British Columbia Tsunami Warning and Alerting Plan

2001 Edition

BRITISH COLUMBIA

Ministry of Public Safety
and Solicitor General

BRITISH COLUMBIA

BRITISH COLUMBIA TSUNAMI WARNING AND ALERTING PLAN

This plan identifies the intended actions to be taken by the Government of British Columbia to disseminate warning to coastal communities of a potentially destructive tsunami.

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Foreword

The Tsunami Warning System in the Pacific is an international program designed to provide timely and effective information and warnings about tsunamis generated in the Pacific Basin. The Provincial Emergency Program has been designated by the Government of British Columbia to be the agency responsible for disseminating warnings to the coastal areas of British Columbia.

This plan describes the procedures to be used in British Columbia to evaluate and disseminate information provided through the Tsunami Warning System. It has been formulated with the help of extracts and data provided by the U.S. National Oceanic and Atmospheric Administration, Department of Commerce, and the Canadian Hydrographic Service, Institute of Ocean Sciences, Fisheries and Oceans Canada, Sidney, BC.

For tsunami warnings to be of value to coastal communities, local governments and the population in general should be aware of the nature of tsunamis and the damage they can cause; and ways to mitigate (prevent or avoid) the destructive aspects of tsunamis. An awareness and education program is introduced in this edition of the plan. British Columbia gratefully acknowledges the past and future cooperative activities in this regard, undertaken with the U.S. states of Washington, Oregon, California, Alaska and Hawaii.

Additional information about tsunamis may be found on the Provincial Emergency Program website at http://www.pep.bc.ca/ or by writing to:

Provincial Emergency Program
PO Box 9201, Stn Prov Govt
Victoria, BC V8W 9J1

Record of Amendment

This manual is a living document that may require amendment on a regular basis.

Amendment recommendations should be forwarded to the attention of the Director of the British Columbia Provincial Emergency Program (PEP). PEP Headquarters will maintain a master record of amendments. Amendments will be controlled by showing the revision date, contained in the footer of any revised page; for example:

Revised 01.12.25	Page 2-8

No.	Date	Chapter and Section	Pages	Entered by

Table of Contents

Chapter 1
Introduction

1.1 Background

A tsunami is a series of ocean waves generated by displacement of the ocean floor, often in conjunction with an earthquake.

For more definitions see Appendix G.

A zone of extreme seismic activity circles the Pacific Ocean from the south of Chile up the coast of South, Central and North America, turning westward along the Aleutian Islands arc, southwards through Japan and the Philippines, westward to Malaysia and Indonesia, and eastward through New Guinea, the southern island groups, and New Zealand. This “Ring of Fire” is the most active seismic feature on earth and periodically produces large ocean waves, called tsunamis, that threaten almost every island and coastal settlement in the Pacific Ocean.

1.2 Purpose

The purpose of this plan is to outline procedures to warn BC coastal settlements, ships, and float planes of the approach of known or possible tsunamis that could affect coastal areas of British Columbia.

SPECIAL CONSIDERATION – LOCAL SOURCE TSUNAMIS

A tsunami generated in conjunction with a nearby large earthquake may not provide sufficient time to implement formal warning and alerting procedures. Persons in coastal areas who experience a large earthquake with shaking lasting a minute or more should assume that a tsunami will arrive within a few minutes and take immediate action to evacuate to safer high ground.

1.3 Scope

This is a **warning plan**. It does not address the detailed actions to be taken by individuals, communities, shipping, or float aircraft on receipt of tsunami warning information. Matters such as alarm systems, possible areas of inundation, evacuation routes and safe areas must be incorporated in local plans. The Provincial Emergency Program can assist in the preparation of local plans and in making educational material available for distribution.

1.4 Tsunami Exercises (Drills)

It is important to regularly practise the warning system. Appendix D provides initial guidance and instructions.

1.5 Mitigation

An essential element of tsunami mitigation is public awareness of the tsunami hazard and what actions are to be safely undertaken when a tsunami is expected. A successful mitigation strategy requires continuing emphasis by local governments and other local authorities, as well as by individuals, industry and the recreational and tourism sectors in tsunami-prone areas.

Appendix E provides some initial guidance concerning implementation of a local tsunami mitigation program.

Chapter 2
Procedures for the Dissemination of Tsunami Warning Information for British Columbia

2.1 Responsibilities

For more information about the tsunami warning system in the Pacific refer to Appendix B.

The overall responsibility for the initiation of tsunami warning information for British Columbia rests with the West Coast/Alaska Tsunami Warning Center (WC/ATWC) situated in Palmer, Alaska.

Tsunami warning information is formally disseminated to only one agency per country, territory, or administrative area. British Columbia receives warning information from WC/ATWC through the Provincial Emergency Program.

Because of the methods of dissemination used in the interest of speed of transmission, many other agencies and individuals may "eavesdrop" on messages from WC/ATWC, or from the Pacific Tsunami Warning Center in Hawaii (PTWC). Formal warning and alerting for all of the province, however, (including ships and float planes) is the responsibility of PEP, which has undertaken the coordination procedures outlined in this chapter.

2.2 Types of Warning Messages

Messages transmitted by WC/ATWC have been refined into categories intended to provide maximum warning of possible tsunami conditions based on scientific observation of previous earthquake effects. Initial messages may be based only on a historical similarity of events, in the interest of "erring on the side of caution".

Tsunami Information Messages/Bulletins are issued with information about an earthquake that is less than magnitude 7.1 in Alaska, British Columbia or the West Coast; or less than or equal to magnitude 7.5 elsewhere in the Pacific Basin. *No tsunami danger is expected* in Alaska, British Columbia, or the West Coast. Usually only one bulletin is issued.

The meanings of the terms* Warning *and* Watch*, in messages received from the tsunami warning centres, must be clearly understood.

Tsunami Warning, Watch, Advisory Bulletins are issued when a tsunami may have been generated which could affect any portion of the WC/ATWC areas of responsibility.

A message may state that an area is in **Warning** status, which means that a tsunami was or may have been generated which could cause damage. Therefore the area warned is strongly advised to evacuate.

A **Watch** status means that a tsunami was or may have been generated, but is at least two hours travel time to the area in Watch status. Local officials should prepare for possible evacuation if their area is upgraded to a Warning.

An **Advisory** is issued when an earthquake greater than magnitude 7.5 has occurred in the Pacific Basin which might generate a tsunami. The tsunami is over six hours travel time to the nearest point on the West Coast or Alaska.

A list of geographic breakpoints can be found in Appendix B.

Areas under Warning, Watch, or Advisory status are defined by the use of geographic breakpoints. WC/ATWC will issue hourly bulletins advising of the situation, until closure.

A **Cancellation Message** will be sent to indicate that any Warning or Watch Bulletin has been cancelled.

WARNING

Means that, for the region identified, the existence of a potentially destructive tsunami was or may have been confirmed by positive evidence.

WATCH

Means that, for the region identified, a tsunami may occur, but that additional information or evidence needs to be determined before a Warning is issued or not.

