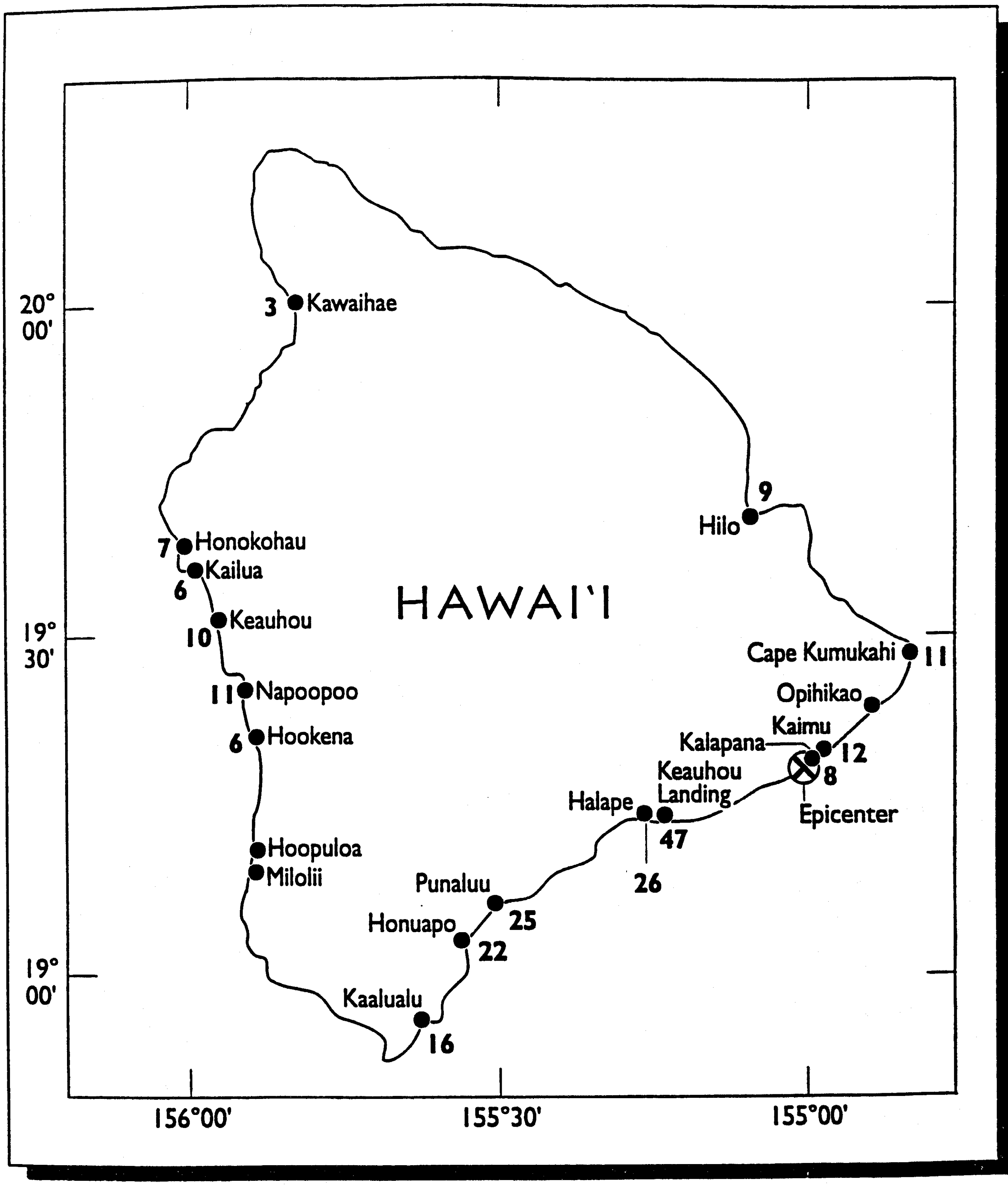

Figure 3. Estimated runups for the 1975 tsunami.

JAPANESE TSUNAMI WARNING SYSTEM

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ABSTRACT

As Japan is a nation small in area and surrounded by seas, a potential threat of a destructive tsunami becomes a national event. The Japan Meteorological Agency, an agency of the national government, has the mandate to issue tsunami warnings. By using an archive of pre-calculated tsunami scenarios, the agency can forecast wave heights for all the coasts of Japan, when the magnitude and epicenter of the generating earthquake are known.

Tsunami warnings and forecasts start from the cabinet level of the national government and are transmitted through the various layers of the national government, to the prefecture governments and eventually, in a matter of minutes, to the local governments. Transmission of the warning and forecasts from the local governments to the general public is done through a variety of media. The response of the warning system to the Sea of Japan Tsunami of July 12, 1993, was well documented and showed successes and loopholes.

INTRODUCTION

As Japan is a nation buffeted by frequent natural disasters -- typhoons, earthquakes, tsunamis, floods, landslides, volcanic explosions and lava flows – the whole nation, from the prime minister to the perspiring farmer and fisherman, is geared to respond to disasters. It is a nation with a nationally coordinated disaster mitigation and emergency management program. To understand how a tsunami warning is issued to the people, one must have some knowledge of governmental structure and news media connections.

By parliamentary action in 1952, the Japan Meteorological Agency (JMA)has been entrusted with the responsibility of issuing tsunami warnings. As the JMA is an agency in the Ministry of Transportation, a cabinet level department of the national government, a tsunami warning issued by the JMA passes through several layers of government to reach the people. On the way down the layers of bureaucracy, those agencies and boards and departments that can contribute to the mitigation of the impending disaster are alerted and mobilized.

Chapter 1 describes in brief the government structure from the national level to the local level of villages and town. How these various governmental entities are tied in closely for emergency management by communication networks exploiting state-of-the-art technology will be described.

Chapter 2 is devoted to the Japan Meteorological Agency, which issues tsunami warnings. The JMA is a very complex organization with headquarters in Tokyo and with Regional Observatories in five other cities. This report will limit the discussion to only those parts of the agency that deal with tsunami warning. A summary of how a tsunami warning is formulated and issued will be given.

From the overall point of view, there are two ways a tsunami warning is transmitted to the people: 1) through the government channels and 2) directly by broadcasts over radio and television. In Chapter 3, how the warning gets to the people by government channels will be described. Japan has developed a few unusual ways in getting the message to the people. In Chapter 4, the role played by radio and television will be described.

In Chapter 5 the case of the 1993 Southwest Hokkaido earthquake and tsunami will be taken up to show how the warnings were disseminated to the people. The chapter ends with an evaluation of the system.

CHAPTER 1. GOVERNMENTAL STRUCTURE IN JAPAN

Governmental structure can be divided into the national government, prefecture governments and local governments. The national government is responsible for the well being of the whole nation. Fortunately Japan does not have possessions, territories and colonies to complicate matters. The prefecture governments correspond to our state governments, and the local governments consist of city, town and village authorities, which are in daily contact with the people.

1-A. The National Government

The national government of Japan is classified as a constitutional monarchy, wherein the emperor is a symbol of national unity, so explicitly stated by the Constitution of Japan. The legislative branch is bicameral, but only the lower house, the House of Representatives, has the power to enact laws. The upper house, the House of Councilors, is an advisory body with no power to enact or veto any legislation. It can delay approval of legislation it doesn't like. The executive branch is headed by a prime minister who is elected by the House of Representatives and then automatically appointed by the emperor to head the executive branch. The prime minister appoints a cabinet of 18 members, of which 13 ministers will be heading the various ministries, which are departments of the executive branch.

Departments at the cabinet level are listed here because most of them participate in emergency management:

The Office of the Prime Minister (OPM),
Ministry of Justice,
Ministry of Foreign Affairs,
Ministry of Finance,
Ministry of Education,
Ministry of Health and Welfare,
Ministry of Agriculture, Forestry and Fishery,
Ministry of International Trade and Industry,
Ministry of Transportation,
Ministry of Postal Service,
Ministry of Labor,
Ministry of Construction ,
Ministry of Home Affairs.

Each ministry has agencies, from a few to a dozen or more. Under the Office of the Prime Minister are about a dozen agencies, of which the ones which participate in emergency management are the Administrative Management Agency, National Land Agency, Defense Agency, National Public Safety Agency, Environment Agency. The National Public Safety Agency is the home of the National Police (Keishichou) which coordinates the communication among the prefecture police forces.

Within the Ministry of Transportation are the Japan Meteorological Agency (JMA) and the Maritime Safety Agency. The Maritime Safety Agency is equivalent to our Coast Guard. The ministry coordinates the railway systems, the harbor systems and airports. During a tsunami crisis, the ministry will be humming with activity.

Many of the agencies have regional offices and outlets. The areas of responsibility of these regional offices vary in size, from one to several prefectures. These offices constitute a layer of bureaucracy between the national agency and the prefectures. In the JMA there are five regional observatories. In the case of tsunami warnings, the regional communication network (L-ADESS) speeds up transmission of messages.

1-B. Prefecture Governments.

Politically Japan is divided into 47 prefectures (*ken)*, which correspond to our states. In area a typical prefecture is about the size of an average county in the U. S., but in population size, it is as well populated as our average state. The prefecture government has a unicameral elected legislature and an executive branch headed by an elected governor. Each prefecture maintains its own police force, which takes on a great role in emergency management. Tokyo, the seat of the national capitol, calls itself Metropolitan Tokyo (*Tokyo-to)*, rather than a prefecture, but in practice the government structure is the same as any other prefecture.

1-C. Local Governments

Local governments consist of population centers classified as cities, towns and villages. Classification depends on the size of the population. When a town reaches a population of more than 50,000, it is usually raised to the status of a city. A city with a population in the millions is divided into wards (*kus*).

Each city, ward, town or village has an elected legislative assembly and an elected mayor or head of the village. The executive staff is based on a civil service system. Even the smallest village has a government office, the *murayakuba*, where villagers register births, marriages, deaths, where application can be filed to obtain various government permits, and where police assistance can be obtained in dire circumstances. Local governments do not have police forces; the maintenance of law and order at the local government level is the responsibility of the prefecture police force.

1 – D. Affiliated Organizations

Besides the formal governmental entities, there are organizations affiliated with the government in dealing with natural disasters. The Japan Weather Association is such an organization. Many former staff members of JMA join the association upon retirement from JMA. In normal times and during disasters it is the public relations arm of JMA.

Other affiliated organizations are the Red Cross, commercial weather forecasters and commercial television and radio corporations.

CHAPTER 2. THE JAPAN METEOROLOGICAL AGENCY

2-A. Structure

As the name indicates, the main task of the Japan Meteorological Agency (JMA) consists of monitoring weather changes and issuing weather forecasts. But from the inception of the agency in the nineteenth century, the agency has been maintaining seismograph stations. The headquarters of JMA in Tokyo has five departments and one of them is Department for Earthquakes and Volcanoes which includes the Tsunami Monitoring Section. In 1941 JMA established a tsunami warning system for the Pacific side of Northeast Japan (Satake, 1995) for local and distant tsunamis. Immediately after the Off Kushiro Earthquake and Tsunami of 1952 (sometimes referred to as the Tokachi Earthquake), parliament mandated that issuance of tsunami warnings be an integral part of the duties (*gyoumu*) of JMA (Tatehata, 1998). This act of parliament clarified the responsibility for tsunami warnings, as other agencies, such as the Geological Survey of Japan and the Research Institute of Earth and Planetary Sciences in the Science and Technology Agency also maintain seismic networks and have expertise to issue tsunami warnings.

Besides the headquarters in Tokyo, there are five regional meteorological observatories (Figure 1), and each has a department for earthquake monitoring with the capability for issuing warnings for near tsunamis. They are: Sapporo Regional Observatory in Sapporo, Hokkaido; Sendai Regional Observatory in Sendai in northern part of Honshuu; Osaka Regional Observatory in Osaka in central Honshuu; Fukuoka Regional Observatory in Fukuoka in Kyushuu; and Okinawa Regional Observatory in Naha, Okinawa Islands. Each observatory maintains a number of seismograph stations within its area of responsibility and seismic data are telemetered in real time to the earthquake department of the observatory. For tsunami purposes the regional observatories function as regional tsunami warning centers with areas of responsibility clearly outlined, as shown in Figure 1. If an earthquake occurs at sea, observatories will determine the source parameters (epicenter coordinates, depth of focus, time of origin, magnitude), and then the responsible observatory will forecast tsunami heights for all the coasts of Japan. For coasts within its area of responsibility, it will issue tsunami bulletins; the bulletin can be a warning, a watch or just an information bulletin. For the other coasts the observatory will transmit results of the forecast to their respective regional observatories.

2-B. Seismic Data Processing and Analyses

JMA maintains an extensive network of seismic stations, 150 throughout Japan (Figure 2). Real time data transmission links are established from the stations to regional observatories and then to the headquarters in Tokyo. The seismic instruments range the gamut of amplification and frequency response: from high frequency accelerometers to ultra-long period seismometers lodged in the bottom of deep wells, from low magnification strong motion seismometers to high gain instruments with hundreds of thousands of amplification, and even extensometers. For rapid real time data processing, Earthquake and Tsunami Observation System (ETOS) was established in 1991 in every regional observatory. ETOS can print out the source parameters a few seconds after P waves have arrived at the stations. The Tokyo headquarters, which considers all of Japan as its area of responsibility, uses Earthquake Phenomena Observation System (EPOS) to receive data nation wide and to determine source parameters. As the headquarters must be on the alert for distant tsunamis that can damage Japan, EPOS, which has international links with Pacific Basin nations, also processes data for very distant earthquakes.

ETOS determines moment magnitude by P waves. Moment magnitude by P waves may not be as accurate as moment magnitude by mantle waves, but it is adequate in case of tsunamigenic earthquakes to decide to proceed to the next stage of tsunami forecasting. If a coastal district is within 600 km of the earthquake epicenter, the potential tsunami is considered to be a local tsunami and the observatory responsible for that coastal district will go into the tsunami forecast mode.

2-C. Tsunami Forecasting .

The tsunami forecast program described in this section has gone into effect in the spring of 1999. The program can produce run up scenarios for all the coasts of Japan for any near tsunamigenic earthquake in seconds. The program makes use of a large archive of pre-calculated numerical simulation tsunami scenarios which are stored in the computer memory bank. In this report, these pre-calculated simulation scenarios will be called virtual tsunamis.

It is assumed that the tsunami generating fault dimensions -- fault length L, fault width W and the slip vector U --are functions of the magnitude M, expressed in the following formulas:

$$\log L(\mathrm{km}) = 0.5M - 1.9; \qquad W \sim L/2;$$
$$\log U(\mathrm{cm}) = 0.5M = 1.4.$$

Virtual tsunamis have been pre-calculated for thousands of sources. The source locations of the virtual tsunamis are at the grid points of the map in Figure 3. For each location virtual tsunamis were calculated for various magnitudes starting from 6.5 and up. All of these virtual tsunamis are stored in the super-computer so that they form an archive of three dimensional matrix of latitude, longitude and magnitude, as shown in Figure 3.

An earthquake is unlikely to fall exactly on a grid point or to agree with a magnitude that was used in pre-calculation. Figure 4 illustrates this. The earthquake (white circle) fell in a phase space boxed by eight points (black circles) where virtual tsunamis are available. For this case the forecast program interpolates among geographical coordinates and magnitudes to obtain the run-ups.

The method of virtual tsunamis and interpolation has been tested against data from historical tsunamis and was found to be satisfactory for warning purposes.

The results of the forecast forms the basis for a tsunami bulletin which may be a warning, a watch, or a “no danger” advisory.

2-D. Tsunami Bulletin, Message, Watch and Warning

After forecasting for all the coasts of Japan, the regional observatory or the headquarters issues a tsunami bulletin covering all the coasts of Japan for public consumption. The types of messages are: “no tsunami”, “tsunami watch”, “tsunami warning”, “major tsunami warning” , “tsunami watch is cancelled”, “ tsunami warning is cancelled”. The table below gives the abbreviated messages and what these simple messages mean.

A regional observatory transmits the bulletin to other observatories, including the JMA headquarter in Tokyo, and to prefectures within its area of responsibility by the Local Automatic Data Editing and Switching System (L-ADESS) (cf. Figure 5). The bulletin is not necessarily automatically passed on by other observatories. An observatory may change the content of the bulletin, after reviewing the bulletin in the light of their own set of data.

At the headquarter in Tokyo, when bulletins are received from a regional tsunami warning center, or when the headquarter itself issues a bulletin, the bulletin is distributed to all the members of the Central Emergency Management Communication Network. This is discussed in the next chapter.

TABLE 1. MESSAGES SENT IN TSUNAMI BULLETINS
(Translated from Nakamori, 1994)

Bulletin	Message	Meaning of Message
Tsunami Watch	No tsunami	There is no danger of tsunami arrival.
	Tsunami watch	Tsunami may arrive. At the highest place the tsunami may attain height of several tens of centimeters.
	Tsunami watch is cancelled.	Fear of tsunami has passed.
	Tsunami warning is cancelled.	Danger of tsunami has passed.
Tsunami Warning	Tsunami	A tsunami is expected. Because the highest expected tsunami can be 2 meters, due vigilance is required in those areas prone to high tsunamis. In other places, the tsunami will likely be several tens of centimeters high.
	Major Tsunami	A large tsunami will arrive. Highest heights can be over 3 meters, in those places that were damaged in previous tsunamis. Utmost vigilance required. In other places, waves can be 1 meter high and vigilance is required.

CHAPTER 3. TSUNAMI WARNING TRANSMISSION THROUGH GOVERNMENT CHANNELS

3-A. Overall Picture

An overall picture of how tsunami warning is transmitted through the government structure is shown in Figure 6. We can distinguish four levels: national, regional, prefecture and local. This may seem to be time consuming but with modern technology it is a matter of seconds from the national level to the local level. The transmission to the people depends on how alert the authorities are at the local level.

It is interesting to notice that the transmission from the cabinet level to the prefecture level uses the fire department circuit.

3-B. Within the National Government Level

Central Emergency Management Communication Network.

At the cabinet level in order to respond and react rapidly to disasters, those ministries and agencies that can contribute to the response are linked together in the Central Emergency Management Communication Network (CEMCN). The hub of this network is the National Land Agency (NLA) in the Office of the Prime Minister. The members of the network are:

Administrative Management Agency in the Prime Minister's Office, Ministry of Construction,
Naztional Land Agency (NLA),
National Fire Department,
Ministry of Postal Affairs,
National Police Agency,
Defense Agency,
Maritime Safety Agency,
Japan Meteorological Agency (JMA),
Nippon Broadcasting Corporation (NHK, the government television and radio network),
Tokyo Electric Power,
Central Electric Power,
Nippon Telephone and Telegraph (NTT), and
Red Cross.

In Figure 7 are shown the communication links within the CEMCN. At Tachikawa, which is an Air Defense Base, are stationed the airplanes and helicopters to be used for surveillance in times of disaster. Take notice that the affiliated organizations mentioned in the sub-chapter 1-D are included in this network

When JMA issues a tsunami bulletin, it goes to the ministries and agencies of the national government through CEMCN and to the prefecture governments. The bulletin consists of one of the cryptic messages of Table 1 for every coastal district in the nation. There is a redundancy in this process, as prefecture governments have already received a bulletin from one of the regional observatories, but redundancy is programmed into the system to forestall any accidental gap in communication.

Central Emergency Management Network (CEMCN) uses wireless communication for fear of telephone lines being out of commission in severe disasters. Even if not damaged, telephone lines can be jammed by overloading. Communication satellite transmission is resorted to whenever messages had to be sent to remote areas of mountainous Japan and when communication had to be established with surveillance helicopters.

Figure 7 illustrates the links among the members of CEMCN. The National Land Agency handles the transmission and relaying of messages.

3-C. Transmission from National Level to Regional and Prefecture Levels.

Let us discuss Figure 6 briefly.

The Ministry of Construction relays the tsunami warning to major construction sites throughout the nation, such as on-going harbor expansions. The Postal Ministry keeps the regional communication systems operating. The National Police monitors and coordinates the communication among prefecture police forces. The Maritime Safety Agency transmits the warning to harbor authorities, fishing fleets and fishermen associations. The regional observatories of JMA transmit the bulletin to prefecture governments. NHK, the government radio and television broadcasting corporation, broadcasts the warning nationally, through all its channels and stations. The central power company starts mobilizing its repair and recovery crews, just in case. The Red Cross and associated organizations will be on stand by basis.

3-D. At the Regional and Prefecture Level.

As mentioned above, a regional observatory of JMA functions as a regional tsunami warning center. The observatory transmits warning to prefecture governments within its area of responsibility by L-ADESS, the Local Automatic Data Editing and Switching System. When a prefecture is in danger of a tsunami, the prefecture does not have to wait for the warning to come from the national government. The regional observatory handles the warning. In addition to the prefecture governor's office, the recipients of the bulletin via the L-ADESS are the regional offices of Maritime Safety Agency, construction offices, local stations of NHK and commercial news media, regional offices of the Red Cross, commercial weather forecast providers, schools, hospitals. When the prefecture office receives the bulletin, it can be certain that action units are on stand by because they have been so advised by L-ADESS.

The L-ADESS has been installed in 1991 to be a redundant system in addition to the networks of Figure 6 to make sure the message gets through.

3-E. Transmission from Regional and Prefecture Levels to the Local Level.

When the prefecture governor's office receives the warning, they transmit the warning to the local governments for action.

3-F. Action at the Local Level.

Local authorities of cities, towns, and villages will receive the tsunami bulletin from the governor's office. Some may have already received it through L-ADESS. Relaying of tsunami warning through all the government levels take but a few seconds, thanks to the intense use of electronic technology. At the local level, when the city, town or village government office receive the warning, the offices must announce the warning to all the people. This is a formidable task, as no group or individual can be ignored.

All practicable methods are used to get the message to all the people. Some of the prominent methods are:

a. Simultaneous Announcement Wireless System (SAWS),

b. Dedicated radio receivers in homes,
c. Mobile Announcer System
d. Radio and television announcements,
e. Sirens and bell ringing,
f. Word of mouth by firemen and volunteers,
g. Telephone network.

3-F-a. Simultaneous Announcement Wireless System.

The Simultaneous Announcement Wireless System (SAWS, Figure 8) is probably unique to Japan. It is a dedicated system of transmitter and receivers installed by the local authority, be it village, town or city, to announce news of importance to urban and rural areas throughout Japan. Funding for the equipment, installation and maintenance comes from the Ministry of Agriculture, Forestry and Fishery. In this system the transmitter is set up in the local government office, and receivers are in hospitals, schools, field offices of construction projects, fire stations, police stations, emergency management offices, farmers union offices, fishermen union offices. Many residents have purchased these receivers for installment in their homes and these receivers are activated when a message is being transmitted.

The proverbial man on the street is not neglected. Posts with receiver-loudspeaker sets installed at busy streets and rooftops of prominent commercial buildings. These posts cover the city, town or village and its outlying areas.

In some places permanent receiver towers have not been installed, but when an important announcement such as a tsunami warning is due, portable receiver-loudspeaker combinations are quickly set up at busy streets to pass on the announcement to the people on the street.

The announcements over the SAWS is not limited to disaster warning. News deemed important are given air time. For example in a farming area, latest quotation on the commodities market is given air time. Special events, such as the agenda for a coming festival, are announced. When deadline for filing taxes is approaching, the citizens are informed in timely manner. During the summer, in the late afternoons, children are advised to stop playing and return home for supper. When Princess Diana of England died in the infamous car crash, the news was deemed significant because of her popularity, and many rural areas broadcast the news over SAWS.

Unfortunately such factors as rain, traffic noise, cold weather which forces people to close windows, reduce the rate of comprehension of announcement content to 15 to 20 percent in urban areas. In some rural areas, this may be the only method of reaching people.

The SAWS is flexible. The system can be used for inter-village communication as well After an announcement has been made, a recipient administrator can query the broadcast source to clarify obscure or unclear points.

3-F-b. Dedicated Residential Radio Receivers.

These radio receivers are hooked up with the Simultaneous Announcement Wireless System. They can be readily purchased by residents who wish to invest in them. Whenever a message is sent, the message triggers the radio on.

3-F-c. Mobile Announcer System

Some population centers may not be able to afford SAWS. In those places when the tsunami warning reaches the local fire station, fire trucks with mounted loudspeakers cruise the area of responsibility to announce the warning. The warning message is on pre-recorded tapes.

Loudspeakers on trucks are a common sight in Japan. During the time of election campaigns, many political candidates use loudspeaker mounted on pick up trucks to make their pitch to the voting public.

3-F-d. Radio and Television Announcements.

Announcements of tsunami warning have priority to cut into ongoing programs on government and commercial television channels and radio stations. The use of news media to transmit tsunami warning will be discussed in the next chapter.

3-F-e. Sirens and Clanging of Bells.

In some villages, sirens are sounded to announce disaster warnings. After the sirens are heard the residents must turn on the radio or television to find out what is the nature of the impending disaster.

In feudal times, most villages and towns had bell towers. The bell was clanged whenever there was a fire or when a disaster such as flooding or storm was anticipated. In case of fire, when the bell clanging is heard, volunteer firemen will visually scan the horizon in search of smoke or orange glow if at night, then rush to the scene of fire. Even today some villages prefer to stick to their traditional ways.

3-F-f. Word of Mouth by Firemen and Volunteers

In some areas firemen or volunteers participating in disaster mitigation programs pass on the warning to local residents by word of mouth, visiting people house by house. This of course is time consuming and is limited in the area that can be covered. Nevertheless in those areas which do not have any of the above mentioned systems, this is about the last resort.

3-F-g. Telephone Network.

In some areas residents have formed telephone networks or clubs so that important news can be received. This again consumes a lot of time as the network center or club coordinator must dial each member one by one.

3-G. Evaluation of Methods

Of the methods listed above for disseminating a tsunami warning to all the people, the two most reliable methods where contamination of the message can be minimized are the SAWS and the Mobile Announcer System. In the SAWS the warning sent out by the JMA regional observatory is transmitted verbatim. In the Mobile System, a pre-recorded audio tape is amplified by the loudspeaker. In the other methods as humans hear the message and then repeat the message at relay points, the human element can sneak in and contaminate or corrupt the message.

In the latest survey done prefecture by prefecture in 1984 , 27.1 per cent of the cities, wards, towns and villages throughout Japan had the Simultaneous Announcement Wireless System or the Mobile Announcer System or both. The percentage was higher in prefectures with heavy urban population and very low in prefectures that are mountainous with deep valleys or in prefectures with mining industry. Since 1984 both systems have been expanded and the value of 27.1 % is not reflective of the situation today.

CHAPTER 4. WARNING BROADCAST BY TELEVISION AND RADIO

Television and radio stations receive tsunami bulletins from JMA headquarters by C-ADESS or from a regional observatory by L-ADESS. At a television station the bulletin is put on the air by means of subtitles on the lower section of the monitor screen or by inserting windows, called TELOPS (television opaque projections). These methods have the advantage of not interrupting the ongoing program. The subtitles report the location of the epicenter, the earthquake magnitude and warning of "tsunami watch", "tsunami" or "large tsunami" for those coastal districts near the station. A TELOP or window usually follows later with a map which outlines the coasts where the warnings apply. The appearance of TELOP with a map may not be timely to be of use, because it takes time to draw a map. The TELOP may use only words but emphasizing dramatically those coasts where the warning applies.

In case the generating earthquake had been severe as to cause damage on land, the subtitle will report the distribution of earthquake intensity city by city, as information from the affected cities drift in. The earthquake intensity reported is the JMA scale which is different from the Modified Mercalli Scale, with which we are familiar.

When the warning is broadcast over the radio, obviously the ongoing program must be interrupted, and the warning is given as a voice message. A program-interrupting warning does have more impact on a listener than subtitles on a television screen.

Japanese television has two government managed channels, and many commercial channels. The government channels and most of the commercial channels belong to L-ADESS or C-ADESS, with their key station usually located in Tokyo. The problem with this system is that many stations in outlying districts defer to the key station in Tokyo so that the warning is delayed. The outlying stations do receive the warning by L-ADESS but wait for subtitles or TELOP to come from the key station.

CHAPTER 5. PERFORMANCE OF SYSTEM IN AN ACTUAL TSUNAMI

Contents of this chapter have been drawn from the article by Nakamori (1994).

5-A. Narration of Events

On July 12, 1993 at night at 22h 17m 12s local Japan time, an earthquake of magnitude 7.8 occurred in the Sea of Japan west of Hokkaido and just offshore from the small island of Okushiri and generated a destructive tsunami (Figure 9). A chronicle of events associated with the tsunami is given here.

Besides the government TV stations of NHK, there are several TV and radio stations in and around Sapporo. They will be called Stations A, B, C, and D in the chronicle.

22h 17 m 12s. Earthquake occurred.

Residents of Aonae on south tip of Okushiri Island dashed out of homes and began running for high ground with only their night clothes.

JMA Sapporo Observatory staff felt earthquake of intensity III (felt distinctly by people in tall buildings, pedestrians on street felt like a truck passing by). ETOS computer put out forecast of:

Coast 1, no tsunami; Coasts 2 and 3, major tsunami.

Staff correction: Coast 1, tsunami watch,
Coast 2, tsunami warning,
Coast 3, major tsunami warning.

22h 22m. Above bulletin put on L-ADESS for following recipients:

Other regional observatories
Prefecture government
Sapporo NHK television and radio
Weather Association of Japan
Commercial weather forecasters

22h 24 m 27s. NHK Sapporo interrupts program to announce tsunami warning by voice

22h 25m. 10 meter wave hits Aonae town. Of 2000 residents, 200 killed, others safe at high ground. Survival rate of 90%.

22h 25m. Radio Station A announces warning by voice.

22h 25m. Radio Station B announces warning by voice.

22h 27m Tsunami bulletin in format of FAX sent over SAWS. A partial list of the recipients is given here.

Regional Maritime Safety Board
NHK Sapporo Station
Hokkaido Police Headquarters
Hokkaido Prefectural Office in Sapporo
Hokkaido JR Railroad Corporation
Self Defense Force, Army
Commercial Radio and Television Stations
Commercial Meteorological Forecast Providers
Weather Association, Hokkaido Office
Sapporo Municipal Office
Hokkaido Electric Power Company
NTT, Hokkaido Office.

22h 28m Television Channel D has warning on TELOP.

22h 29m. Television Channel A has warning on super TELOP.

22h 29m Radio Station C announces warning, relayed from key station in Tokyo.

23h 10m. Okushiri Island local authorities receive tsunami warning officially.

There are two reasons for warning by SAWS being five minutes later than by L-ADESS. At JMA Sapporo Observatory ETOS and LADESS are in the main operation room and the only thing staff members had to do to transmit via L-ADESS was to press buttons. For SAWS the warning had to be formatted to be compatible to the system, which took time, and the transmitter of SAWS was in another room. And at SAWS recipients' offices, the print out of the warning took another minute. All in all, five minutes elapsed between ETOS warning and SAWS recipients' getting the word, or ten minutes after earthquake.

Transmission of the warnings down the layers of government slowed down at the local levels. The warning was received by the local government office on Okushiri Island 50 minutes after the earthquake and 45 minutes after the arrival of the main punch of the tsunami.

When the earthquake occurred at 22h 17 m, NHK TV Sapporo was showing a documentary, coming from the NHK Tokyo. The channel had a seismometer in the building which registered an intensity III, and the channel displayed at 22h 19 55s by means of TELOP that the intensity of the earthquake was III. When the tsunami warning came in at 22h 22m by LADESS, the station suspended the documentary program and announced by voice the content of the bulletin at 22h 24m.

Station A broadcasts by means of television and radio. Although it does not have the benefit of being hooked up to LADESS directly, but because it subscribes to the services of the Weather Association, which receives LADESS, it got the warning through the Weather Association at 22h 23m, and the radio component of the Station announced by voice the warning at 22h 25m, only a minute later than NHK. The television component displayed a TELOP on the announcement at 22h 29m. The delay was caused by the time it took to compose a TELOP window.

Station B also has television and radio components and it also subscribes to the services of Weather Association. The radio component announced the warning at 22h 25m, about the same time as Station A. The television channel displayed the warning window at 22h 56m, as part of the scheduled news broadcast which comes form its key broadcasting channel in Tokyo.

Station C has only television and subscribes to the services of a commercial weather forecast provider. As the commercial provider was hooked up to LADESS, Station C was able to announce the tsunami warning as part of the regularly scheduled news broadcast at 22h 29m.

Station D subscribes to the Weather Association and received the bulletin soon enough to display the warning by means of TELOP at 22h 28m 50s.

5-B. Evaluation

The warning did not reach the residents of Okushiri Island in time. But considering that the first wave did hit parts of the island as early as three minutes after the earthquake, present day technology was unable to be of much assistance.

The tsunami generating zones on the western side of the Japanese Archipelago in the Sea of Japan are very close to the coast. For the residents in the coastal areas facing a tsunami source directly, the only salvation is to run to high grounds when the ground underfoot starts shaking, just as the 90% of the people of Aonae Town did.

The warning did reach most of the people of Hokkaido and northern Honshuu in time to take evasive action.

As the time lag of the warnings reaching the Okushiri Island town office was scandalously too long, improvements are being studied in the communication systems. One proposal is the use of communication satellite in LADESS and the SAWS.

Historically more destructive tsunamis have occurred on the eastern side of the Japanese Archipelago, on the Pacific Ocean side. In January 1993, six months before the Southwest Hokkaido earthquake and tsunami, a tsunami was generated off Kushiro, on the Pacific side of Hokkaido. The ETOS system was effectively used and warnings were issued minutes after the earthquake. The communications systems also operated effectively and proper measures were taken before tsunami arrival.

For us, the point to remember is that the disaster mitigation program in Japan is a nationally coordinated effort, with resources of government, commercial interests and popular demands fully behind it. The installation of redundant communication circuits is a point to learn.