2.3 Coordination within British Columbia

Example BC Tsunami Advisory Bulletins are found in Chapter 3.

The **Provincial Emergency Program (PEP)** will initiate internal procedures to activate the provincial emergency response management structure, and prepare (with CHS below) the initial **BC Tsunami Advisory Bulletin** for

distribution to cooperating agencies and communities at risk.

The PEP Emergency Coordination Centre is responsible to maintain lists of 24/7 contact information for all cooperating agencies and coastal communities.

PEP will also provide copies of BC Tsunami Advisory Bulletins to **Emergency Preparedness Canada (BC/Yukon Region)** for distribution to Federal Agencies not specifically included as cooperating agencies below. PEP will provide information copies of Tsunami Advisory Bulletins to other ministries and agencies of the BC Government and liaise with Washington State Emergency Management.

The **Regional Tidal Superintendent, Canadian Hydrographic Service (CHS), Fisheries and Oceans Canada** is responsible to apply local and actual ocean and tidal conditions to data contained in tsunami bulletins, to determine if a significant threat occurs to coastal communities, vessels and float planes.

On receipt of a WC/ATWC Tsunami Information Message or Advisory Bulletin, PEP will immediately inform CHS and forward a fax copy of the message, whether or not the message indicates that a tsunami has been generated.

When a tsunami has been generated, CHS will provide PEP with anticipated wave height information, and actual wave arrival times and wave heights at BC coastal tidal gauges.

Maritime Forces Pacific (MARPAC) Operations Centre, Canadian Forces, is responsible for passage of tsunami information from PEP to all potentially affected naval vessels, Canadian Forces bases and stations, and the Rescue Coordination Centre (Victoria).

Should tsunami messages be received by MARPAC via a US defence communications network, MARPAC Operations Centre will relay them to PEP.

Marine Communications and Traffic Services Centre, Canada Coast Guard, Prince Rupert will rebroadcast BC Tsunami Advisory Bulletins received from PEP to all vessels operating in affected areas along the BC coast. Messages will continue to be repeated until a cancellation or "all clear" is received.

Navigation Canada (NAVCAN), Vancouver International Airport will rebroadcast Tsunami Advisory Bulletins received from PEP to all float aircraft operating in affected areas along the BC coast. Messages will continue to be repeated until a cancellation or "all clear" is received.

A map showing coastal RCMP detachments and communities with local emergency program coordinators is at Appendix C.

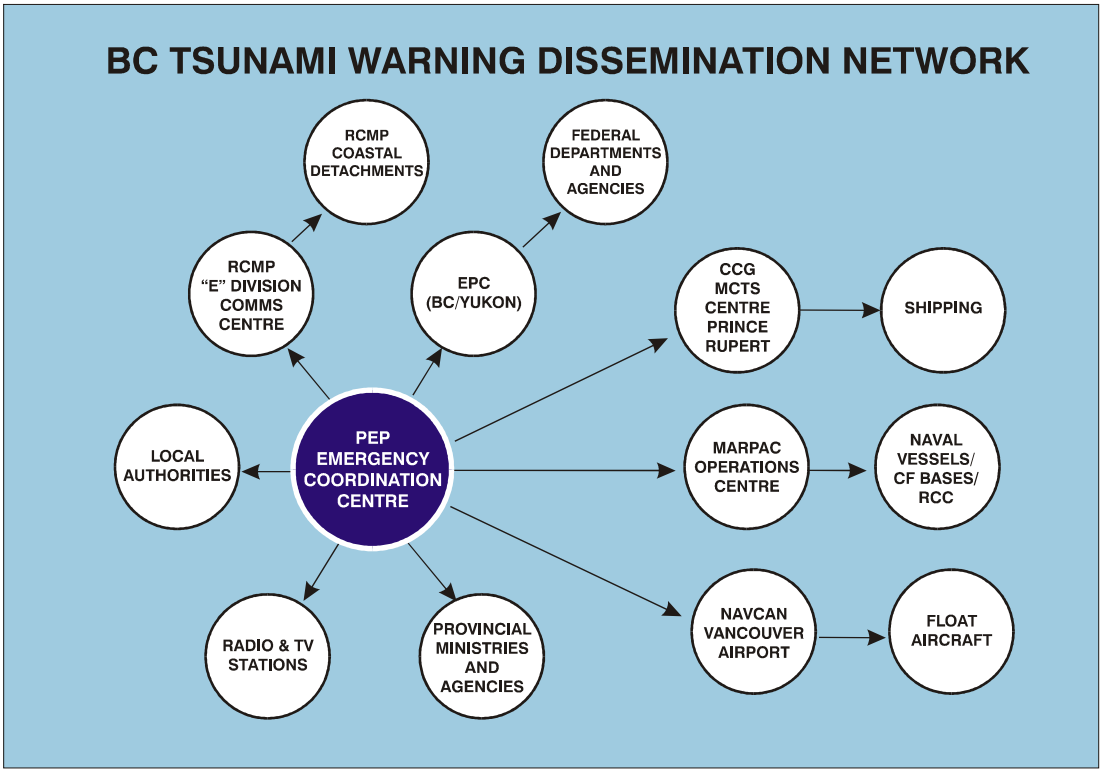
"E" Division, Royal Canadian Mounted Police Communications Centre, Vancouver will rebroadcast Tsunami Advisory Bulletins received from PEP to all RCMP detachments in affected coastal areas. RCMP coastal detachments will alert the population within their areas of jurisdiction in accordance with local authority plans, and taking into consideration populations at risk outside of local authority jurisdictions such as First Nations reserves, logging and fish farm operations, parks and campgrounds, marinas, float plane docks, etc.

Local Authority Emergency Program Coordinators in coastal areas at risk will alert their populations in the manner specified in local plans. Coordinators should work closely with their supporting RCMP detachment to ensure adequate coverage of their areas and to avoid duplication of effort.

Radio and Television news agencies will be provided with Tsunami Advisory Bulletins by PEP and will be requested to broadcast them as received and every 5 minutes for 15 minutes, or longer. When provided, cancellation or "all clear" messages will also be broadcast.

2.4 Warning Dissemination Network

A diagram showing the flow of warning and alerting information is on the following page.



2.5 Communication within the WC/ATWC Area

WC/ATWC passes tsunami messages using a variety of communications means. PEP ECC can receive messages via:

- Satellite - (NOAA) Weather Wire system;
- By NAWAS phone and facsimile;
- Electronic mail; and
- Internet. The latest message is displayed at URL http://wcatwc.gov/message.txt

Messages are also sent via the US Department of Defense facilities. MARPAC Operations can receive this traffic and serves as a backup or alternate communications route in the event that PEP cannot receive messages.

A typical WC/ATWC message as received by PEP is shown below. Examples of the several other types of WC/ATWC messages are maintained at PEP for internal reference and are not repeated in this plan.

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WEST COAST AND ALASKA TSUNAMI WARNING CENTER/NOAA/NWS
ISSUED DEC 6 AT 1843 UTC

...THIS IS AN INFORMATION MESSAGE...