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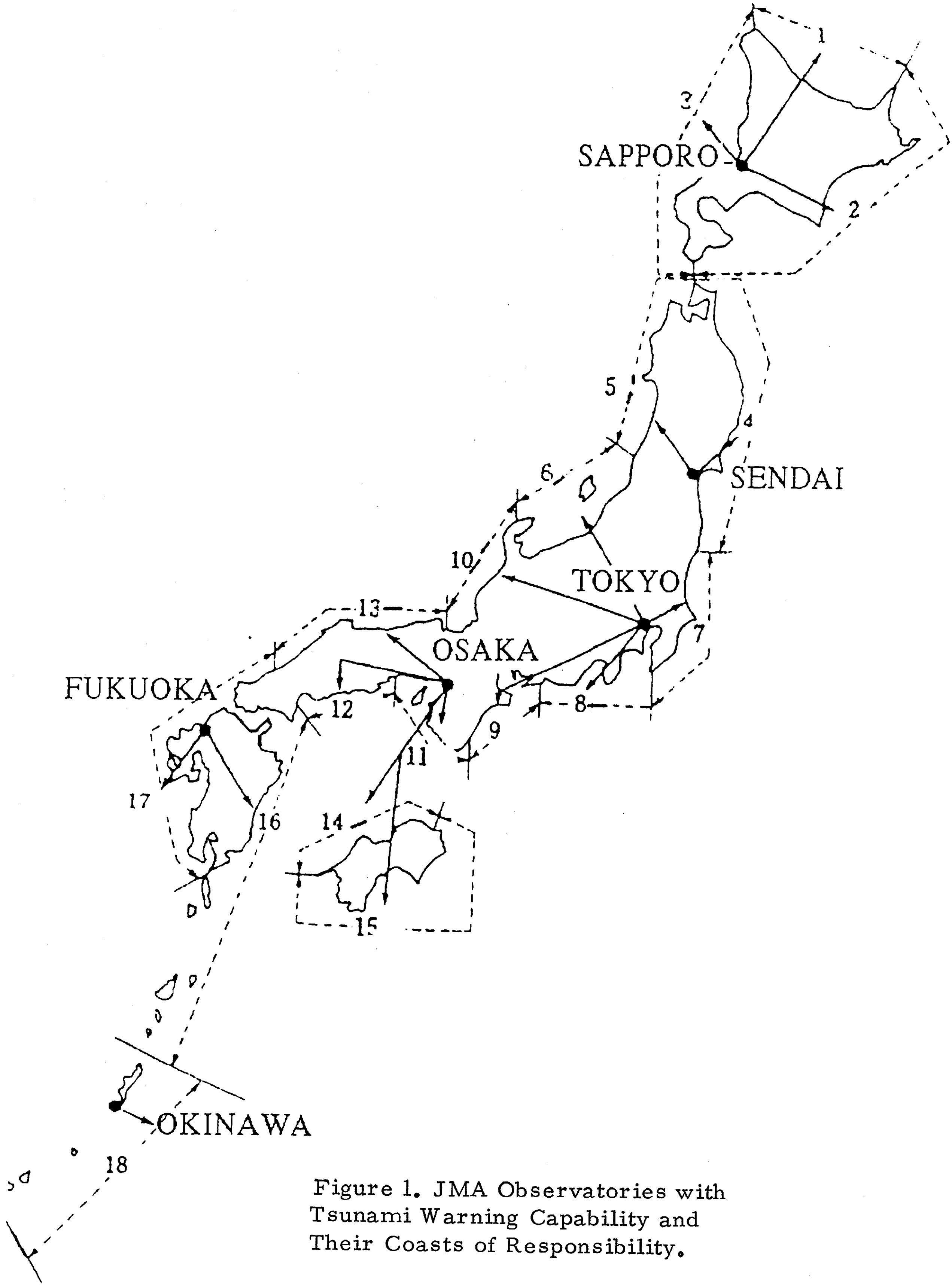


Figure 1. JMA Observatories with Tsunami Warning Capability and Their Coasts of Responsibility.

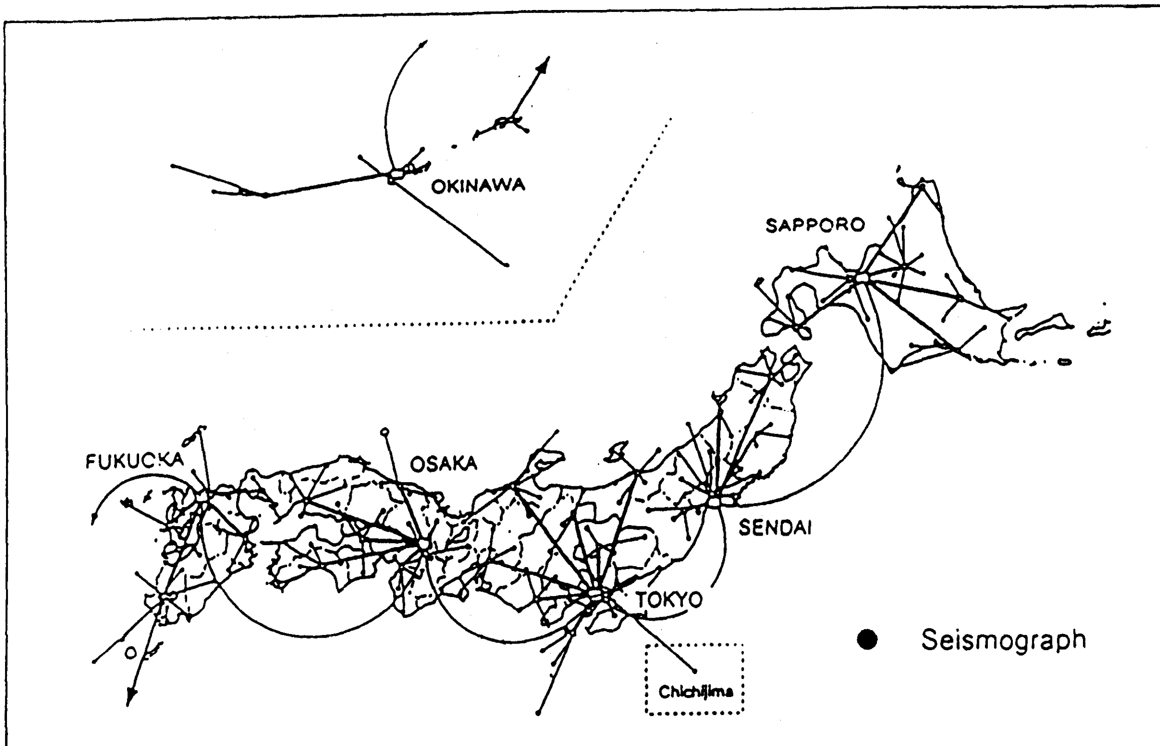


Figure 2. JMA Seismograph Network

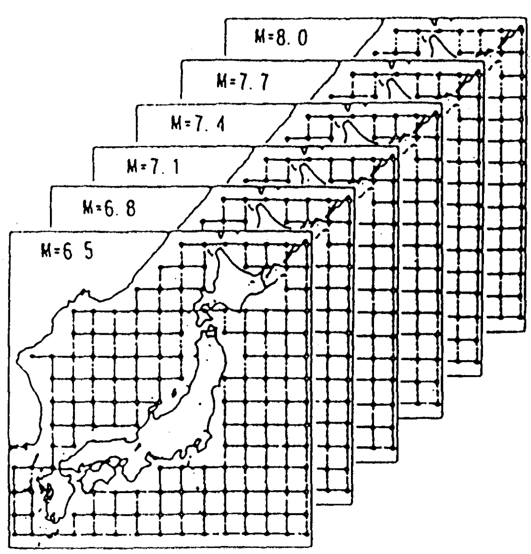
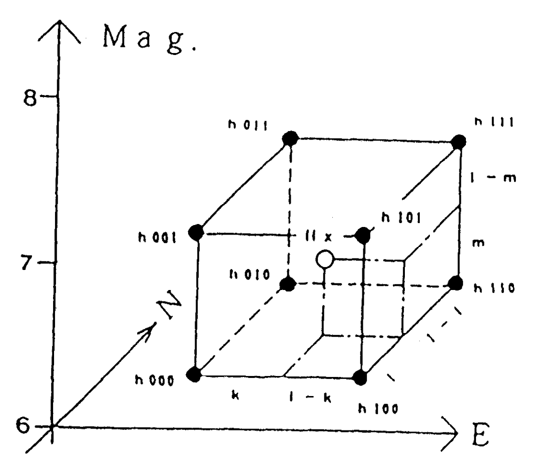


Figure 3 Archived Matrix of Pre-calculated Virtual Tsunamis



$$Hx = [(1-l)\{(1-k)h000 + kh100\} + l\{(1-k)h010 + kh110\}]^{1-m}$$
$$[(1-l)\{(1-k)h001 + kh100\} + l\{(1-k)b010 + kh111\}]^{m}$$

Figure 4 Interpolation Scheme among Virtual Tsunamis

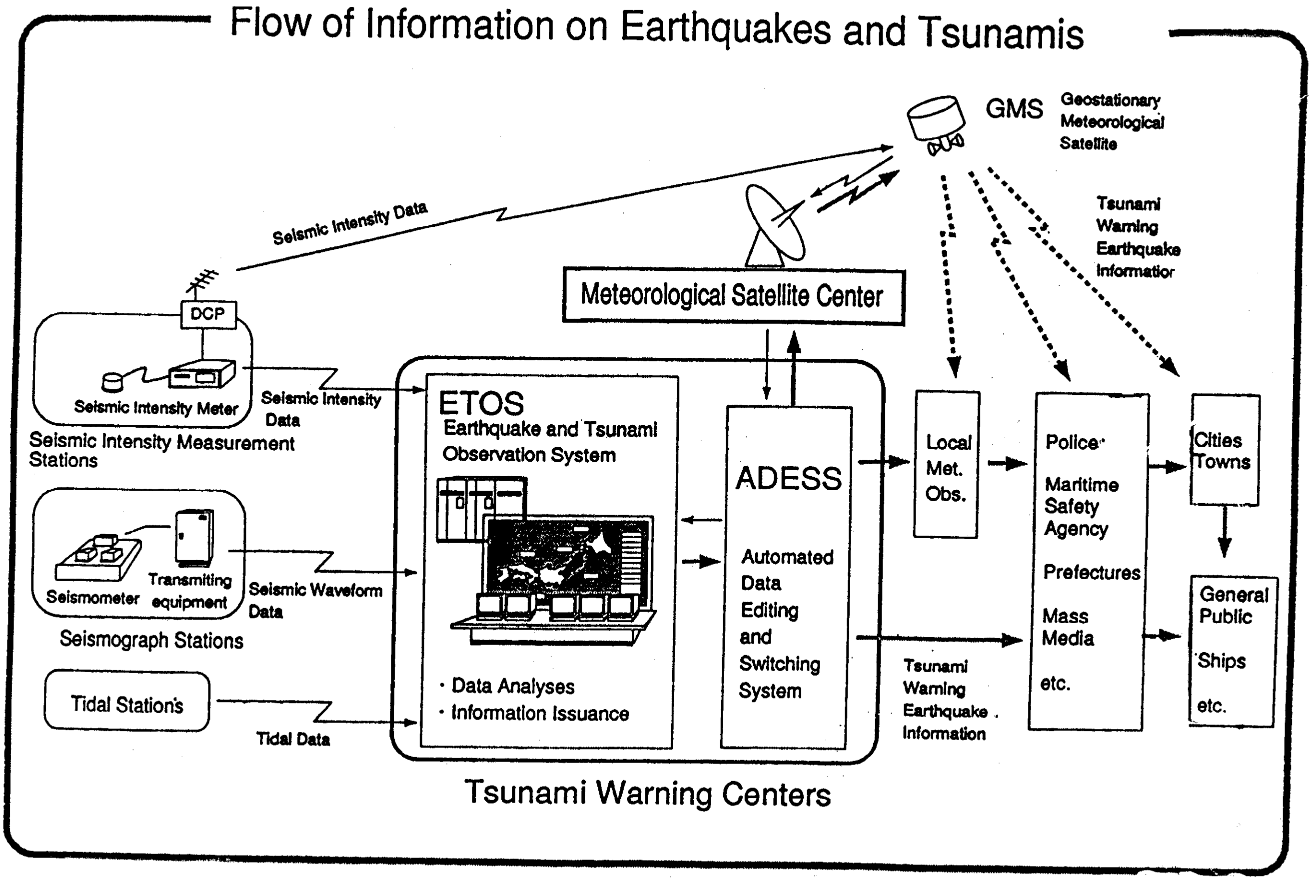


Fig. 5 Flow chart of tsunami forecasts. This figure designates the data acquisitions, data processing, and dissemination of warnings to people though media.

FIGURE 6. NATION WIDE EMERGENCY MANAGEMENT COMMUNICATION NETWORK

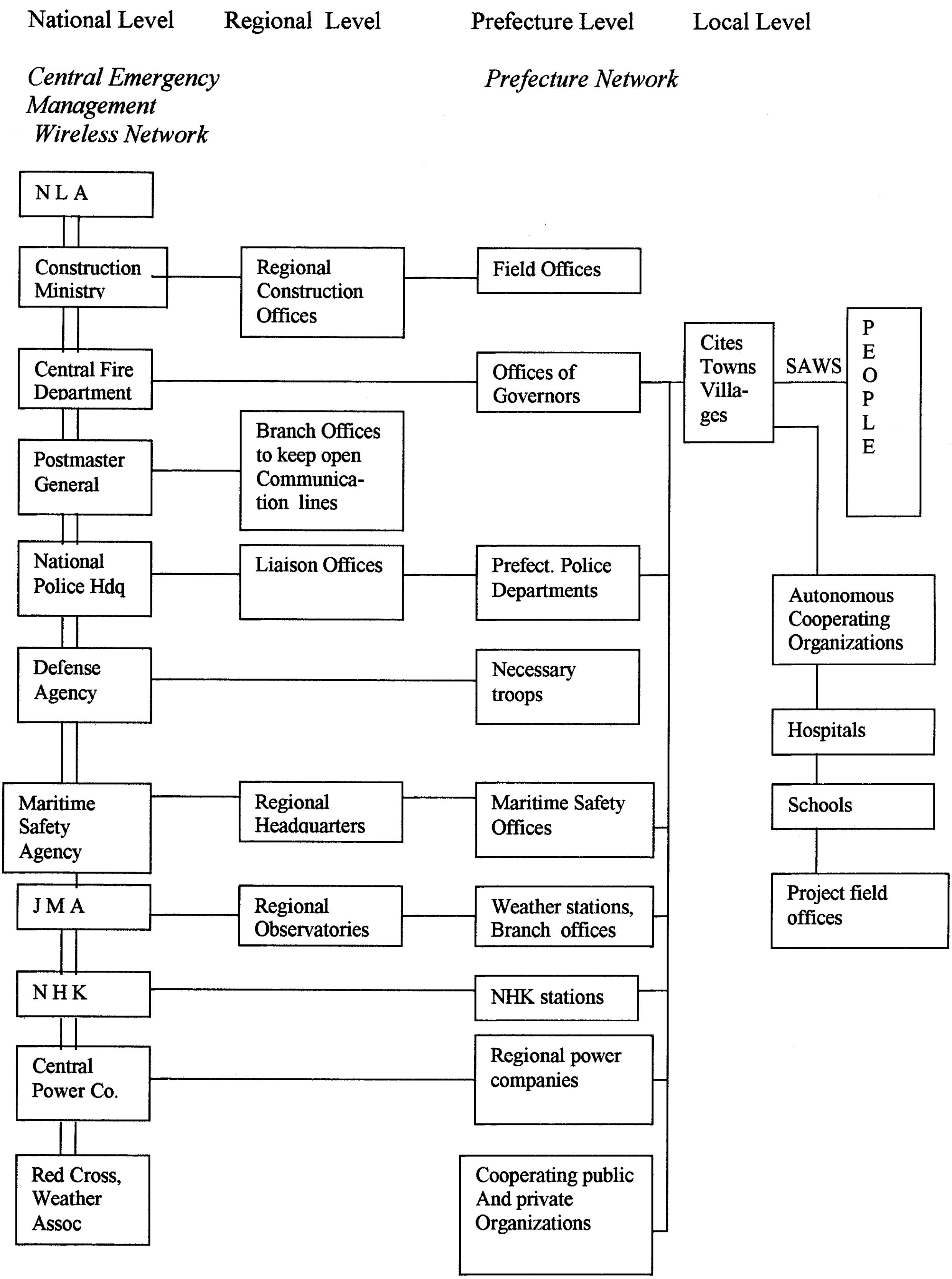
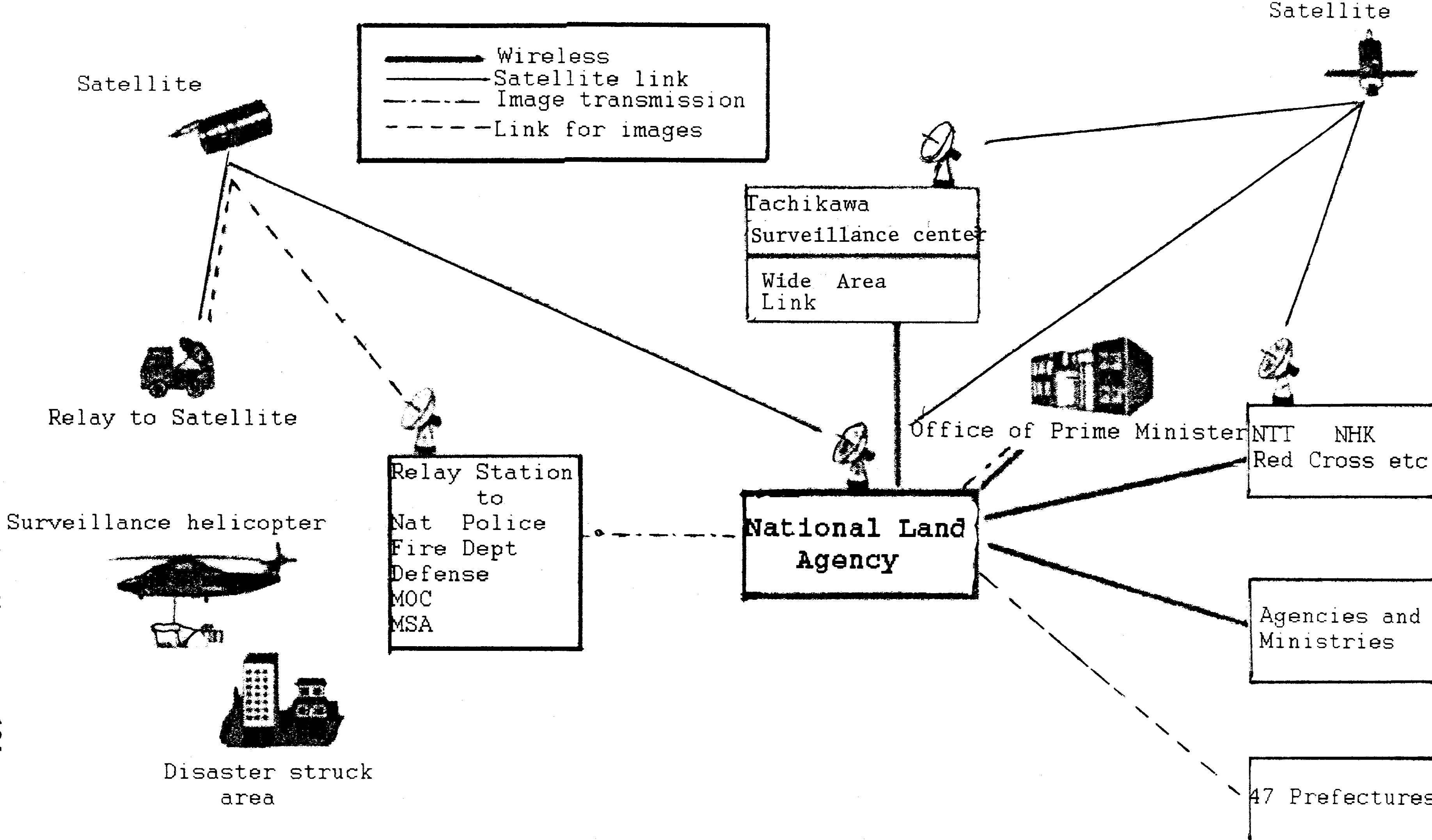


Figure 7 Central Emergency Management Communication Network



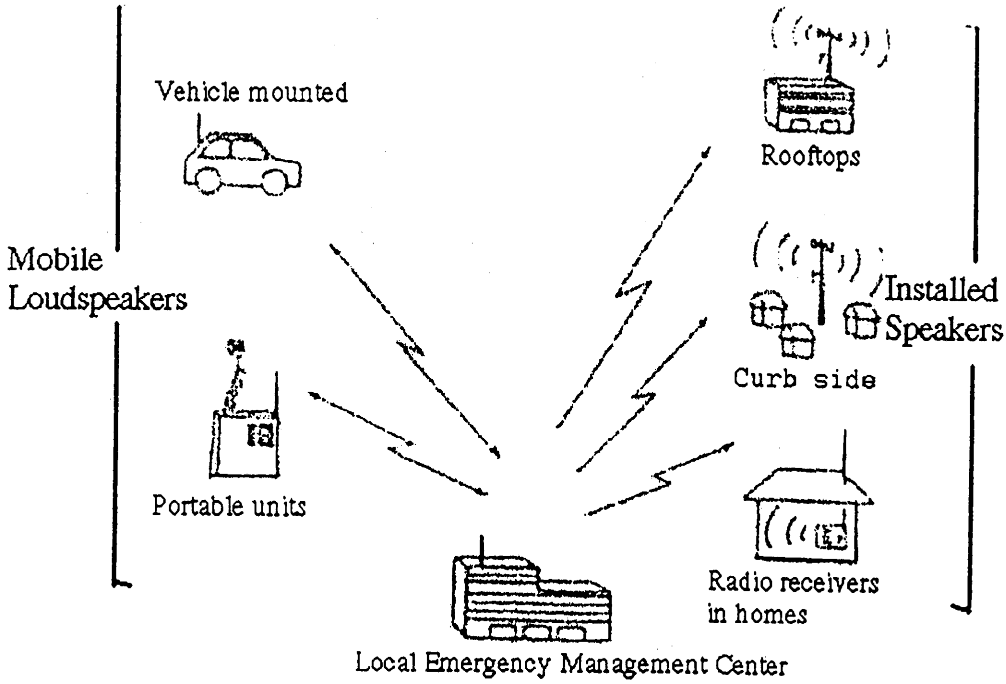


Figure 8 Simultaneous Announcement Wireless System

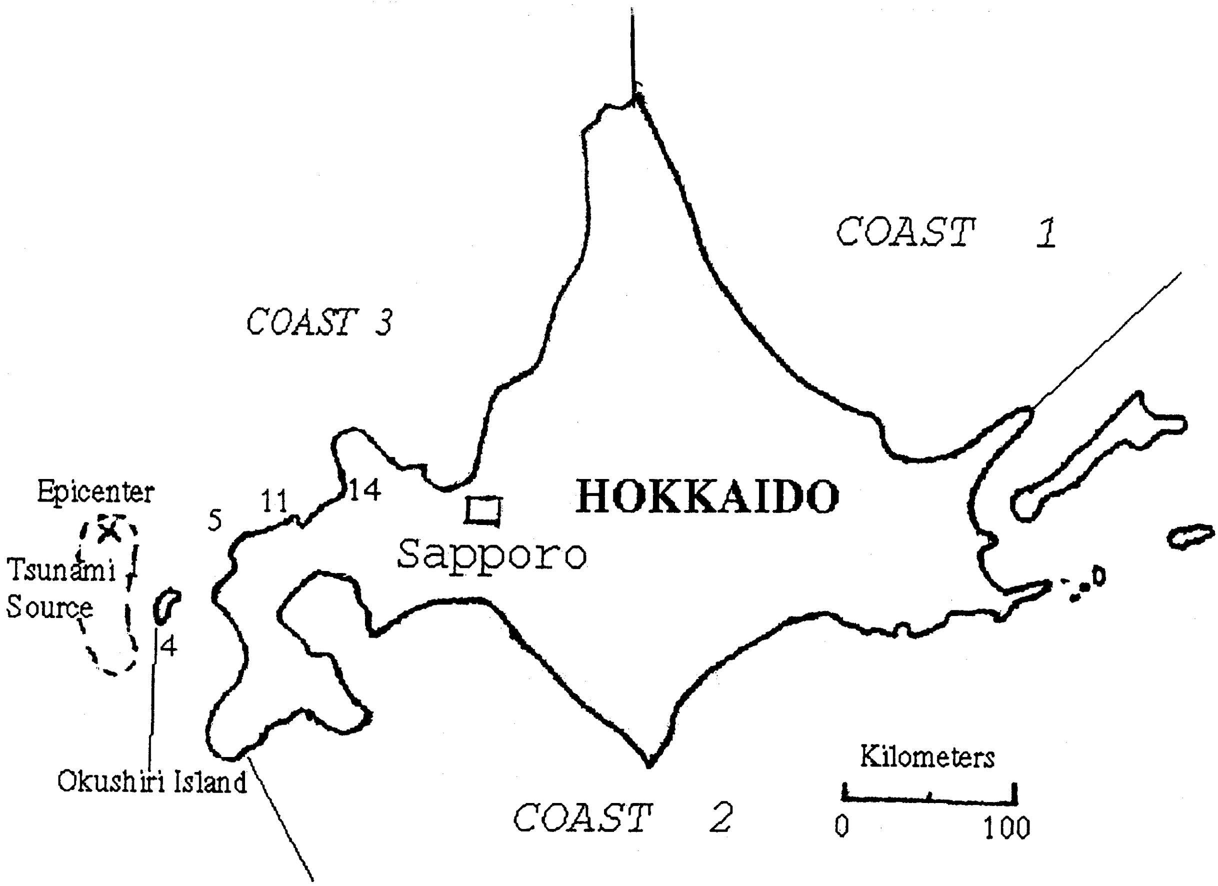
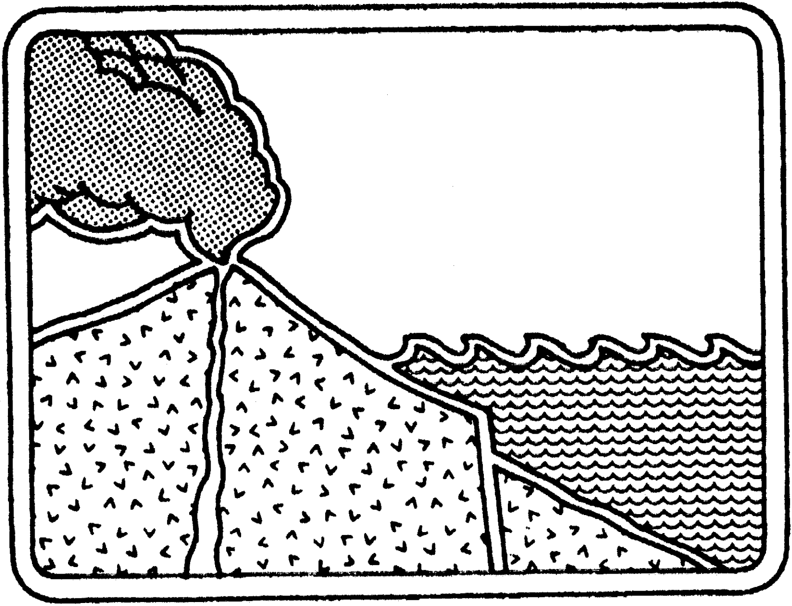


Figure 9 Epicenter, Tsunami Source, Tsunami Travel Times (minutes) for Earthquake of July 12, 1993.



CONTEMPORARY ASSESSMENT OF TSUNAMI RISK AND IMPLICATIONS FOR EARLY WARNINGS FOR AUSTRALIA AND ITS ISLAND TERRITORIES

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ABSTRACT

The natural hazard of tsunami relative to Australia and its Island Territories it has been perceived to be of little or no consequence – and hence a small risk – when compared to our other more frequent natural disaster of meteorological origin, or even occasional earthquakes. The historical record shows that tsunami damage, although rare, has occurred along the eastern seaboard (from the 1877 and 1960 Chile earthquakes), and northwest coast (from the 1983 Krakatoa (Indonesia) volcanic eruption and the 1977 and 1994 Indonesian earthquakes) of the continent. Because of the infrequent occurrences of tsunamis, they are little known and, in some cases, have been forgotten. However there is a need for tsunami mitigation, because, as an island nation, Australia is totally dependent on its coastal facilities for sustainable development, with more than 90% of the population domiciled in this environment. Recent devastating tsunamis in the Pacific region emphasise this need.

As part of Australia's contribution to the United Nations IDNDR (1990 – 2000) program, Emergency Management Australia's Australian IDNDR Coordination Committee specifically directed one project to assess the risk of tsunamis on the shorelines of Australia and its island territories. A specific methodology was developed, invoking a multidisciplinary approach to quantitatively and qualitatively define the hazard and the vulnerability, and then integrate these elements into a comprehensive risk assessment. More than 350 earthquakes occurring in the Pacific, Indian and Southern Oceans and locally to the shores of Australia, and specific submarine volcanoes and landslide were considered as possible tsunamigenic sources. In the period 1788 through 1995 more than 60 registrations on tide-gauge records were identified, together with anecdotal information. The outcomes have been presented as an "information resource" in terms of hazard, vulnerability and risk assessment maps and commentaries, comprehensive tsunami data base, maps of potential tsunamigenic sources, tsunami travel time charts and relationships between relevant tsunami parameters.

These outcomes have been delineated in terms of proactive applications necessary to upgrade both tsunami warning procedures by the Bureau of Meteorology and response actions through counter disaster planning by the emergency services authorities. As such, Australia is currently developing its own regional tsunami warning system.

INTRODUCTION

Tsunamis in Australia ? Yes!

As is now known - the 1883 Krakatoa (Indonesia) volcanic eruption (large waves along Western Australian coast), 1960 Chile earthquake (serious damage to built and natural environments along parts of the eastern seaboard), 1977 Sumba and 1994 East Java (Indonesia) earthquakes (large waves up to 6m in height, with some minor damage, along the northern coast of Western Australia) and the 1995 Loyalty Is earthquake (with 40 cm waves recorded on the central coast of New South Wales).

These are but a few examples to show that, although damaging tsunamis are rare on Australian shorelines, the potential risk related to this natural hazard must be assessed for the future. The vulnerability of Australia's coastal and island territories communities, and hence warning and response procedures, are the relevant questions. This is emphasised by the fact that a significant part of the Australian economy relates to onshore and offshore development in petroleum and gas, port facilities for international exports, coastal industrial complexes, fishing industry, major tourist centres and residential developments, and supports about 90% of Australia's population - as it exists today and with planned expansions in the near future.

On the worldwide scale, the United Nations International Decade for Natural Disaster Reduction, 1990 - 2000 (IDNDR) had identified tsunamis as one of the significant natural hazards which pose a threat to both human life and property, for coastal communities and small island nations, specifically mentioning nations of the Pacific Basin (Bernard, 1993). Testament to this is clearly shown by the several devastating tsunamis during the Decade, the most recent of note being the 1998 Papua New Guinea event. Tsunami mitigation is thus an essential requirement to ensure the reduction of future potential losses for such a natural peril.

As part of Australia's IDNDR program, facilitated through Emergency Management Australia (EMA), a project to comprehensively assess the tsunami risk to Australia and its Island Territories was undertaken by the Bureau of Meteorology and the Centre for Earthquake Research in Australia. This paper summarises the outcomes of the project and progress for future development of tsunami mitigation measures.

AUSTRALIA'S IDNDR TSUNAMI PROJECT

In August 1994, the Bureau of Meteorology facilitated the first national workshop on tsunamis in Australia. (Bureau of Meteorology, 1994; Rynn, 1994). Both the need for, and the significance of, an assessment of tsunami risk for Australia and its Island Territories were highlighted as the necessary critical step in mitigating the potential affects of tsunamis impacting on our coastal areas. The IDNDR Project "Contemporary Assessment of Tsunami Risk and Implications for Early Warnings for Australia and Its Island Territories" (designated Project 11/94) (Rynn and Davidson, 1996) was a pilot project which has addressed the need for mitigation of tsunamis in Australia and its Island Territories (Figure 1). It is in accord with the IDNDR/STC targets of "assessment of risk, planning for mitigation, warning systems" and the project criteria of Australia's IDNDR Coordination Committee.

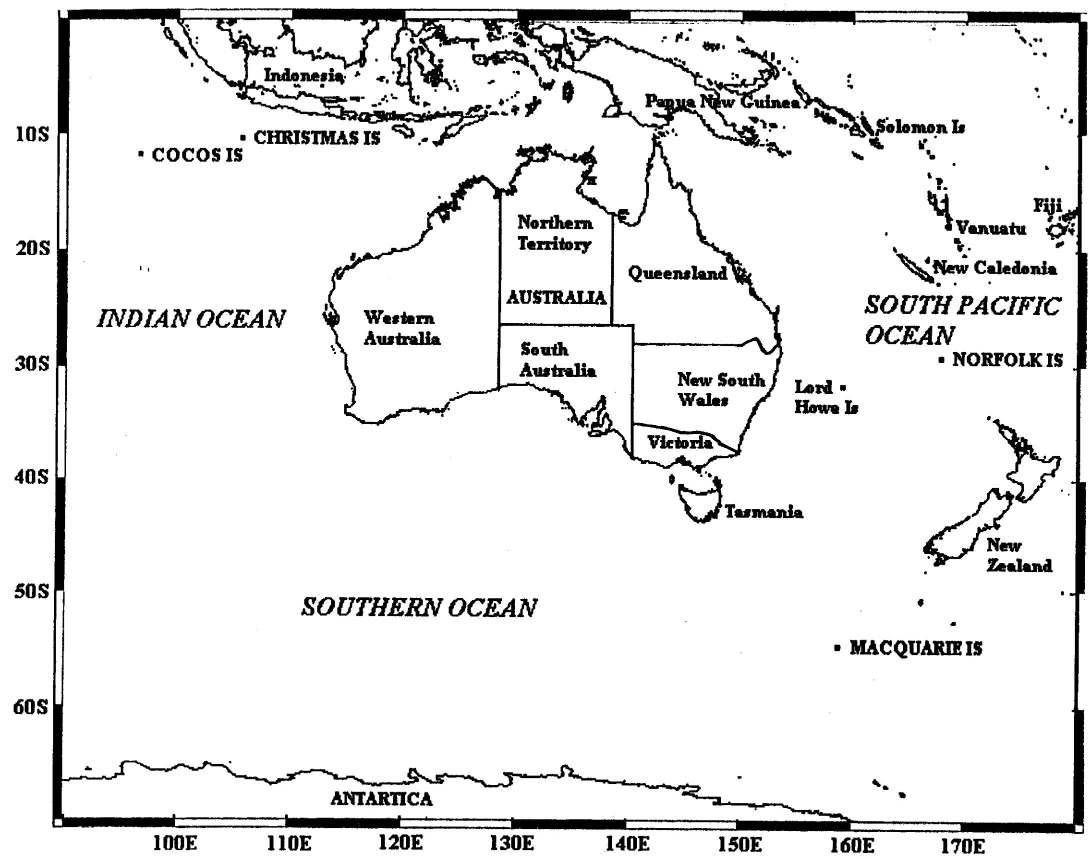

Figure 1 : Australia's IDNDR Project 11/94 Area - Australia and Its Island Territories

The **aim** of this pilot project was to assess, in both quantitative and qualitative terms, tsunami risk according to (Figure 2)

RISK = HAZARD X VULNERABILITY

where HAZARD defines the scientific content, including historical tsunami data, potential tsunamigenic sources, relevant parameter determinations, probabilistic estimates and tsunami travel time charts,

and VULNERABILITY delineates the built and natural environments and possible effects thereon from tsunami and the human elements.

This invoked a multidisciplinary approach integrating the earth and marine sciences, engineering and emergency management through multi-institutional involvement both nationally (Bureau of Meteorology, CERA, National Tidal Facility (NTF), EMA, various States agencies, and internationally NOAA in Boulder and Seattle (USA) and the International Tsunami Commission, (ITC).