AN EARTHQUAKE, PRELIMINARY MAGNITUDE 5.2, OCCURRED AT
0940 AST ON DEC 6, OR 1040 PST ON DEC 6, OR 1840 UTC ON DEC 6.
THE EARTHQUAKE WAS LOCATED 50 MILES NW OF DENALI PARK HDQTS., AK.
OR 100 MILES SW OF FAIRBANKS, AK.
AT 63.9N, 150.4W, 3 MILES DEEP.


EVALUATION:  THE MAGNITUDE AND LOCATION ARE SUCH THAT A TSUNAMI
WILL NOT BE GENERATED.  THIS WILL BE THE ONLY BULLETIN ISSUED.

THE LOCATION AND MAGNITUDE ARE BASED ON PRELIMINARY INFORMATION.
WEST COAST AND ALASKA TSUNAMI WARNING CENTER: HTTP://WCATWC.GOV.
FURTHER INFORMATION WILL BE ISSUED BY THE U.S. GEOLOGICAL
SURVEY, GOLDEN, CO., HTTP://WWWNEIC.CR.USGS.GOV, OR THE
ALASKA EARTHQUAKE INFORMATION CENTER, UAF GEOPHYSICAL
INSTITUTE, FAIRBANKS, ALASKA, HTTP://WWW.AEIC.ALASKA.EDU/.
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Chapter 3
British Columbia
Tsunami Advisory Bulletins

3.1 General

PEP will not usually issue a BC Tsunami Advisory Bulletin when a WC/ATWC Information Message indicates that a tsunami has not been generated.

Provincial Emergency Program staff will extract information contained in WC/ATWC bulletins, correlate it with information from the Regional Tidal Superintendent, and disseminate it to selected agencies and the general public in the form of **BC Tsunami Advisory Bulletins**. The first bulletin should be issued as quickly as possible, to be followed by sequentially numbered supplementary bulletins (not less frequently than hourly) as further information is received.

3.2 Content of Initial BC Tsunami Advisory Bulletin

PEP will issue a BC Tsunami Advisory Bulletin when a WC/ATWC Advisory Message indicates that a tsunami may have been generated outside their Area of Responsibility, if there is a possibility of damage in BC.

If possible, the initial bulletin should contain the following information:

- brief description of the event;
- whether or not it is known that a tsunami has been generated;
- the part(s) of the BC coastline placed in warning status;
- the part(s) of the BC coastline placed in watch status;
- actions to be taken in areas placed in warning status;
- actions to be taken in areas placed in watch status;
- estimated time of arrival and height of the first wave; and
- special instructions.

3.3 How Coastal Areas are Described in Bulletins

Although WC/ATWC bulletins received by PEP will refer to BC coastal areas in terms of "breakpoints" as described in Appendix B, it is unlikely that breakpoints such as Cape Flattery or Langara will be meaningful to the general public without reference to a map. The areas defined by breakpoints will therefore be converted by

PEP into terms that will be more easily understood.

The following descriptions will, therefore, be used when referring to BC coastal areas in tsunami advisory bulletins:

The Entire BC Coastline: When the entire coastline from the Cape Flattery, Washington breakpoint north to the Sitka, Alaska breakpoint has been placed in either warning or watch status, the area will be described as "The Queen Charlotte Islands and the coastline from Port Renfrew on Vancouver Island north to Stewart on the Alaska border."

Coastal areas bordered by the Strait of Juan de Fuca and the Georgia Strait will not be included in advisory bulletins. These areas will be affected by local tsunamis only, and in such circumstances there will be insufficient time to prepare bulletins.

Coastline from the Sitka, Alaska Breakpoint to the Langara Island, BC Breakpoint: This area will be described as "The coastline from Prince Rupert north to Stewart on the Alaska border."

Coastline between the Langara Island, BC Breakpoint and the Northern Tip of Vancouver Island Breakpoint: This area will be described as "The Queen Charlotte Islands and the mainland coast from Queen Charlotte Strait north to Prince Rupert."

Coastline between the Cape Flattery, Washington Breakpoint and the Northern Tip of Vancouver Island Breakpoint: This area will be described as "The West Coast of Vancouver Island from Port Renfrew north, and the coastal areas bordering Queen Charlotte Strait and Johnstone Strait."

3.4 Types of Bulletins and their Purpose

The British Columbia Provincial Emergency Program may issue any one, a combination of, or all of the following Tsunami Advisory Bulletins, described and illustrated in the following pages:

- **Tsunami Warning**
- **Tsunami Watch**
- **Tsunami Information**
- **Tsunami Cancellation**
- **Tsunami All Clear**

A **Tsunami Warning Bulletin** is issued upon receipt of evidence that a tsunami exists; or when a significant earthquake has occurred that may have caused a tsunami, and the travel time from the epicentre to any portion of the BC coast is three hours or less. The purpose is to cause recipients to activate their local plans, such as when evacuation of low-lying areas should be considered.

TSUNAMI WARNING

THIS IS A BC TSUNAMI ADVISORY BULLETIN
FROM THE BRITISH COLUMBIA PROVINCIAL EMERGENCY PROGRAM

BC BULLETIN NUMBER _____

A. AN EARTHQUAKE OF MAGNITUDE _____ OCCURRED AT _____ HOURS BC TIME IN THE PACIFIC OCEAN _____. THIS HAS CAUSED TSUNAMI WAVES THAT WILL IMPACT THE BC COAST.

B. THE FIRST WAVE IS EXPECTED TO REACH __ _____ AT APPROXIMATELY ____ LOCAL TIME, _____ AT APPROXIMATELY ___ LOCAL TIME, AND _____ AT APPROXIMATELY ___ LOCAL TIME. HEIGHT OF THE INITIAL WAVE IS ESTIMATED TO BE ____ METRES OR _____FEET.

C. THE FOLLOWING AREA(S) IS/ARE PLACED IN A **WARNING** STATUS
(delete non-applicable sub-paragraphs):

1. THE QUEEN CHARLOTTE ISLANDS AND THE WEST COAST OF VANCOUVER ISLAND FROM PORT RENFREW NORTH TO STEWART ON THE ALASKA BORDER.

2. THE COASTLINE FROM PRINCE RUPERT NORTH TO STEWART ON THE ALASKA BORDER.

3. THE QUEEN CHARLOTTE ISLANDS AND THE MAINLAND COAST FROM QUEEN CHARLOTTE STRAIT NORTH TO PRINCE RUPERT.

4. THE WEST COAST OF VANCOUVER ISLAND FROM PORT RENFREW NORTH, AND THE COASTAL AREAS BORDERING QUEEN CHARLOTTE STRAIT AND JOHNSTONE STRAIT.