A specific **methodology** was developed based on proven earthquake mitigation studies (Rynn et al, 1996), storm surge study for Mackay, Australia (Smith and Greenaway, 1994), international collaboration with NOAA and ITC, Lander and Lockridge, 1989, tsunami hazard studies in New Zealand (De Lange and Hull, 1994) and the needs of the relevant Australian agencies. The component relative to the assessment of the tsunami risk is shown in Figure 2. The quantitative and qualitative results from this assessment were then available to consider mitigation measures (including disaster planning for, and response to, a potential tsunami occurrence by emergency services authorities) and the nature of tsunami warnings relevant to Australia and its Island Territories.

AUSTRALIAN IDNDR COORDINATION COMMITTEE

PROJECT 11/94 - TSUNAMI RISK ASSESSMENT FOR AUSTRALIA

RISK = HAZARD X VULNERABILITY

HISTORICAL RECORD
NEWSPAPERS
TIDE GAUGES
WAVE HEIGHTS
RUN-UP LEVELS
STATISTICS

TSUNAMI CATALOGUE
TSUNAMIGENIC SOURCES
TRAVEL TIME CHARTS

BUILT ENVIRONMENT
INFRASTRUCTURE
TOPOGRAPHIC MAPS
HYDROGRAPHIC CHARTS
POTENTIAL DAMAGE
COLLATERAL DAMAGE
SOCIO-ECONOMIC

DISASTER PLANNING
EMERGENCY MANAGEMENT
LOCAL RESPONSE

RISK ASSESSMENT - TSUNAMI ZONATION MAP

MITIGATION

POLICY FOR TSUNAMI WARNINGS

CERA / JR - AUG96

Figure 2 : The Approach for Tsunami Risk Assessment

The **OUTCOMES** of this pilot project were delineated as :

- Development of a specific methodology
- Comprehensive catalogue of tsunami-related records and information and derived parameters for Australia and its Island Territories (Australian Tsunami Data Base)
- Identification of potential tsunamigenic sources (earthquakes, volcanoes, submarine landslides), both adjacent to and far distant from Australia
- Probabilistic estimates of frequency of occurrence of tsunamis
- Tsunami travel time charts for tsunami-prone coastal areas
- Tsunami hazard map
- Vulnerability assessment by delineation of coastal and island built environments at potential risk (map of vulnerable areas)
- Tsunami risk map and commentary
- Preparation of a "Source Document on Tsunami Risk" to provide practical information for planning by local authorities, preparation of local response plans and Bureau of Meteorology procedures for tsunami warnings
- Identification of future projects that require more detailed analyses.

TSUNAMI HAZARD ASSESSMENT

Australian Tsunami Data Base

In quantitatively defining the HAZARD, the study involved the collection, collation and analyses of instrumental data (tide-gauge records), anecdotal information (newspaper reports, marine journals, archival information, Bureau of Meteorology reports, port authorities records and private files) and published scientific papers and reports. While utilising this "more obvious" approach, an additional innovative approach was also adopted. This involved consulting global and local Australian earthquake catalogues to select possible tsunamigenic earthquakes to further analyse the tide-gauge records.

No central registry for either the tide-gauge records or the anecdotal data exists. All such data for mainland Australia is the province of each particular State. The tide-gauge records were obtained from repositories in the eight State capitals and from provincial cities. All anecdotal data were available only in the State capitals, either in their State Library or Australian Archives office. A summary of the statistics relating to the tsunami data base is given in Table 1.

TABLE 1 STATISTICS OF TSUNAMI DATA AND ANALYSES

ELEMENT	STATISTICS	REMARKS
Time period for study		1788 - 1995
Number of tsunamis observed	65	From tide-gauge records, scientific publications and anecdotal sources
Tsunamigenic sources considered;		
Earthquake	400	300 teleseismic (far field) 100 local Australian (near field)
Submarine volcano	4	
Submarine landslide	1	
Tide-Gauge stations utilised	100	
Tide-Gauge records analysed	>3000 days	
Newspaper articles studied	>300	
Other anecdotal information	>100	

The major tsunami occurrences which have inflicted damage to the built and natural environments have been on the Australian east coast from Brisbane to Hobart and the north west coast from King Sound to North West Cape. Other smaller tsunamis have been recorded on tide-gauges both along these coasts and other parts of the nation (maximum recorded wave amplifications of few tens of centimetres peak-to-peak). The locations of the tsunamigenic earthquake sources shown on Figure 3, with a selection of tsunami data is given in Table 2.

A compendium of copies of the tide-gauge records and anecdotal information (newspaper articles and other source documents), together with the analytical results of the tsunami parameters and relationships between them, constitute the Australian Tsunami Data Base (1788-1995), currently in preparation (Rynn and Davidson, 1999).

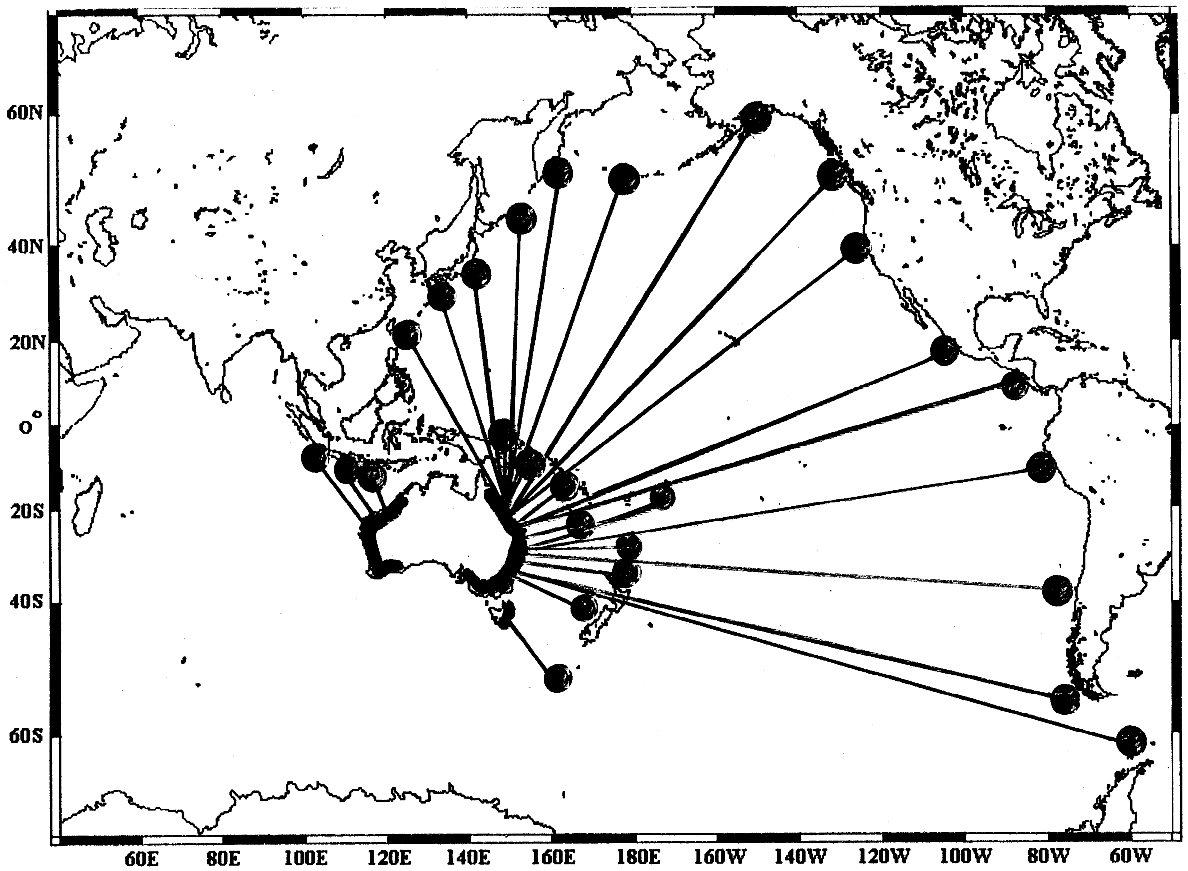

Figure 3 : Earthquake Sources for Known Tsunamis Impacting the Coastlines of Australia and Its Island Territories - 1788 through 1995

TABLE 2
SELECTION OF KNOWN TSUNAMIS ALONG AUSTRALIAN COASTLINES

TSUNAMIGENIC SOURCE			TSUNAMI OBSERVATION						DAMAGE
			IMPACTED AREA	TRAVEL TIME (HR:MIN)	AVERAGE DISTANCE (KM)	TIDE GAUGE MAX AMPLITUDE (zero - peak : M)		TSUNAMI DURATION (HRS)	
1868	AUG 13	Chile earthquake Mw = 7.6	East coast : anecdotal evidence, Sydney - Newcastle region	(17:00)	12670	-		-	
1877	MAY 09	Chile earthquake Mw = 7.6	East coast : anecdotal evidence, Sydney - Newcastle region	(17:00)	12525	-		-	Newcastle harbour
1883	AUG 28	Krakatoa (Indonesia) volcano	West coast : anecdotal evidence, maximum waves in northwest	(4:00)	2175	-		-	Wave action on beaches
1917	JUN 26	Tonga earthquake Mw = 7.7	East coast : Sydney region, tide-gauges only	3:45	4105	Fort Denison	0.08	35	None
1922	NOV 11	Chile earthquake Mw = 7.5	East coast : New South Wales tide-gauges only; many reports of unusual wave motion	16:25	11835	Fort Denison	0.08	100	None
1946	APR 01	Aleutians earthquake Mw = 6.9	East coast : Sydney region, tide-gauges only	16:50	9020	Fort Denison	0.04	53	None
1949	AUG 22	Queen Charlotte Is earthquake Mw = 7.3	East coast : Sydney region, tide-gauges only	18:00	11470	Fort Denison	0.02	(10)	None
1952	NOV 04	Kamchatka earthquake Mw = 7.6	East coast : Sydney region, tide-gauges only	14:30	8955	Fort Denison	0.19	100	None
1960	MAY 22	Chile earthquake Mw = 7.6	East coast : Brisbane to Hobart. Most tide-gauges around east and south coasts	16:25	10600	Fort Denison	0.80	170	Considerable, from Brisbane to Eden; most severe at Sydney, Evans Head
1964	MAR 28	Alaska earthquake Mw = 7.6	East coast : New South Wales tide-gauges and observed waves	17:10	11890	Fort Denison	0.22	90	None
1976	JAN 14	Kermadec Is earthquake Mw = 7.3	East Coast : New South Wales tide-gauges only	4:50	2350	Port Kembla	0.09	21	None
1977	APR 21	Solomon Is earthquake Mw = 6.8	East coast NE Queensland coast tide-gauges only	6:20	1805	Townsville	0.02	(6)	None
1977	AUG 18	Sumba/Indonesia earthquake Mw = 7.2	West coast : North West Cape to Broome; 6m wave at Cape Leveque	2:50	970	Dampier	0.40	21	None
1989	MAY 23	Macquarie Is earthquake Mw = 7.4	East coast Tasmania and New South Wales tide-gauges	2:20	1430	Port Kembla	0.22	23	None
1994	JUN 02	East Java/Indonesia earthquake Mw = 7.0	West coast : Carnarvon to Broome	3:40	1460	Dampier	0.28	20	Inundation at Baudino; fuel tankers pipelines ruptured with resulting oil spills off Onslow
1995	MAY 16	Loyalty Is earthquake Mw = 6.8	East coast: New South Wales and southeast Queensland tide-gauges	3:00	1950	Crowdy Head	0.04	26	None

TSUNAMI HAZARD MAP

Analyses of instrumental data (tide-gauge records), the numerical estimates of relevant tsunami parameters from visible observations noted in anecdotal information, and previously published studies of specific tsunamis, formed the data base for the quantitative assessment of the hazard, employing a deterministic (real data) approach. The quantification of "Tsunami Hazard Zones" (HI/MED/LO) is based on specific characteristics as summarised in Table 3.

The tsunami-hazard map for Australia and its Island Territories is shown in Figure 4.

TABLE 3
TSUNAMI HAZARD ZONES
FOR
AUSTRALIA AND ITS ISLAND TERRITORIES

CHARACTERISTIC	TSUNAMI HAZARD ZONES		
	HI	MED	LO
RUN-UP HEIGHT	>4m	2-4m	<2m
TSUNAMI MAGNITUDE	>2	1	<0
TSUNAMI WAVE HEIGHT FROM HISTORIC TSUNAMIS TAKEN FROM TIDE GAUGE RECORDS	>1m	0.1 - 1m	<0.1m
DAMAGE OBSERVED FROM HISTORIC TSUNAMIS	SIGNIFICANT	MINOR	NONE
COASTLINE ADJACENT TO NEAR-FIELD TSUNAMIGENIC SOURCES	YES	NO	NO
POTENTIAL TSUNAMI INUNDATION IN THE FUTURE	PROBABLE	POSSIBLE	UNLIKELY

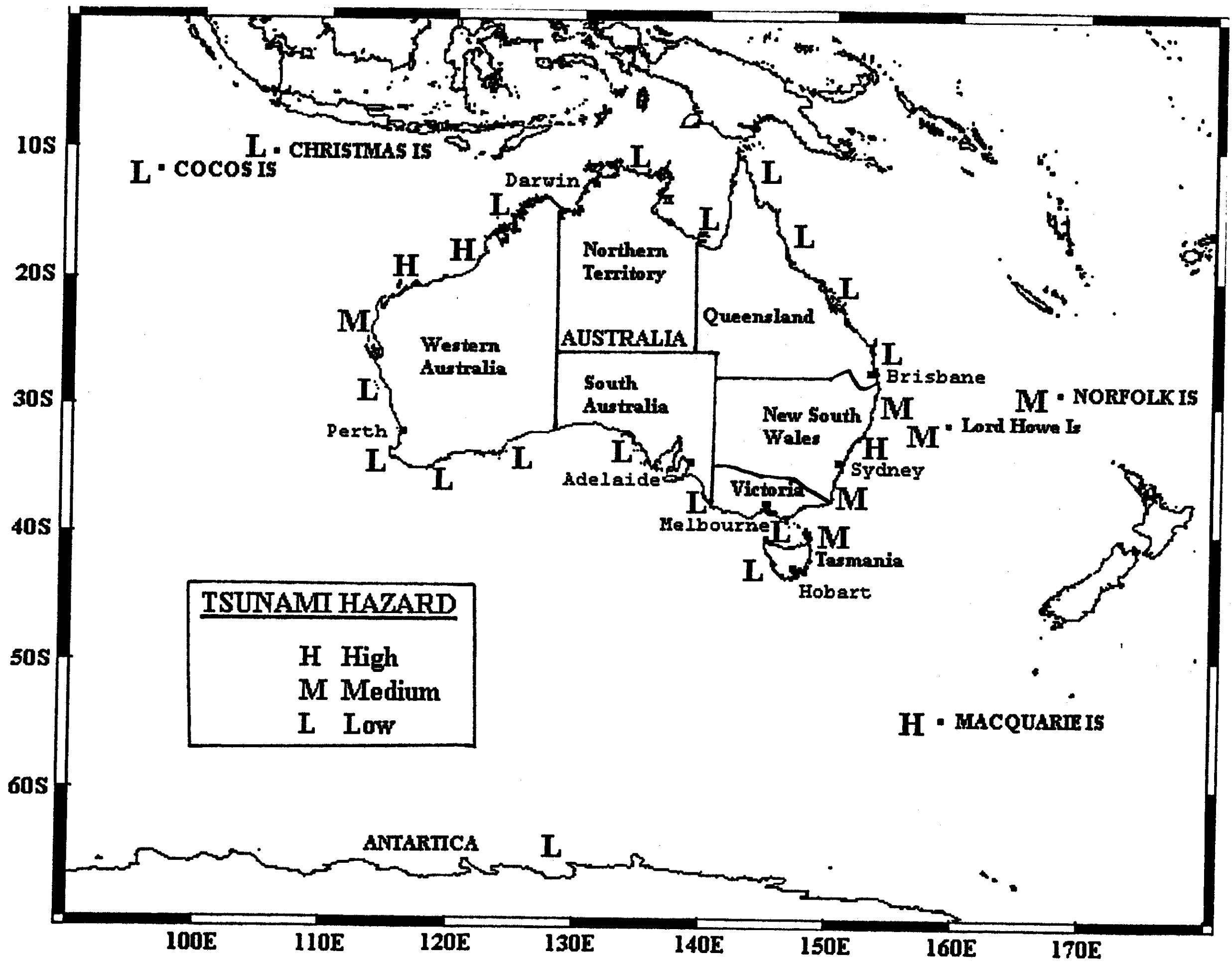

Figure 4 : Tsunami Hazard Map for Australia and Its Island Territories

Potential Tsunamigenic Sources

Four (4) classes of potential tsunamigenic sources have been identified :

(i) Earthquake - Based on analyses of the earthquake catalogues, published earthquake source mechanisms, and historic tsunami observations of impacts on our shorelines, the map shown in Figure 5 was compiled

(ii) Submarine Volcanoes - Based on available information, five such sources were identified: Eastern Indonesia (including Krakatoa), Papua New Guinea (New Britain - New Ireland), Kermadec Is region, Tonga-Samoa volcanic arc, South Fiji Basin region.

(iii) Submarine Landslides - No information is available but possible submarine landslides in the Tasman Sea have been speculated

(iv) Extra-terrestrial impacts - Although no definitive information is available, the Earth's geologic record shows such asteroid impacts have occurred and the possibility of associated tsunamis cannot be discounted; in this case possible future impacts in the South Pacific, Southern and Indian Oceans are noted.

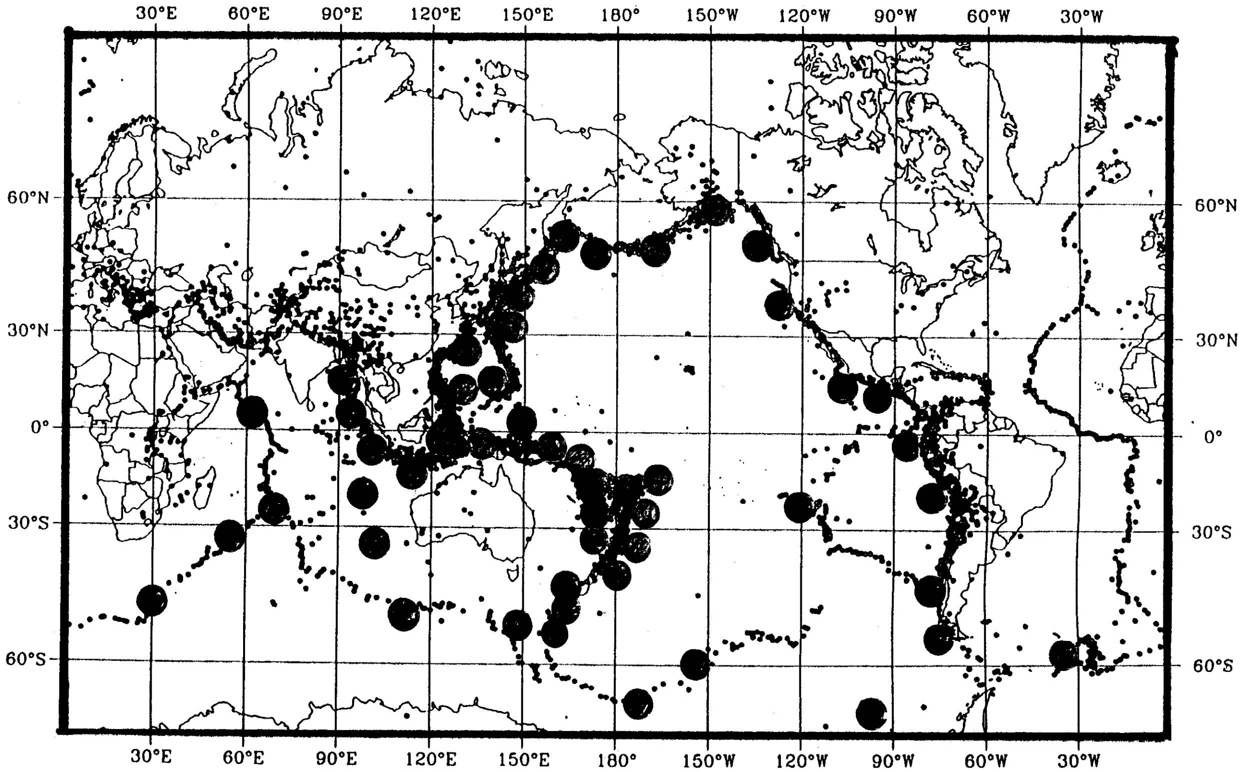

Figure 2.2 Map of global shallow seismicity, 1963–88, $M > 5$, depth <70 kilometers. [Courtesy of National Earthquake Information Center, U. S. Geological Survey.]

[Base map per BOLT, 1993]

Figure 5 : Potential Tsunamigenic Sources from Earthquakes Relative to Australia and Its Island Territories

Probabilistic Estimates of Frequency of Exceedance

Statistical estimates of such probabilities have not been quantified in this project. It was considered that the data set, particularly relative to some geographical location (for example; Sydney and the Fort Denison tide-gauge), is not sufficient for such mathematical calculations. Some other studies have made numerical estimates, but these have been considered unreliable and possibly misleading. However, this parameter continues to be a point of discussion, and deserving of further consideration.

Tsunami Travel Time Charts

For this Pilot Project, tsunami travel time charts for tsunamigenic sources in the Pacific and Southern Oceans have been provided by the Pacific Tsunami Warning Centre (PTWC) in Honolulu, Hawaii, USA, and those for sources in the Indian Ocean and near-shore Australia region by the National Tidal Facility (NTF), Flinders University, Adelaide, Australia.

TSUNAMI VULNERABILITY ASSESSMENT

Vulnerability has been defined in qualitative terms as the integration of the existing state of and planned future expansion of the coastal and islands built and natural environments with known tsunami occurrences and reported damage therefrom. As for the hazard assessment, this vulnerability assessment had to be undertaken for each individual State and Island Territory, in relation to their respective coastlines.

The vulnerability inventory has been delineated in terms of generic elements for :

built environment - major ports, harbours, fishing industry, offshore oil and gas fields, industrial sites, residential communities, infrastructure, tourist centres, future significant developments, near-shore island communities

natural environment - significant coastal geography, tourist areas, as shown for all Australian coastlines in Figure 6.

A preliminary vulnerability assessment for designated coastal areas of the Australian States and Island Territories defined in terms of vulnerability levels HI/MED/LO is given in Table 4.

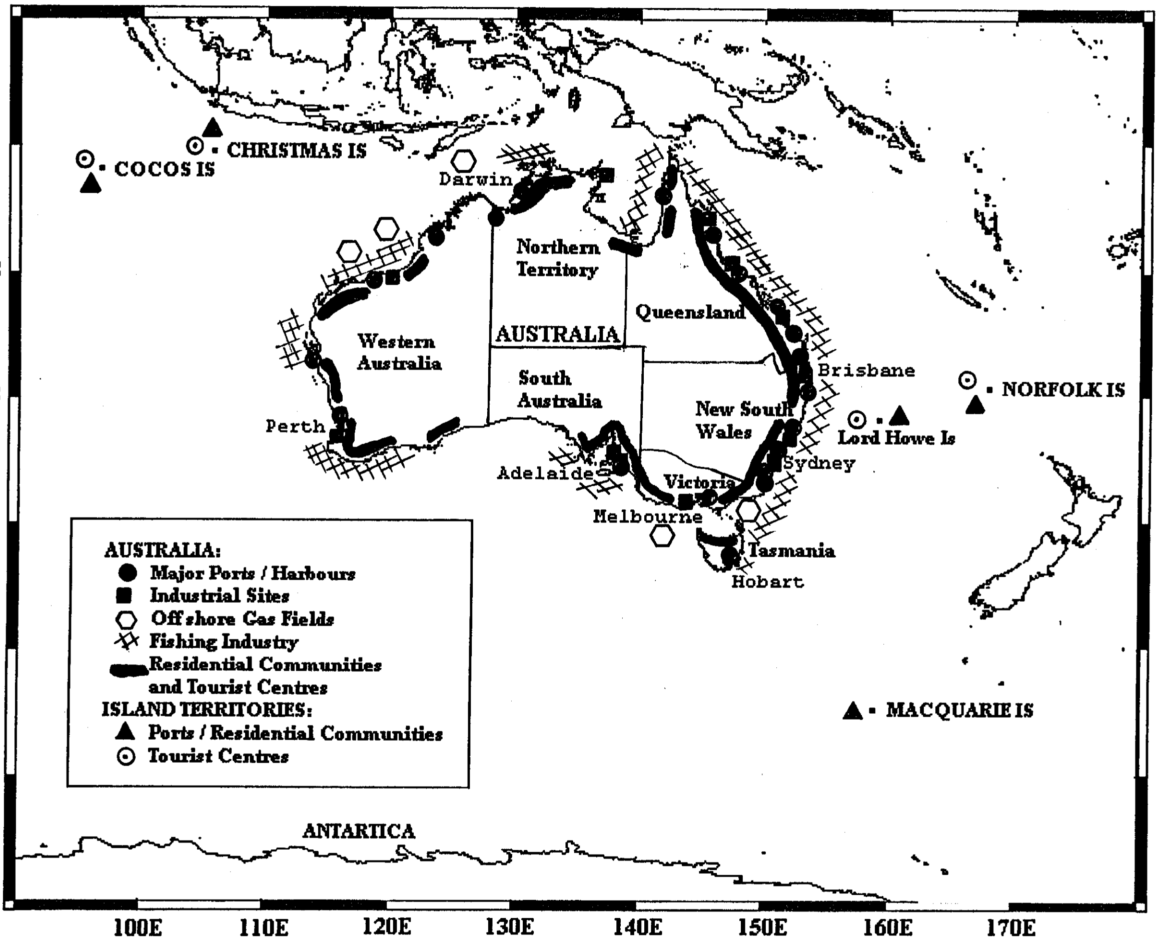

Figure 6 : Vulnerable Elements Along Australia's Coastlines Relative to Potential Tsunami Impacts

TABLE 4
VULNERABILITY ASSESSMENT (PRELIMINARY)

COASTAL REGION	VULNERABILITY												
	ELEMENT							POTENTIAL			LEVEL		
	MAJOR PORTS/HARBOUR	INDUSTRIAL SITES	FISHING INDUSTRY	OFFSHORE OIL AND GAS	TOURIST CENTRES	RESIDENTIAL COMMUNITIES	MARINE ENVIRONMENT	DAMAGE	INUNDATION	EVACUATION	HI	MED	LO
QUEENSLAND													
North Coast - Gulf of Carpentaria	X	X	X			X			X	X		X	
- Torres Strait Islands			X			X	X						X
East Coast - Cape York to Rockhampton	X	X	X		X	X	X		X	X	X		
- Rockhampton to Brisbane	X	X	X		X	X	X	X	X	X	X		
- Brisbane to Gold Coast	X	X	X		X	X	X	X	X	X	X		
NEW SOUTH WALES													
East Coast - Tweed Heads to Newcastle	X	X	X		X	X		X	X	X	X		
- Newcastle to Wollongong	X	X	X		X	X		X	X	X	X		
- Wollongong to Cape Howe	X		X		X	X						X	
Lord Howe Island	X				X	X		X	X	X		X	
TASMANIA													
East Coast - Flinders Is to Hobart	X		X		X	X	X					X	
North Coast - Flinders Is to King Is	X		X		X	X						X	
West Coast	X				X	X							X
VICTORIA													
South Coast - Gippsland	X		X	X	X	X		X		X	X		
- Wilsons Promontory to Portland	X	X	X	X	X	X		X		X	X		
SOUTH AUSTRALIA													
South Coast - Mt Gambia to Port Lincoln	X	X	X		X	X		X			X		
- Great Australian Bight													X
WESTERN AUSTRALIA													
South Coast - Esperance to Cape Leewin	X		X		X	X						X	
West Coast - Cape Leewin to Shark Bay	X	X	X		X	X					X		
- Shark Bay to NW Cape	X	X	X		X	X	X		X	X		X	
- NW Cape to King Sound	X	X	X	X	X	X	X	X	X	X	X		
North Coast - King Sound to Wyndham	X					X							X
NORTHERN TERRITORY													
North Coast - Wyndham to Gulf of Carpentaria	X		X	X	X	X	X					X	
ISLAND TERRITORIES													
INDIAN OCEAN - COCOS IS													
- CHRISTMAS IS	X					X	X		X			X	
PACIFIC OCEAN - NORFOLK IS	X	X				X	X		X			X	
SOUTHERN OCEAN - MACQUARIE IS	X					X	X		X			X	
	X						X	X	X	X	X		
AUSTRALIAN ANTARCTIC TERRITORY													
	X					X	X						X

TSUNAMI RISK ASSESSMENT

The tsunami risk assessment for Australia and its Island Territories is determined by an integration of the hazard and vulnerability assessments (per Figures 2, 4, 5 & 6). The results are presented in Figure 8 as a zonation map. The associated commentary in Table 5 defines the potential risk levels as Zones A to E in terms of the hazard and vulnerability elements. A description of these zones for various geographical segments of the coastlines of Australia and its Island Territories is given in Table 6.

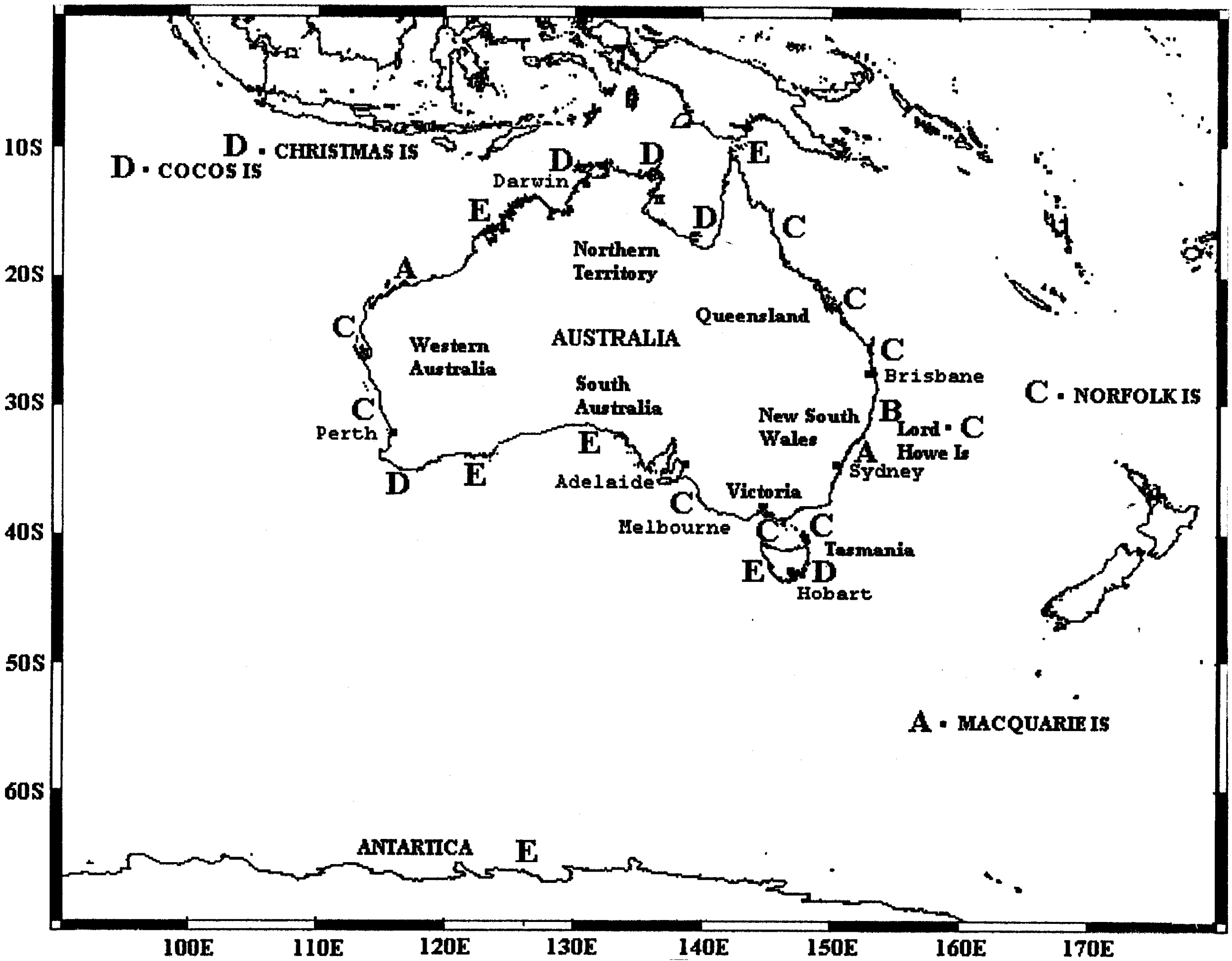

Figure 7 : Tsunami Risk Assessment for Australia and Its Island Territories as the Zonation Map

TABLE 5
COMMENTARY FOR TSUNAMI RISK ZONATION MAP FOR AUSTRALIA AND ITS ISLAND TERRITORIES

ELEMENT	TSUNAMI RISK ZONES								
	ZONE A	ZONE B		ZONE C		ZONE D			ZONE E
HAZARD ZONE (Figure 4, Table 3)	HI	HI	MED	MED	LO	HI	MED	LO	LO
RUN-UP HEIGHT (AVERAGE)	>6M	>4M	2-4M	2-4M	<2M	>4M	2 - 4M	<2M	<2M
WAVE HEIGHT	>1M	>1M	0.1 - 1M	0.1 - 1M	0.1M	>1M	0.1 - 1M	<0.1M	<0.1M
VULNERABILITY LEVEL (Figure 7, Table 4)	HI	MED	HI	MED	HI	LO	LO	MED	LO
CONTROLS TO POTENTIAL DAMAGE									
INUNDATION	YES	PROBABLE	POSSIBLE	POSSIBLE	UNLIKELY	PROBABLE	POSSIBLE	UNLIKELY	UNLIKELY
WAVE ACTION	YES	YES	POSSIBLE	POSSIBLE	NONE	YES	POSSIBLE	NONE	NONE
POTENTIAL DAMAGE									
BUILT ENVIRONMENT									
PORT/HARBOUR FACILITIES	YES	YES		YES		YES			FEW
INDUSTRIAL	YES	YES		YES		SOME			NO
FISHING INDUSTRY	YES	YES		YES		YES			NO
MARINAS	YES	YES		YES		SOME			NO
INFRASTRUCTURE	YES	YES		YES		YES			SOME
RESIDENTIAL DEVELOPMENT	YES	YES		YES		YES			SOME
TOURIST AREAS	YES	YES		YES		YES			NO
NATURAL ENVIRONMENT									
COASTLINES	YES	POSSIBLE		UNLIKELY		UNLIKELY			NO
WATERWAYS	YES	POSSIBLE		UNLIKELY		NO			NO
COLLATERAL DAMAGE									
HYDROLOGICAL - FLOODING	YES	POSSIBLE		POSSIBLE		UNLIKELY			NO
- WAVE ACTION	YES	POSSIBLE		MINOR		UNLIKELY			NO
GEOLOGICAL - EROSION	YES	POSSIBLE		UNLIKELY		NO			NO
CORAL REEFS	YES	POSSIBLE		UNLIKELY		NONE			NO
DEBRIS DEPOSITION	YES	POSSIBLE		NO		UNLIKELY			NO
POLLUTION	YES	POSSIBLE		POSSIBLE					NO
HUMAN ENVIRONMENT									
POPULATION DENSITY	HIGH	HIGH		HIGH/MEDIUM		MEDIUM/LOW			LOW
DEVELOPMENT	HIGH	HIGH		HIGH		MEDIUM/LOW			LOW
RECREATIONAL/OFF-SHORE ISLANDS	YES	YES		YES		SOME			SOME