5. REMAINDER OF BC COAST IS IN A **WATCH** STATUS.

D. PEOPLE WHO ARE WITHIN 15 METRES OR 50 FEET OF SEA LEVEL SHOULD MOVE IMMEDIATELY TO HIGHER GROUND.

E. VESSELS SHOULD MOVE IMMEDIATELY TO DEEP WATER. FLOAT AIRCRAFT SHOULD BECOME AIRBORNE OR MOVE TO A SAFE HAVEN.

F. STAY TUNED TO YOUR LOCAL RADIO STATION. DO NOT CALL THE POLICE OR OTHER EMERGENCY SERVICES UNLESS TO REPORT AN EMERGENCY. FURTHER REPORTS WILL FOLLOW.

G. ISSUED AT _____ PST/PDT _____
DATE

A **Tsunami Watch Bulletin** is issued when seismic information indicates that an earthquake has occurred which is capable of causing a tsunami, and the tsunami travel time to any portion of the BC coast is more than three hours. The purpose is to cause emergency personnel to be on standby.

TSUNAMI WATCH

THIS IS A BC TSUNAMI ADVISORY BULLETIN
FROM THE BRITISH COLUMBIA PROVINCIAL EMERGENCY PROGRAM

BC BULLETIN NUMBER _____

A. AN EARTHQUAKE OF MAGNITUDE _____ OCCURRED AT _____ HOURS BC TIME IN THE PACIFIC OCEAN _____. THIS HAS CAUSED TSUNAMI WAVES THAT WILL IMPACT THE BC COAST.

B. THE FIRST WAVE IS EXPECTED TO REACH __ _____ AT APPROXIMATELY ____ LOCAL TIME, _____ AT APPROXIMATELY ___ LOCAL TIME, AND _____ AT APPROXIMATELY ___ LOCAL TIME. HEIGHT OF THE INITIAL WAVE IS ESTIMATED TO BE ____ METRES OR _____FEET.

C. THE FOLLOWING AREA(S) IS/ARE PLACED IN A **WATCH** STATUS
(delete non-applicable sub-paragraphs):

1. THE QUEEN CHARLOTTE ISLANDS AND THE WEST COAST OF VANCOUVER ISLAND FROM PORT RENFREW NORTH TO STEWART ON THE ALASKA BORDER.

2. THE COASTLINE FROM PRINCE RUPERT NORTH TO STEWART ON THE ALASKA BORDER.

3. THE QUEEN CHARLOTTE ISLANDS AND THE MAINLAND COAST FROM QUEEN CHARLOTTE STRAIT NORTH TO PRINCE RUPERT.

4. THE WEST COAST OF VANCOUVER ISLAND FROM PORT RENFREW NORTH, AND THE COASTAL AREAS BORDERING QUEEN CHARLOTTE STRAIT AND JOHNSTONE STRAIT.

D. NO IMMEDIATE ACTION IS REQUIRED UNLESS YOUR AREA IS UPGRADED TO WARNING STATUS.

E. STAY TUNED TO YOUR LOCAL RADIO STATION. DO NOT CALL THE POLICE OR OTHER EMERGENCY SERVICES UNLESS TO REPORT AN EMERGENCY. FURTHER REPORTS WILL FOLLOW.

F. ISSUED AT _____ PST/PDT _____
DATE

A **Tsunami Information Bulletin** *may* be issued to advise the particulars of the occurrence of a major earthquake, with the evaluation that a damaging tsunami that could affect BC was not generated.

This type of bulletin is likely to be issued only in unusual circumstances, such as when there has been a tsunami elsewhere in the Pacific and erroneous information about BC vulnerability may have been circulated (or misconstrued) by the media and general public.

TSUNAMI INFORMATION

THIS IS A BC TSUNAMI ADVISORY BULLETIN
FROM THE BRITISH COLUMBIA PROVINCIAL EMERGENCY PROGRAM

BC BULLETIN NUMBER _____

A. THIS IS A TSUNAMI INFORMATION MESSAGE. NO ACTION IS REQUIRED. THE WEST COAST/ALASKA TSUNAMI WARNING CENTRE HAS ISSUED AN INFORMATION BULLETIN ADVISING THAT AN EARTHQUAKE , PRELIMINARY MAGNITUDE _____ , OCCURRED AT _____ HOURS BC TIME, ON _____ (DATE).

B. THE EARTHQUAKE WAS LOCATED AT _____ (REFERENCE POINT), AT _____ LAT _____ LONG, _____- KILOMETRES DEEP.

C. EVALUATION (SELECT ONE OF THE FOLLOWING OPTIONS):

(THE MAGNITUDE IS SUCH THAT A TSUNAMI WILL NOT BE GENERATED. THIS WILL BE THE ONLY BULLETIN ISSUED. THE LOCATION AND MAGNITUDE ARE BASED ON PRELIMINARY INFORMATION.)

OR

(AN INVESTIGATION IS UNDERWAY TO DETERMINE IF A TSUNAMI HAS BEEN GENERATED. ADDITIONAL BULLETINS WILL BE ISSUED HOURLY (OR MORE FREQUENTLY) AS INFORMATION BECOMES AVAILABLE. STAY TUNED TO YOUR LOCAL RADIO STATION. DO NOT CALL THE POLICE OR OTHER EMERGENCY SERVICES UNLESS TO REPORT AN EMERGENCY.

D. ISSUED AT _____ PST/PDT _____
DATE

Approved by:_____

A **Tsunami Cancellation Bulletin** is issued to cancel all previously-issued tsunami advisory bulletins, and when it has been determined that the threat has ended. The circumstances may be such that a wave exists (but has been observed to be too small to be damaging), or if previous bulletins were based on erroneous information.

When this bulletin is issued it will be the last bulletin that PEP will issue and it will so state in the bulletin text.

TSUNAMI CANCELLATION

THIS IS A BC TSUNAMI ADVISORY BULLETIN
FROM THE BRITISH COLUMBIA PROVINCIAL EMERGENCY PROGRAM

BC BULLETIN NUMBER _____

A. CANCEL ALL PREVIOUSLY ISSUED TSUNAMI ADVISORY BULLETINS.

B. NO AREA OF THE BC COASTLINE WILL BE AFFECTED.

C. THIS WILL BE THE LAST BULLETIN ISSUED.

D. ISSUED AT _____ PST/PDT _____
DATE

Approved by:_____

A **Tsunami All Clear Bulletin** is issued when the tsunami threat is over and no further waves are expected. Local authorities and other agencies may issue their own "all clear" in accordance with the instructions in the BC Advisory.

When this bulletin is issued it will be the last bulletin issued by PEP.

TSUNAMI ALL CLEAR

THIS IS A BC TSUNAMI ADVISORY BULLETIN
FROM THE BRITISH COLUMBIA PROVINCIAL EMERGENCY PROGRAM

BC BULLETIN NUMBER _____

A. THE TSUNAMI THREAT IS ENDED AND NO FURTHER WAVES ARE EXPECTED.

B. LOCAL AUTHORITIES MAY DECLARE. AN "ALL CLEAR" AT THEIR OWN DISCRETION IF NO DAMAGING WAVES HAVE MATERIALIZED TWO HOURS AFTER THE EXPECTED TIME OF WAVE ARRIVAL, OR TWO HOURS HAVE PASSED SINCE THE LAST WAVE OCCURRED.

C. THIS WILL BE THE LAST BULLETIN ISSUED.

D. ISSUED AT _____ PST/PDT _____
DATE

Approved by:_____

Appendix A
Characteristics of Tsunamis and the Threat to British Columbia

A.1 Tsunamis and their Causes

At present there is no method to determine if a tsunami has been generated by an earthquake except to note the magnitude and location of the epicentre; and then detect the arrival of characteristic tsunami waves at a network of tidal stations, and buoys in the open ocean which respond by a satellite link.

A tsunami is a series of ocean waves generated by the sudden displacement of large volumes of water by thrust-type submarine earthquakes, submarine volcanic eruptions, slumps, meteor impact, or coastal landslides. Shallow-focus submarine earthquakes are by far the most frequent cause of tsunamis, but not all major coastal or near-coastal earthquakes produce tsunamis.

Tsunamis can be categorized as local, regional or Pacific-wide, depending upon the size of the area affected.

Pacific-wide tsunamis are infrequent but are of great destructive potential because the initial waves are large and they impact upon many coastal areas. For example, a tsunami on May 22, 1960, spread death and destruction across the Pacific Ocean from Chile to Hawaii, Japan and the Philippines.

Regional tsunamis are by far the most common. The areas affected are smaller than those of Pacific-wide tsunamis, either because the energy released is of insufficient magnitude to generate a Pacific-wide tsunami or because the geographical configuration of the region inhibits the tsunami's spread. An example of a regional tsunami is one that originated off the Philippines on August 16, 1976, in which approximately 8,000 people were killed.

Local tsunamis are often brought about by submarine or coastal landslides and volcanic explosions. An example is the tsunami of July 9, 1958, at Lituya Bay, Alaska, where wave run-up exceeded 525 metres but the destruction was confined to a very limited area.

A.2 Characteristics of Tsunamis

Tsunamis travel outward in all directions from the source area. Their speed depends on the depth of water, so that waves undergo accelerations or decelerations in passing over an ocean bottom of varying depth. In the deep and open ocean they can reach speeds of 800 kilometres per hour with the distance between successive crests as much as 650 kilometres. The height of the waves may range from 30 to 60 centimetres, producing only a gentle rise and fall of the sea surface, unnoticed by ships or aircraft.

As a wave enters the shoaling waters of a coastline, its speed diminishes, its wave length decreases, and its height increases greatly due to the piling up of water. The configuration of the coastline, shape of the ocean floor and the characteristics of the advancing waves play an important role in the destruction caused. A wave may be of negligible size at one point on a coast and of much larger size at other points. Sounds and inlets may cause funnelling effects that magnify the initial wave and then, through resonance, subsequent waves.

The first visible indication of an approaching tsunami may be a recession of water caused by the trough preceding the advancing wave. Conversely, a rise in water level may be the first event. Under certain conditions the crest of an advancing wave may overtake the preceding trough while some distance offshore, causing the wave to proceed shoreward as a bore — a wave with a churning front.

The force and destructive effects of tsunamis should not be underestimated. At some locations the advancing turbulent front will be the most destructive part of the wave. In other situations, the greatest damage will be caused by the outflow of water back to the sea between crests, sweeping all before it and undermining roads, buildings and other works or infrastructure. Ships, unless moved away from shore, may be dashed against breakwaters, wharves and other craft, or be washed ashore and left grounded after the withdrawal of the seawater.

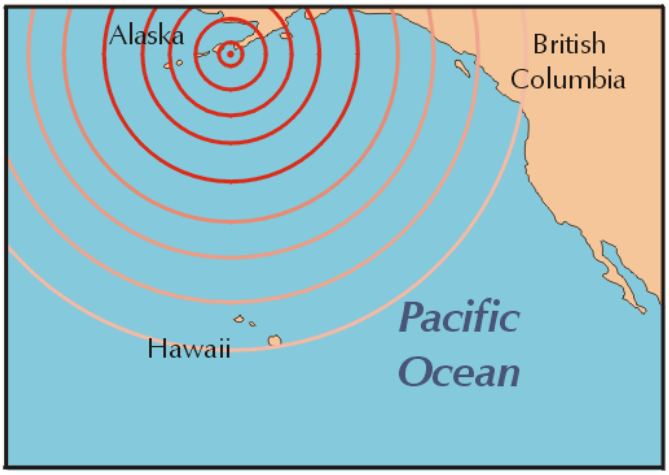
A.3 The Threat to British Columbia

The areas most vulnerable to distant tsunamis are the inlet systems along the west coasts of Vancouver Island and the Queen Charlotte Islands, and the mainland coast between the southern tip of the Queen Charlotte Islands and the northern tip of Vancouver Island.

Pacific-wide Tsunamis: The effects on the BC coast of a Pacific-wide tsunami (one which does not originate along the coasts of Alaska, British Columbia, Washington, Oregon or California) may be negligible or severe depending upon the magnitude of the tsunami, its source distance, and direction of approach.

The time required for a Pacific-wide tsunami to reach the BC coast will vary between approximately 5½ to 18 hours, depending upon its place of origin.

Regional Tsunamis: In the Tsunami Warning System, BC is part of a region extending from the western tip of the Aleutian Islands to the southern tip of California. Because of the vast coastal area encompassed by this region, tsunamis generated within it may impact quite differently at different locations. In some instances the effects will be experienced only locally.



Because of the direction of wave travel and the large earthquakes which generate the waves, the principal source area for regional tsunamis affecting BC is Alaska, including the Aleutian Islands. A well-documented event is the tsunami generated in Prince William Sound, Alaska on March 27, 1964, which caused 107 deaths in Alaska and more than $84 million in damage. Destruction outside Alaska caused a further 15 deaths and $21 million property damage, including $5 million at Port Alberni where the maximum wave height was measured at 4.1 metres.

The time for a tsunami generated in the Alexander Archipelago of Alaska to reach the northern part of the BC coast might be less than one hour. From the western

tip of the Aleutians, the time to reach the northern BC coast would be under five hours.

Local Tsunamis: Local (relatively small) tsunamis may result from earthquakes occurring off the BC coast or in inner waters such as Juan de Fuca Strait, the Strait of Georgia, or Puget Sound.

The potential also exists for a local tsunami to be so large that it becomes a Pacific-wide tsunami (a matter of concern for other nations) and one that introduces the problem of minimal warning time before it reaches land in British Columbia. The greatest damage to BC coastal areas would result from a large subduction earthquake in the northern portion of the Cascadia subduction zone that extends approximately 100 kilometres seaward of the outer coast.

The areas most affected would be along the west coast of Vancouver Island because of their proximity to the source. Wave heights up to nine metres could occur (based on worst-case estimates), with the first arrivals in one-half hour or less. The Strait of Georgia, although sheltered by Vancouver Island, would be impacted, especially at its northern end (Johnstone Strait) where wave heights could approach seven metres. Around the Vancouver area, wave heights would be only about one metre, but if wave arrivals were to coincide with a high tide there would be flooding in low-lying areas.