TABLE 6
TSUNAMI RISK ZONES FOR COASTLINES OF AUSTRALIA AND ITS ISLAND TERRITORIES

COASTAL REGION	HAZARD	VULNERABILITY LEVEL	RISK ZONE
QUEENSLAND			
North Coast - Gulf of Carpentaria	LO	MED	D
- Torres Strait Islands	LO	LO	E
East Coast - Cape York to Rockhampton (inside Great Barrier Reef)	LO	HI	C
- Rockhampton to Brisbane	LO	HI	C
- Brisbane to Gold Coast	MED	HI	B
NEW SOUTH WALES			
East Coast - Tweed Heads to Newcastle	MED	HI	B
- Newcastle to Wollongong	HI	HI	A
- Wollongong to Cape Howe	MED	MED	C
Lord Howe Island	MED	MED	C
TASMANIA			
East Coast - Flinders Is to Hobart	MED	MED	C
North Coast - Flinders Is to King Is	LO	MED	D
West Coast	LO	LO	E
VICTORIA			
South Coast - Gippsland	LO	HI	C
- Wilsons Promontory to Portland	LO	HI	C
SOUTH AUSTRALIA			
South Coast - Mt Gambier to Port Lincoln	LO	HI	C
- Great Australian Bight	LO	LO	E
WESTERN AUSTRALIA			
South Coast - Esperance to Cape Leewin	LO	MED	D
West Coast - Cape Leewin to Shark Bay	LO	HI	C
- Shark Bay to NW Cape	MED	MED	C
- NW Cape to King Sound	HI	HI	A
North Coast - King Sound to Wyndham	LO	LO	E
NORTHERN TERRITORY			
North Coast - Wyndham to Gulf of Carpentaria	LO	MED	D
ISLAND TERRITORIES			
INDIAN OCEAN - COCOS IS	LO	MED	D
- CHRISTMAS IS	LO	MED	D
PACIFIC OCEAN - NORFOLK IS	MED	MED	C
SOUTHERN OCEAN - MACQUARIE IS	HI	HI	A
AUSTRALIAN ANTARCTIC TERRITORY	LO	LO	E

OTHER FACTORS RELEVANT TO TSUNAMI RISK

False tsunamis

While conscious efforts in mitigating the effects of the natural hazard of tsunami are now being considered in Australia, one must be aware that all "severe wave-actions" are not necessarily the result of tsunamis. It must be recognised that these "similar waves" - or false tsunamis - can be generated by sources other than tsunamigenic sources. These include meteorological effects (such as hurricanes, cyclones, east coast lows, and Southern Ocean lows) and tidal effects (such as tidal bores). Many of these have been noted along various parts of the Australian coastline. Hence **CAUTION** must be exercised in performing tsunami hazard analyses and subsequent risk assessments, and in integrating this information into tsunami warnings, policy issues and counter-disaster planning.

Paleotsunamis

In recent times, several claims have been made to the occurrence of paleotsunamis along the Australian coast and northwest coasts. Some of these suggest inundation of up to many tens of metres in areas, where today, major habitation exists. Many questions have been raised as to the geological evidence cited and nature of the tsunamigenic sources. Hence **CAUTION** must be exercised in considering such pre-historic events in hazard and risk assessments.

Misinformation

Extreme care must be taken when translating scientific information on tsunami risk and consequent mitigation measures to the relevant warning and response authorities and the community in general. In Australia's case, this is most relevant because the natural hazard of tsunami is indeed a rate phenomenum, particularly in relation to potential damage therefrom. Specifically, this relates to :

- results of statistical analyses of merge data
- the fact that all large waves are not a consequence of tsunami action - indeed, virtually all result from severe weather conditions (such as storm surges associated with cyclones)
- highly questionable return period / exceedance frequency estimates
- media articles (newspaper, television) wherein scientific information and inferences are precised by journalists.

There is indeed a duty of care in all disciplines to ensure that the correct information, and uncertainties contained therein, are transmitted responsibly to the community. For Australia, lessons need to be learnt from the more tsunami-prone countries.

PRACTICAL APPLICATIONS OF TSUNAMI RISK ASSESSMENT

The results and outcomes of this tsunami risk assessment, in both quantitative and qualitative terms, can be implemented into tsunami mitigation strategies through practical applications, as summarised in Table 7 :

Based on the outcomes of this Project, in terms of the specific methodology developed, comprehensive data base and the risk assessment, a series of **RECOMMENDATIONS** have been prepared suggesting possible future directions and research towards further understanding the tsunami hazard for Australia and its Island Territories.

TABLE 7 IMPLEMENTATION OF PRACTICAL APPLICATIONS OF TSUNAMI RISK ASSESSMENT INTO MITIGATION MEASURES	
PRACTICAL APPLICATIONS	MITIGATION MEASURES
1. EMERGENCY MANAGEMENT	Improvement in counter disaster capabilities, including inter-agency liaison and cooperation (Bureau of Meteorology, EMA, State Governments emergency services authorities, Local Government)
2. DISASTER PLANNING	Tsunami disaster plans (Federal, State, Local Governments; agency-specific)
3. GIS MAPPING	Data bases of maps and attributes
4. ENGINEERING CODES OF PRACTICE	Information for future development in built environment and infrastructure for engineering design and codes of practice
5. LAND-USE PLANNING	Developmental planning for loss reduction and sustainable development
6. WARNING SYSTEMS	Integrate information for upgrade of warning systems
7. RESPONSE AND RESCUE	Upgrade response, search and rescue and evacuation procedures and plans
8. EMERGENCY PERSONNEL TRAINING	Organise seminars, workshops etc and arrange specific training exercises
9. INSURANCE NEEDS	Information available for insurance industry procedures in post-tsunami recovery
10. COMMUNITY EDUCATION	Continue to advise the community through meetings and published material
11. SIMULATED TSUNAMI EXERCISES	Plan and conduct such exercises

TSUNAMI WARNINGS

At this time, the Bureau of Meteorology is the agency responsible for preparing and disseminating tsunami warnings in Australia. For the Pacific Basin, this is based on advise provided by the Pacific Tsunami Warning Centre in Hawaii, USA. For the Indian Ocean, relative to the Western Australia coast, this is supplemented with information provided by global seismological agencies and Indonesian authorities, and the Bureau's Regional Office in Perth. The need to upgrade has been recognised and would include greater integration with other relevant Australian agencies, (and so include more local Australian content), updating the Bureau's tsunami (seismic sea-wave) operational manuals and in-house training programs, more detailed information to be provided to response agencies, assessment of potential damages and media liaison. This IDNDR project's "Information Resource" will form part of the basis for such an upgrade.

RESPONSE TO TSUNAMIS

The major factors in understanding an area's vulnerability to tsunami to so reduce potential losses are AWARENESS and PREPAREDNESS. The key elements therein are pre-event mitigation programs, an effective counter disaster plan, an appropriate and realistic warning system, and preparedness of the response and recovery agencies. Valuable lessons can also be learnt from real experiences of tsunami disasters in other parts of the world.

At this time, little information on potential tsunamis striking Australia's coastline and consequent mitigation measures are available to emergency services authorities. The need for better interaction among the key agencies, through increased liaison and cooperation, has been identified and is currently in progress. This will lead to further development of necessary counter disaster plans at the local level. This project provides necessary information for input into this endeavour.

AUSTRALIAN TSUNAMI WARNING SYSTEM (ATWS)

(This section has been prepared in collaboration with Mr Bruce Neal, Assistant Director-Services, Bureau of Meteorology, Melbourne, Australia, as Chairman of the ATWS Committee).

Following the National Tsunami Workshop held in Brisbane, Australia in August 1994, the outcomes of the Australian IDNDR project discussed herein, and with the growing interest by the scientific community and emergency services considerations and heightened awareness of potential impacts of tsunamis, Australia is currently establishing an improved Australian Tsunami Warning System. The national agencies involved are the Bureau of Meteorology (BoM), Australian Geological Survey Organisation (AGSO), National Tidal Facility (NTF), Emergency Management Australia (EMA) and Australian Marine Safety Authority (AMSA). Technical advice is also being provided by the Centre for Earthquake Research in Australia (CERA).

The ATWS will consider the roles, responsibilities and functions of these national agencies so that future warnings will benefit the Australian community and, potentially, neighbouring countries in the southwestern Pacific and southeastern Indian Ocean basins. An operational framework is under development to provide :

- Arrangements for monitoring tsunamis: For both the Pacific Ocean area (continuing the close collaboration with PTWC) and Indian Ocean area
- Maximum effectiveness of ATWS: Considered to be the key issue for the success of ATWS, wherein EMA will play an important role in interfacing the community response agencies and human communications factors in dealing with the general public
- Management arrangements: Setting up a Committee of Management from the responsible national agencies with BoM operational managers and scientific experts on tsunamis as advisers where required
- Communication arrangements: To ensure the required rapid response times and multiagency nature of the ATWS are adequately addressed
- Operational arrangements: To address necessary operational issues such as modern instrumentation, scientific studies and funding
- Development of the Indian Ocean capability: Installation of suitable instrumentation in this region and increase collaboration with Indonesia.

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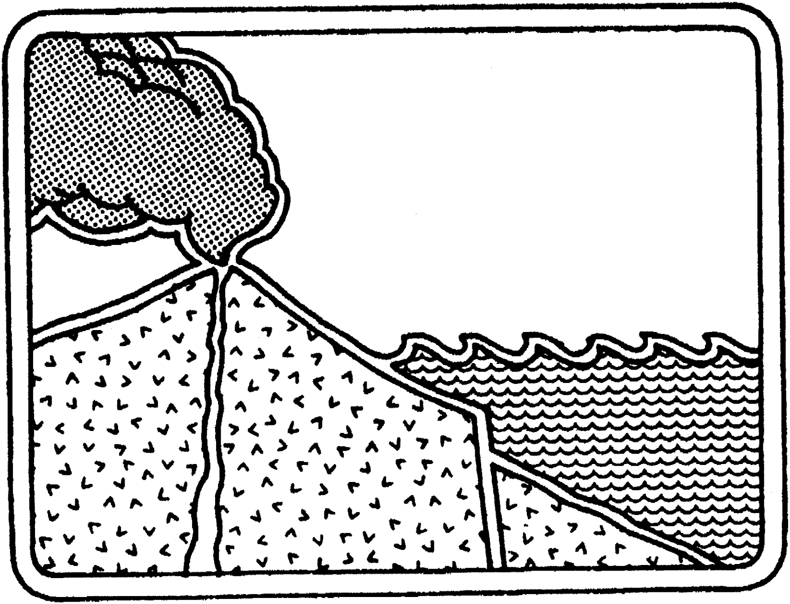

THE PACIFIC TSUNAMI MUSEUM: A MEMORIAL TO THOSE LOST TO TSUNAMIS, AND AN EDUCATION CENTER TO PREVENT FURTHER CASUALTIES

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ABSTRACT

In spite of significant advances in our understanding of the science of tsunamis, the basic facts about the dangers of tsunami waves are not understood by the general public. For those living in the Hawaiian Islands tsunamis are the most deadly of all natural disasters, having resulted in 291 fatalities since 1837. The town of Hilo in particular has suffered great destruction and loss of life with 177 victims, therefore making it an appropriate site for a museum focused on tsunamis. In mid-1998 the Pacific Tsunami Museum opened in downtown Hilo. The Museum has two goals: (1) to preserve the local history of tsunamis in Hawaii as a memorial to those lost, and (2) to prevent further loss of life from tsunami waves by fostering tsunami education, preparedness, and other mitigating measures. These two goals are compatible and produce a powerful synergism. The local history of tsunamis in Hawaii contains many true stories of tragedy, sacrifice and heroism, as well as accurate descriptions of the tsunami run-up phase. It is the power of these true stories as told by the survivors themselves which has the ability to capture the imagination and educate audiences of residents and visitors who most need to understand the danger of tsunamis. Funded by private donations and a grant from FEMA, the Museum is currently planning a dozen permanent exhibits to be installed by the end of 1999. An ambitious outreach program is already underway and includes development of curriculum packages for all public and private schools statewide, plus specialized literature targeted at specific groups including surfer, boaters, visitors, businesses occupying inundation areas, etc. The Museum has established an archive collection of photographs, films, videos, and artifacts, which will be made available to other educational organizations around the world, and has already assisted in the production of television documentaries aired nationally including those produced by the National Geographic Society, the Discovery Channel, the History Channel and a tsunami education special produced by KGMB-TV to be shown in Hawaii during April, 1999, Tsunami Awareness Month. Future plans for exhibits, educational programs, and possible alliances with the tsunami research community are discussed.

INTRODUCTION

Among the greatest challenges facing the tsunami mitigation community is to gain and keep the attention of the public, and to educate them to the danger posed by tsunami waves. The public at risk must be taught the steps needed in order to be prepared for the next tsunami, and the appropriate action to take when a tsunami is imminent. Civil liberties in the United States and many other countries preclude wholesale exclusion of the population from inundation zones, even during times of imminent threat. If the population is respond in an appropriate way, they must be taught both the danger and the behavior of tsunami waves. Public science education has never been an easy task. The short attention span fostered by the "sound bit" of the "television age" has exacerbated the problem. Yet people with no interest in science will listen with rapt attention to tales of tragedy and heroic survival. Once their attention has been captured, they can be taught the basics needed for community tsunami mitigation measures to be effective. The Pacific Tsunami Museum in Hilo, Hawaii has two primary goals. The first is to preserve local history of tsunami disasters. Downtown Hilo, Waiakea, Keaukaha, and the Laupahoehoe community are all areas that have been radically altered by tsunamis. Homes, businesses, schools, and entire residential and business districts have been destroyed or relocated as a result of tsunamis. The local histories of these destructive events include many stories of sacrifice, heroism and tragedy. By preserving these stories the Museum will serve as a memorial to those lost to tsunami waves. The Museum's second primary goal is to prevent future loss of life to destructive tsunami waves. This will be accomplished through public education about the tsunami threat. At the Museum we have found from experience that these two goals are entirely compatible and can produce a powerful synergism. Through direct observation we have witnessed thousands of visitors interacting with various types of information about tsunamis. In general, upon first encountering a science-oriented description of tsunami waves, most visitors spend only a few seconds reading the material. However, once a visitor has read or heard the true-life story of tsunami victims, they often return with renewed interest in order to gain a fuller understanding of the phenomenon. Put simply, the words of the survivors are the most powerful means of delivering the education message needed by the public if we are to prevent further loss of life to tsunami waves.

FOUNDING OF THE MUSEUM

The establishment of the Museum is an interesting story in itself. The original idea for a tsunami museum in Hilo came from tsunami survivor, Jeanne Johnston. From the beginning, the project has been a grass-roots, community effort. Business and civic leaders, tsunami scientists, and concerned citizens, have all given unselfishly of their time and effort to organize and found the museum. Unfortunately, many obstacles have delayed progress at the museum, including a major downturn in the local economy. Ironically the first meeting of a newly established board of directors of the Museum was scheduled for October 4, 1994 and had to be cancelled due to a Pacific-wide Tsunami Warning. Yet, the idea of a tsunami museum would not die. The museum was very fortunate to have Mrs. Susan Tissot, a museum professional, serve as Executive Director from 1994 until 1998. With her background in museum administration she was able to take the vision of the survivors and the knowledge of the tsunami experts and develop a sound foundation for the museum.