Local tsunamis may also be caused by submarine slides in areas such as the Strait of Georgia, or as occurred in April 1975 in Kitimat Inlet. These could occur independently or in association with an earthquake.

Little can be done to warn of local tsunamis because their travel time is so short. Persons living in coastal areas must assume that a tsunami may have been generated if a large earthquake has occurred off the coast or in inner waters, and react accordingly.

A.4 British Columbia Tsunami Damage Pictures

These photographs were taken on March 27-28, 1964, following the tsunami at Port Alberni, BC. Residents received enough warning to allow a speedy middle-of-the-night evacuation, and there were no fatalities.

Appendix B
The Tsunami Warning System in the Pacific

B.1 General

Following an extremely destructive tsunami which struck Hawaii in 1946, a Tsunami Warning System for the Pacific was established, with international agreement and protocols developed by the Intergovernmental Oceanographic Commission (IOC) of the United Nations. The Pacific Tsunami Warning Center (PTWC) was established at Ewa Beach, Hawaii, and still operates.

The Pacific Tsunami Warning System includes most of the nations bordering the Pacific Ocean. Together they operate a number of seismic, tidal, communications, and dissemination facilities to:

- detect and locate major earthquakes occurring in the Pacific Basin;
- determine whether or not tsunamis have been generated; and
- provide timely and effective information and warnings to minimize tsunami effects.

Management of the Pacific Tsunami Warning System is the responsibility of the US Department of Commerce, National Oceanic and Atmospheric Administration (NOAA) which funds about 75 per cent of the detection and reporting equipment and the personnel to operate them.

The Canadian Hydrographic Service, Fisheries and Oceans Canada, operates the tidal gauges in BC which detect actual wave arrivals.

The BC Provincial Emergency Program operates the equipment necessary to receive warnings applicable to British Columbia, and develops procedures to give people the warning they need to survive a tsunami that originates far from our shores.

B.2 The Pacific Tsunami Warning Centre (PTWC)

The PTWC, Ewa Beach, Hawaii, is the operational centre for the Tsunami Warning System in the Pacific. It collects and evaluates information provided by participating countries and issues bulletins regarding the occurrence of major earthquakes and possible or confirmed tsunamis.

Earthquake information is provided to the PTWC from a number of seismic stations throughout the Pacific. Tsunami information is provided from tidal stations that register the characteristic signature of tsunami waves and their heights. Seismic information is received almost instantly, but tsunami information is slower because it depends upon the arrival of tsunami waves at the tidal stations.

Tsunami warnings issued by the PTWC are in the form of Warning Bulletins or Warning/Watch Bulletins, which are issued on the basis of seismic information only. When an earthquake of sufficient magnitude has occurred in a tsunamigenic area, a Warning/Watch Bulletin is issued without waiting for confirmatory data from tidal stations.

Currently, the Pacific Tsunami Warning Centre will be the sole provider of Tsunami Information Bulletins and Tsunami Warning/Watch Bulletins for the Pacific Basin **other than for Alaska, British Columbia, Washington, Oregon and California.**

B.3 The West Coast/Alaska Tsunami Warning Centre (WC/ATWC)

When the tsunami associated with the great Alaskan earthquake of 1964 happened, PTWC was able to pass warning to the West Coast of North America in time to allow evasive action in areas such as Port Alberni, BC, which received significant wave damage. Excellent colour photographs of that damage can be seen on the PEP website.

However, recognizing that Alaskan communities would have benefited from faster warning in that local event, a second warning centre was established at Palmer, Alaska… the Alaska Tsunami Warning Center (ATWC). In 1982 the ATWC's area of responsibility was changed

to include the west coast of North America down as far as California, and thus including all of British Columbia's coast. ATWC became a regional warning centre, and its relationship with the parent PTWC is "transparent" to British Columbia.

Redesignated the West Coast/Alaska Tsunami Warning Center (WC/ATWC), the organizational objective is to detect and locate major earthquakes in the Alaskan region and the West Coast of Canada and the United States. WC/ATWC, regardless of the location of an earthquake, will be the sole provider of Tsunami Information, and Tsunami Watch/Warning and Cancellation Bulletins for the area of Alaska, British Columbia, Washington, Oregon and California.

The system has remote seismic stations and tide gauge stations in Alaska, and seismic stations and tide gauges along the West Coast of Canada and the United States, including tide gauges at Bamfield, Winter Habour and Langara Island, and a number of seismological stations in Western Canada operated by the Geological Survey of Canada's Pacific Geoscience Centre in Sidney, BC.

Additional technical details about the warning system based on WC/ATWC, and all earthquake/tsunami messages processed by the WC/ATWC may be found on the center's website at http://wcatwc.gov/.

When a significant earthquake occurs in any tsunamigenic area between Kamchatka, Russia and the southern tip of California, the WC/ATWC will immediately issue a Warning/Watch Bulletin placing certain portions of the coast in warning status and others in watch status. The threshold magnitude for the issuance of bulletins varies from area to area, and has been refined over time. The length of coastline warned will vary with the magnitude and location of the particular earthquake.

B.4 Warning Area Breakpoints

To assist in identifying areas of the coastline placed in warning or watch status a number of geographical "breakpoints" have been established from Attu, Alaska south to the California–Mexico border as follows:

Attu, AK
Adak, AK
Nikolski, AK
Unalaska, AK
Sand Point, AK
Kodiak, AK
Seward, AK
Cordova, AK
Yakutat, AK
Sitka, AK
Langara Island, BC
Northern Tip Vancouver Island, BC
Cape Flattery, WA
Point Grenville, WA
Clatsop Spit, OR
Cascade Head, OR
Cape Blanco, OR
Oregon–California Border
Cape Mendocino, CA
Point Arena, CA
Point Sur, CA
Point Conception, CA
California–Mexico Border

Breakpoints will be referred to in WC/ATWC Tsunami Warning/Watch Bulletins to clarify the areas being placed in warning status or watch status, e.g., "A Tsunami Warning is issued for the area from Sand Point, AK, along the south coast of Alaska to Langara Island, BC. A Tsunami Watch is issued for the area from Nikolski, AK, to Sand Point, AK, and for the area along the British Columbia coast from Langara Island, BC, and the Washington coast to Point Grenville, WA." or "A Tsunami Warning is issued for the area from Langara Island, BC, south along the Washington coast to Point Grenville, WA."

The coastline between two breakpoints will be placed either in warning or watch status but never both.

B.5 Dissemination Agencies

In order to limit the number of agencies to be contacted, Tsunami Warning/Watch and Warning Bulletins are usually issued to only one agency per country, territory, or administrative area.

The Provincial Emergency Program (PEP) has been designated the British Columbia Dissemination Agency

for tsunami bulletins issued by the warning centres and is referred to as such in the National Oceanic and Atmospheric Administration's *Communication Plan for the Tsunami Warning System*.

PEP has the responsibility for evaluating tsunami information received from the warning centres and deciding on the appropriate action to be taken in respect to British Columbia's coastal areas.

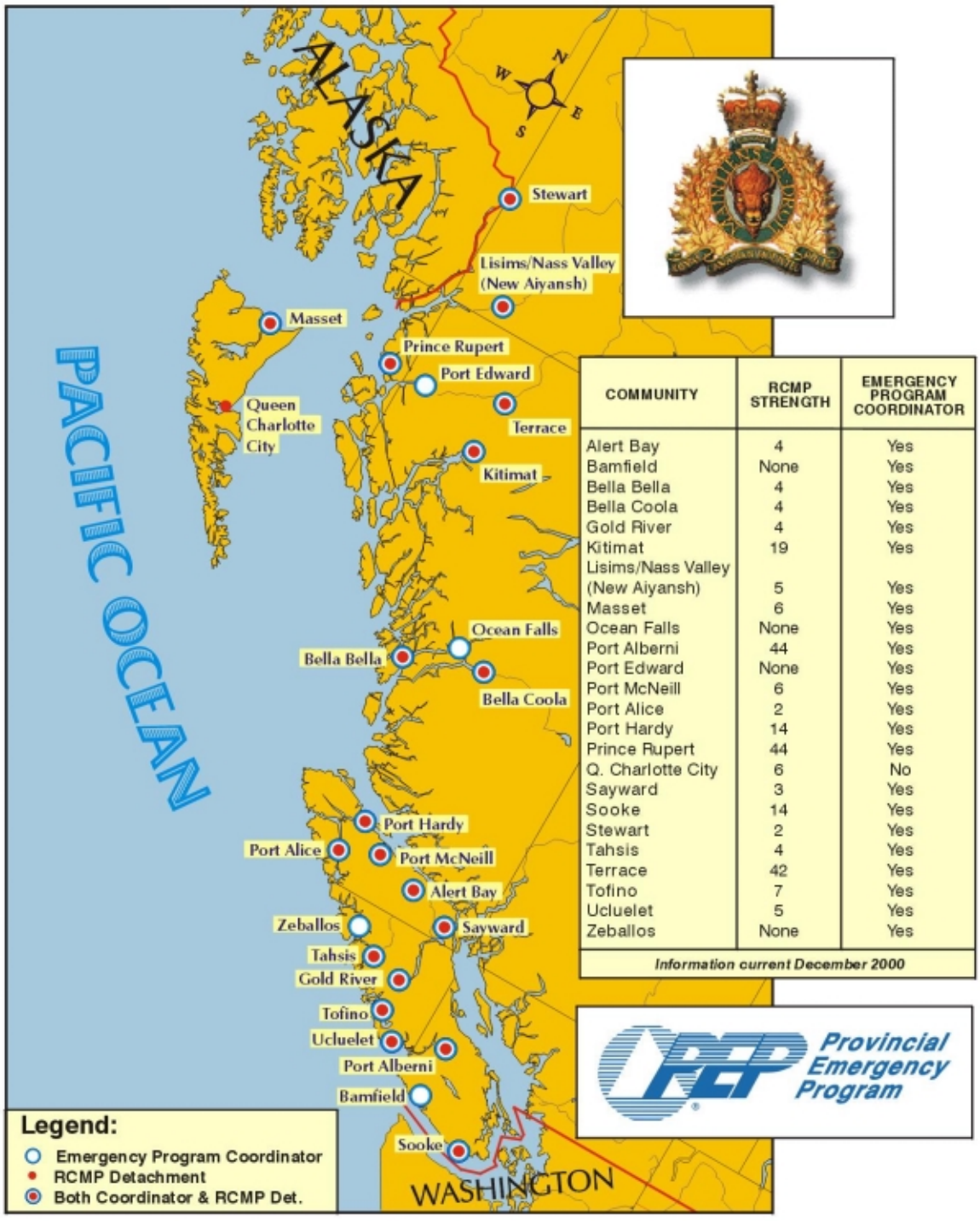
Appendix C
Locations of Coastal Communities at Risk

C.1 Map of Communities at Risk

The map on the following page indicates those communities that could be at serious risk from a regional tsunami. Other, smaller settlements in the same local areas are equally vulnerable.

The map also indicates those communities which host a detachment of the RCMP, and those that have an appointed Emergency Program Coordinator under the requirements of *the British Columbia Emergency Program Act.*

The means of local warning in very remote areas is by marine radio and the broadcast media.



COMMUNITY	RCMP STRENGTH	EMERGENCY PROGRAM COORDINATOR
Alert Bay	4	Yes
Bamfield	None	Yes
Bella Bella	4	Yes
Bella Coola	4	Yes
Gold River	4	Yes
Kitimat	19	Yes
Lisims/Nass Valley (New Aiyansh)	5	Yes
Masset	6	Yes
Ocean Falls	None	Yes
Port Alberni	44	Yes
Port Edward	None	Yes
Port McNeill	6	Yes
Port Alice	2	Yes
Port Hardy	14	Yes
Prince Rupert	44	Yes
Q. Charlotte City	6	No
Sayward	3	Yes
Sooke	14	Yes
Stewart	2	Yes
Tahsis	4	Yes
Terrace	42	Yes
Tofino	7	Yes
Ucluelet	5	Yes
Zeballos	None	Yes

Information current December 2000

Provincial Emergency Program

Coastal Communities at Risk and Local Warning Capabilities

Appendix D
Tsunami Warning Exercises

D.1 General

To ensure that the BC Tsunami Warning System will function adequately in a real emergency, it will be exercised approximately every 8-10 months. Exercise participants will not be required to make any special provisions or preparations.

The Director, Provincial Emergency Program, will always provide written notification of the intent to conduct an exercise. In some instances the day of the exercise will be given, in others only the week. Exercises may take place during or after normal working hours.

Exercise report forms will be mailed to participants along with the letter of notification that an exercise is to be conducted. At the completion of each exercise, participants will fill in a report form showing the times that information was received and actual or simulated actions taken. Consolidated reports will be used to identify shortcomings in the warning system and to make recommendations for improvement.

The completed forms should be mailed to:

Director
Provincial Emergency Program
PO Box 9201 Stn Prov Govt
Victoria, B.C. V8W 9J1

D.2 Exercise Procedures

General: To avoid the possibility of confusing exercise play with a real tsunami, participants must preface telephone calls with the statement:

"This is _____. I am phoning with regard to a tsunami exercise that is underway. I repeat, this pertains to an exercise only and not to a real tsunami."

Tsunami bulletins and other messages used during exercises will begin and end with the words “EXERCISE (CODENAME)”

Commencement: Each exercise will commence with a specially prepared WC/ATWC bulletin being handed to the PEP ECC duty officer. Exercise evaluation staff will record the time of receipt and the subsequent actions taken by the Duty Officer and other ECC personnel.

To ensure that the entire warning system will be exercised, the specially prepared WC/ATWC bulletins will place all BC coastal areas in either warning or watch status.

Exercise Activities: The procedures followed at PEP should follow the internal criteria in force for notification of management, call-out of staff, activation of the response management structure, and initial coordination with the Regional Tidal Superintendent, Canadian Hydrographic Service.