The board of directors, representing a broad spectrum of the community ranging from corporate CEOs and a Newspaper publisher, to a retired school principle, have brought to the Museum a tremendous range of expertise and awareness of community sensitivities to the memorial aspects of the Museum. A scientific advisory council was established including the directors of both the Pacific Tsunami Warning Center and the International Tsunami Information Center, as well as representatives of National Geophysical Data Center and the University of Hawaii. The head administrator for the Hawaii County Civil Defense Agency serves as the public safety advisor to the Museum. An all important Educational Advisory Committee was formed composed of both in- service and retired teachers and school administrators representing every major island in the State of Hawaii. Almost immediately museum volunteers set about the task of collecting oral histories from tsunami survivors. This task was undertaken with a sense of urgency, despite the lack of funding, as many survivors of the 1946 tsunami are quite elderly. Warren Nishimoto, Director of the Oral History Center at the University of Hawaii, conducted workshops for the Museum in order to train volunteer interviewers. He also began carrying out interviews with tsunami survivors himself. Survivor interviews are recorded on digital audio tape and later transcribed for the Museum archive collection. The Museum's education committee has organized several very successful "tsunami essay contests" where students submit written interviews with adult friends or relatives who experienced the tsunamis of 1946, 1960, or 1975. Prizes have been donated by local businesses and the contest has been expanded state-wide. In 1999 a senior-citizen division will be included for the first time. The Museum also sponsored a "tsunami photo contest" in an effort to begin establishing a photographic archive collection. Since that time several hundred photographs have been added to the Museum archives. The Museum has also established ties with other archival collections of photographs including the Bishop Museum in Honolulu, the Hawaii State Archives, the Kona Historical Society, the Hana Historical Society on Maui, and the National Geophysical Data Center in Boulder, Colorado. The Pacific Tsunami Museum now has copies of virtually every photograph related to tsunamis found in each of these other archives and is presently setting up a photographic database to be accessible on terminals at the Museum and ultimately over the Internet. The Museum intends to make photographs from its own collections available to educators at a nominal cost, avoiding the high cost of photographic reproduction by in-house printing of high-resolution scanned photographic images. Funds from professional media use of tsunami archive materials will help the Museum to support the archive facility. One of the greatest challenges facing the Museum has been to find a permanent home and to produce state-of-the-art permanent exhibits for effective tsunami education. The poor economic climate in Hawaii and cost estimates in the millions of dollars from professional museum design firms left the Museum in the doldrums. The Museum board turned to the private sector for support and in May 1998, 1st Hawaiian Bank donated a beautiful building in downtown Hilo to become the Museum headquarters. This historic building, built in 1930, survived both the 1946 and 1960 tsunamis. In June 1998, the Museum opened its doors with temporary displays donated by the Bishop Museum, the Pacific Marine Environmental Lab, the University of Hawaii at Hilo, and others. Staffed entirely by volunteers, many of whom are retired teachers and tsunami survivors themselves, the Museum has began averaging nearly 100 visitors each day. Not only are local school groups and island residents frequent visitors, but also many tourists from around the world are attracted to the Museum. Thus far foreign visitors have come from nearly every European country, as well as from Brasil, Papua New Guinea, French Polynesia, Korea, Taiwan, and numerous visitors from Japan. Though the current exhibits are relatively simple displays, these displays and the student essays have been quite effective in drawing visitor attention and have provided the staff with an opportunity to study what attracts visitor interest and how Museum visitors learn about tsunamis. The Museum has also produced a booklet on local tsunamis in Hawaii which is available for sale at the Museum and will be given to educators across the state as part of a tsunami education packet. Since its first days the Museum has been sought out by documentary film makers as a resource for information, photographs and interviews with survivors. The staff at the Museum have even been able to guide and educate these media groups about the importance of tsunami education. In April 1999, KGMB-TV, the CBS network affiliate in Honolulu, will present a 30-minute special on tsunamis. The special focuses not on the sensational aspects of tsunami waves but on the human stories of survivors, education about the tsunami phenomenon, and on measures to take in preparation for the next tsunami.

DEVELOPMENT OF THE MUSEUM - PHASE I

In 1998 the Pacific Tsunami Museum received a matching-funds grant from the Federal Emergency Management Agency through the Hawaii State Civil Defense Agency. These funds were earmarked for tsunami education through the production of permanent exhibits and outreach education programs. After much consideration the Museum staff and board decided not to contract out the production of museum exhibits, but instead to build the capacity at the Museum to produce its own exhibits and outreach materials. This approach not only maintains the Museum's community-oriented focus but also provides for continuing, long-term, up-to-date tsunami education programs.

ARCHIVE FACILITY

The first step was the establishment of an archive facility to support the education outreach programs and the production of exhibits. Photographs, films, videos, and documents of historic interest are scanned, stored on computer memory and transferred to CD-ROM. All materials are currently being entered into state-of-the-art museum database software specifically designed to include photographic images. Though only available for use by museum staff at present, the database will eventually be available for searches by the public on terminals in the Museum and ultimately over the Internet. In addition to archiving photographic materials, oral histories from tsunami survivors are also being transcribed and archived at the Museum. A very important aspect of the Museum's oral history program has been the collection of video oral histories. The Museum now conducts interviews with tsunami survivors from every island in the State. These are videotaped on high-quality digital equipment and edited in-house to produce professional quality video productions for use in the Museum's educational outreach program and as components of the permanent exhibits. There is another important aspect to the oral history audio and videotaped interviews. Even more than 50 years after a devastating tsunami, many survivors still feel quilt at having lived when others died. This is particularly acute when a survivor has lost a family member. We let prospective interviewees know that their interviews will be used in tsunami education programs and that by sharing their often painful memories they will be helping to prevent further loss of life to future tsunami waves. Furthermore, our chief interviewer is Jeanne Johnston, a tsunami survivor herself. She is very effective at putting interviewees at ease and helping them begin to let their stories out. For many survivors being interviewed becomes a cathartic experience helping them better deal with feelings of guilt and at the same time providing powerful material for use in the Museum's tsunami education programs.

OUTREACH PROGRAMS

Many of those at greatest risk from tsunamis are drawn to the sea for ocean recreation. Shoreline fishermen, divers, kayakers, boaters, and surfers all practice their sports in areas highly vulnerable to the tsunami threat. Each of these groups has its own community of enthusiasts, often with their own special lingo and culture. A broad-brush approach to tsunami education simply will not work with many of these sportsmen and women. The Museum has decided to target each group with specialized educational materials and approaches. For example, a special poster on the tsunami threat to surfers is being produced in cooperation with local surf shops. World-class board surfers and body boarders are joining in the effort by permitting use of their photographs as well as providing statements to the effect that "you can't surf tsunami waves" and "if you do, you may die!" The archive facility maintains desktop publishing and laser printing equipment for the production of these specialized outreach printed materials which will be made available at surf shops and surfing contests. Public service radio announcements will be made available to radio stations popular with surfers. Several station have already indicated their eagerness to participate in the "surfer tsunami education program." All target groups will be educated using materials and approaches specifically designed for efficiency and effectiveness with that particular group. The largest single group targeted by the Museum is the somewhat captive audience of school children throughout the State of Hawaii. Because the Museum's Education Advisory Committee is made up of experienced educators, they fully understand the difficulties of getting a "new curriculum" established in the schools. The "Tsunami Essay Contest" was one of the first steps and continues as a highly successful annual event across the State. During the summer of 1998 teacher interns worked at the Museum developing curriculum materials. The archivist and video team are collecting photographic materials and video oral histories from each island community. This is being done in order to make tsunami education material more relevant to students on a particular island. For example, a child on the island of Kauai may not pay much attention to a story about what happened in Hilo or at Laupahoehoe. However, if they hear a story about a tsunami striking Hanalei Bay on Kauai, they will pay closer attention and more easily identify with the events. The Educational Advisory Committee will be sponsoring a teacher institute on tsunamis during the summer of 1999 which will include both public and private school teachers, and plans to have tsunami education become an integral part of both public and private school training throughout the State of Hawaii. In addition to education in Hawaii, the Museum is working in collaboration with the UH Sea Grant Program and PREL (Pacific Resources in Education and Learning) to expand disaster education to island nations in the Pacific basin. A university student from Micronesia is producing educational materials on tsunamis and storm surge for the islands of Pohnpei, Pingelap and Mokil. These will be the first disaster mitigation materials related to tsunamis ever made available in the native languages of these small, highly vulnerable islands. Both written materials in pamphlet form and posters in a cartoon format are being produced.

PERMANENT EXHIBITS

One of the most ambitious and exciting projects at the Museum is the production of state-of-the-art permanent exhibits. A team of university faculty and staff, tsunami researchers, and committed community members have joined together to produce professional-quality exhibits. A brief description of each exhibit is given below.

1. Laupahoehoe - The first exhibit, scheduled to open on April 24, 1999, deals with the community of Laupahoehoe. The story of this lovely peninsula and its tragic destruction in 1946 will be told through a display with historical photographs and text. Touch sensitive video kiosks will permit selection of mini-documentaries relating events in greater detail including the pre-contact Hawaiian history of Laupahoehoe, the rescue of the crew of the clipper ship Hornet at Laupahoehoe (Mark Twain's first magazine article), the prosperous turn-of- the-century village at the point, and the tragic events the morning of April 1st, 1946, when 16 students and four teachers were lost. Videotaped interviews of survivors make this part of the exhibit extremely powerful. A commemorative quilt and a set of oars actually used in the rescue of three school boys will be on display.

2. The Baycam - Hilo Bay - A video camera mounted on the roof of the Museum will show activities on Hilo Bay and special events in downtown Hilo. The video feed will be shown in the Museum and mirrored on the Museum's Website for access worldwide. Eventually a closed circuit link will be set up between the Museum and the University of Hawaii at Hilo research vessel in order to share sea-going research and education activities in ocean science with public school students viewing from the Museum.

3. Ocean Science in Hawaii - An area of the Museum will be furnished with four computer stations: (1) CD- ROM of tsunami wave simulations showing generation, propagation, and run-up phases, (2) CD-ROM with a tsunami database showing a world map with sites and data on all major tsunamis, (3) various ocean science- related CD-ROM-based software including special NOAA programs specifically developed for ocean science education in Museums, (4) high-speed links to Internet sites restricted to tsunami-related Websites and sites showing oceanographic information about Hawaii, i.e. wave buoys, etc.

4. Hilo 1946 - A physical scale model of pre-tsunami Hilo complete with a working model train will form the centerpiece of this exhibit. It will also include videotaped oral histories keyed to areas of the model and selected through a touch-sensitive video screen.

5. Keiki Corner - Children's Exhibit Area - This exhibit will include a kid-sized wet scale model of Hilo bay front periodically activated to create tsunami waves. An animated children's story with sea animal characters will tell the story of a tsunami coming from Alaska to Hawaii and how the animals learn to save themselves from disaster.

6. Science of Tsunamis - This exhibit will explain how different mechanisms can create tsunamis, how the waves travel across the oceans, and how they behave as they come ashore. How scientists go studying tsunamis will add a human aspect to the exhibit.

7. Hilo 1960 - This exhibit will include photos, a base map, and a mirror-model showing Hilo before and after the 1960 tsunami. Videotaped oral histories will be keyed to areas of the map and selected through a touch- sensitive video screen.

8. Local Tsunamis - The southern shore of the Island of Hawaii will be featured as the source of two deadly locally generated tsunamis: 1868 and 1975. Visitors will stand on a platform watching the surf along the shore on a video screen. The platform will begin to shake simulating an earthquake, which is followed by a tsunami. Waves are shown advancing around the island on a video screen and narration explains what has happened in the past and how to prepare for the next one.

9. Tsunami Warning System - This exhibit will simulate the activities which occur at the Pacific Tsunami Warning Center following an earthquake. Seismic wave data will be simulated as well as tide station reports. The visitor will be asked to make decisions about a "Tsunami Warning" evaluating lives lost without a warning and economic cost if a "false alarm." Civil Defense messages and radio and TV reports will be simulated to provide realism to the experience.

10. Tsunamis Across the Pacific - A wall-sized map of the Pacific will be the focus of this exhibit indicating the site of a dozen major tsunamis which have occurred around the Pacific including the tsunamis created by Krakatoa in 1883 and in Papua New Guinea in 1998. Video kiosks on both sides of the map will feature mini- documentaries about each tsunami selected via touch sensitive video screens.

11. Recent Tsunamis - This exhibit will provide documentary information, photos, video clips, and access to Websites relating the most recent tsunamis in the world.

12. The Tsunami Theater - The old bank vault of the Museum will be turned into a state-of-the-art sound- surround theater for groups of up to 16 visitors wishing to see tsunami videos produced with the help of the Museum by major production companies including National Geographic, the Discovery Channel, and the History Channel. The Museum's own "tsunami experience" video production will ultimately be created for showing in the Tsunami Theater. The facility will also double as a video studio for recording interviews with tsunami survivors.

THE FUTURE

One of the most important and most obvious needs facing the Museum is to become self-supporting financially. A small nucleus of paid staff will be necessary to expand operating hours and provide continuity to Museum operations. At present no admission fee is charged for entrance to the Museum. Once approximately half of the permanent exhibits are in place, a nominal fee will be charged. When the full complement of permanent exhibits is fully operational the fee will be increased, but the board fully intends that the fee remain nominal in comparison to many visitor attractions in Hawaii. Furthermore, deep discounts will be made for local residents and education groups. The Museum will continue to update, fine-tune, and expand the permanent exhibits, and plans to begin a series of temporary exhibits which may become part of the outreach program as traveling exhibitions. Finances permitting, the Museum would also like to expand its scope to include information on other types of natural disasters such as hurricane storm surge, landslides, and flooding events in Hawaii. The Museum would like to help fill another important need in the State of Hawaii by becoming an "ocean science museum" to both help interest and train students in ocean science. This would be a collaborative effort with the State Department of Education and the Kalakaua Marine Education Center at the University of Hawaii at Hilo. The Museum would also like to more directly serve the tsunami mitigation community. We feel that we can play an important role in helping educate those involved in both disaster mitigation and relief efforts by providing educational materials and first-hand personal contact with tsunami survivors. We would hope to become both a source and clearing house for education materials and thereby help eliminate wasteful duplication of effort. The Museum would also like to serve the tsunami research community. There are several ways in which we feel we can help. Survivor stories often contain valuable information useful in reconstructing historic tsunamis or in examining aspects of the phenomenon. For example, Dr. Dan Walker has documented an unusual optical phenomenon observed during the Kuril Island tsunami of 1994. Several observers on Oahu saw a "tsunami shadow" approaching from the horizon and a resident at Punaluu actually videotaped the shadow. In late 1997, I received a letter from a gentlemen from California who had been a sailor in the radio room of a Navy ship steaming toward Oahu on the morning of April 1, 1946. Over the radio he heard two pilots in a PBY reporting that they had seen a "line" or "something" on the surface of the water and it had "outrun" their aircraft. At this time no one was aware that a tsunami was approaching Oahu. This retired gentlemen had never heard of the "tsunami shadow" as reported by Dr. Walker, but his account adds validity to Dr. Walker's supposition that such an optical effect might be associated with tsunami waves in general. Another way in which the Museum might be able to serve the research community is by providing a team of trained interviewers with experience in interviewing tsunami survivors and prepared for the cultural sensitivities of a particular region. Equipped with digital audio and video equipment, such an interview survey team might accompany the post-tsunami survey teams on their data collecting expeditions. The interviews would not only provide addition information of scientific interest, but could become effective tsunami education materials for the countries effected by the tsunami. The Museum would further like to assist the research community by serving as a resource of documents, photographs and data. To further this end, both George Curtis and I have placed our personal collections of materials in the Museum library and have received contributions of materials from Sig Wigen, Jim Lander, Fumio Yamashita, Fumihiko Imamura, and others. The Museum has even set up an office for a visiting "tsunami expert in residence." This office facility with its access to the Museum library and archive facility would be available for a scientist on sabbatical or other type of professional leave who would be willing to share their expertise with the Museum. I personally feel that once a visiting scientist has spent time with those who have lost parents, siblings, or children, they will never look at the tsunami phenomenon in the same way again and will approach their work with renewed dedication. Many of you are already committed to the Museum and we'd like for the tsunami research and mitigation community as a whole to adopt the Museum. We ask you to send copies of tsunami-related photographs, documents, and reprints to us. Help us turn the Museum into a comprehensive tsunami repository for your use. After all, the reason we all study tsunamis is not just because they are a fascinating natural phenomenon, but in order to prevent the tragic loss of life from the phenomenon. That is what this Museum is all about. The motto of the Pacific Tsunami Museum is "Let us not forget."

MEMORIUM

PROFESSOR MARTIN VITOUSEK

Dr. Martin Vitousek was a pioneer tsunami researcher in Hawaii. He passed away February 14, 1999 at the age of 74 of a severe stroke at Kona, Hawaii. He taught and did research at the Hawaii Institute of Geophysics of the University of Hawaii. He received his PhD. from Stanford University. He was associated with the University of Hawaii most of his career. He originated the concept of the deep ocean tsunami wave sensor. He developed the sensor system and located it at various places in the Hawaiian and other Pacific Islands. During the Pacific nuclear testing programs, he was in charge of gathering the tsunami wave effects data for the tests. Dr. Vitousek was an experienced sailor and pilot. He used these skills in his many research programs involving tsunami wave detection and measurement throughout the Pacific Ocean.

TSUNAMI WEB SITE DIRECTORY

A web site with an index of the papers published during the last 16 years of *Science of Tsunami Hazards* is being published by Dr. Antonio Baptista. The web site has the following URL:

http://www.ccalmr.ogi.edu/STH

The journal issues in PDF format are available at the following URL:

http://www.epubs.lanl.gov/tsunami

and on a CD-ROM from the Tsunami Society. A collection of computer generated tsunami animations is also on the CD-ROM.

The International Tsunami Information Center maintains a web site with current information of interest to the Tsunami community. The director of ITIC, Mr. Michael Blackford is expanding the tsunami news section on the web site. The web site has the following URL:

http://tgsv5.nws.noaa.gov/pr/hq/itic.htm

The West Coast and Alaska Tsunami Warning Center maintains a web site with tsunami information. The web site has the following URL:

http://www.alaska.net/~atwc/

A beautiful web site about Tsunamis is being published by **Tsunami Society** member, Dr. George Pararas-Carayannis. His tsunami web site has the following URL:

http://www.geocities.com/capecanaveral/lab/1029

A web site about The National Tsunami Hazard Mitigation Program is maintained by **PMEL**. The web site has the following URL:

http://www.pmel.noaa.gov/tsunami-hazard

Several members of **The Tsunami Society** have helped develop a web site for the **Pacific Tsunami Museum** in Hilo, Hawaii. The web site has the following URL:

http://planet-hawaii.com/tsunami

A remarkable website by Michael Paine on Tsunamis from Asteroid Impacts from the Australian perspective has the following URL:

http://www1.tpgi.com.au/users/tps-seti/spacegd7.html

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See 1999 Journal Issue for Desired Style (page 57-63 for example)

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All text to be single space.

Indent 5 spaces to start a new paragraph.

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