Such matters as the consultation time required to make a decision to issue a BC Tsunami Advisory Bulletin should be consistent with a real tsunami situation. Before warnings are issued, the Tidal Superintendent will ensure that realistic timings are allowed for the gathering of tidal, current, or other information required for decision-making.

The information available to the Regional Tidal Superintendent will be limited to that contained in exercise bulletins. The Tidal Superintendent may assume information that might otherwise normally be available through other reporting systems.

The internal local authority or coordinating agency level activity is not normally exercised unless community officials are in total agreement and are prepared to provide their own evaluation and control personnel.

Appendix E
Tsunami Hazard Mitigation

E.1 General

Tsunamis cannot be prevented, but the risks presented by this serious natural hazard can be reduced and even eliminated. We know that lives can be saved through emergency evacuations if we have adequate warning of the arrival of a tsunami, but experience has shown that we may not have adequate warning, and even if we do not everyone is prepared to react properly.

There are many aspects of preparation to consider: Where do people evacuate to? What is the safe route to get there? Has anybody in authority in the local area at risk ever thought about their responsibilities to educate everybody in their community about tsunamis? Who should give guidance to the local authority on what can or could be done? What about protecting property from tsunamis? How about tourists in the area?

These are all elements in the design of a tsunami risk mitigation program for an area which is considered to be vulnerable to tsunami wave damage. The consequences of failure to do so could include mass fatalities, loss of a community's industry and housing, and even total destruction of poorly-sited communities.

E.2 Responsibilities

Every community is different. Some are isolated. Some are locally governed and administered by a regional district office situated many kilometres away. Some have emergency services while others do not.

No matter where, or no matter what the other circumstances are, the individual has a responsibility to know the risks he/she takes simply by living close to the ocean. Because tsunamis are infrequent natural events, individuals require constant education to substitute for personal experience.

Beyond the individual's responsibility to be personally prepared, it is the responsibility of governments at all levels to be the educators. This entails properly assessing the risk, area by area, and preparing aids to the individual to shorten reaction time after warning of an approaching tsunami.

Governments should also consider restricting development in areas determined to be at great risk, preventing damage to crucial facilities through special construction techniques, and so on.

Finally, technology needs to be exploited to enhance tsunami detection, warning and alerting systems, and communications techniques.

E.3 Mitigation is International in Scope

Just as tsunami warning and alerting is already an international plan and process, the effort to mitigate tsunami risk is being approached using similar techniques in California, Oregon, Washington, Alaska, Hawaii and British Columbia. Components of the mitigation strategy are being tackled by the appropriate government bodies, and the results are being shared amongst the five US states, US federal government agencies, Canadian federal government agencies, and British Columbia.

Today, citizens move freely. Californians may vacation on Vancouver Island beaches, and so on. It makes sense that lessons learned about tsunami preparedness in one state or province should apply when a person is visiting another.

E.4 Components of the Tsunami Mitigation Strategy

Improved Detection of Tsunamis: This component is being addressed at the federal government level. The US National Oceanic and Atmospheric Administration (NOAA) is deploying satellite-linked buoys in the open ocean to detect the small changes in sea state as tsunami waves pass under them. The Canadian Hydrographic Service is installing tidal gauges on the BC coast that can be read remotely in real time to monitor

the arrival of tsunami waves on land. Seismic sensors are being tied together regionally, irrespective of their ownership, to provide a greater degree of accuracy in the detection of earthquakes that could be accompanied by tsunamis.

Tsunami Models and Mapping: Scientists are using past tsunami experience to create tsunami "models" which will provide a greater ability to predict those areas at more serious risk, and to determine wave heights which could be expected based on local coastal conditions. Mapping of developed coastal areas then needs to be carried out to depict areas of expected tsunami flooding.

Internationally accepted sign advising that an area is at risk of flooding in the event of a tsunami.

Local Preparedness Planning: Models and mapping are used to determine safe evacuation routes, site shelters, and critical facilities which should be considered for relocation over time. Land use planners could restrict development to appropriate use for vulnerable areas, acknowledging of course that some industrial activities must be located at sea level and be at risk. Acceptance of risk in such cases should be accompanied by enhanced protection measures. Buildings and other structures such as bridges that "must" sit in a potential tsunami inundation area should be specially strengthened.

Local Warning and Alerting: Traditional methods of local alerting of populations such as sirens are still effective. Other methods, some of which use high technology systems, may prove to be better. At the time of writing, only one BC community uses a siren for mass warning.

Internationally accepted sign identifying a recommended evacuation route.

Local response tactics: Short of evacuation to higher ground, there has been no concerted development of the tactics needed to respond to a tsunami by local emergency responders.

Public Awareness and Education: An educational curriculum of tsunami education for school children should be developed. Materials that help to understand tsunamis need to be developed for use by local planners, emergency management personnel, and elected officials. Informational aids to keep the public ever-aware of the tsunami hazard need to be developed and distributed by a wide variety of government agencies and service organizations. On Vancouver Island's west coast, the tourism industry brings in many thousands of transient visitors (not all of whom speak English) who will likely be vulnerable while in the area and should know what to do if a tsunami ocurs.

Appendix F
Glossary of Abbreviations

F.1 Organizations

Although organizational abbreviations are generally spelled out the first time they are used in this plan, the following listing is provided for reference. Some of these abbreviations, not used in the plan as such, may be found in tsunami bulletins.

AOR	Area of Responsibility (of the WC/ATWC)
ATWC	Obsolete name; see **WC/ATWC**
CCG	Canada Coast Guard, Canada Department of Fisheries and Oceans
CHS	Canadian Hydrographic Service, Canada Department of Fisheries and Oceans
EPC	Emergency Preparedness Canada
GSC	Geological Survey of Canada, Canada Department of Natural Resources
IOC	Intergovernmental Oceanographic Commission (United Nations)
IOS	Institute of Ocean Sciences, Canada Department of Fisheries and Oceans
ITIC	International Tsunami Information Center, Honolulu, HI
MCTS	Marine Communications and Traffic Services Centre, Canada Coast Guard, Canada Department of Fisheries and Oceans
MARPAC	Maritime Forces (Pacific), Canadian Forces, Department of National Defence
NAVCAN	Navigation Canada (air traffic control organization)
NOAA	National Oceanic and Atmospheric Administration, United States Department of Commerce
NWS	National Weather Service, a function of NOAA
PEP	(British Columbia) Provincial Emergency Program
PGC	Pacific Geoscience Centre, Sidney, BC, Geological Survey of Canada, Canada Department of Natural Resources
PTWC	Pacific Tsunami Warning Center
RCC	Rescue Coordination Centre
RCMP	Royal Canadian Mounted Police
TWS	Tsunami Warning System (for the Pacific)
WC/ATWC	West Coast/Alaska Tsunami Warning Center

F.2 Other Abbreviations

State, provincial and national abbreviations follow international postal and North Atlantic Treaty Organization convention and are used without periods.

AK	Alaska, USA
BC	British Columbia, Canada
CA	California, USA
CDA	Canada
HI	Hawaii, USA
US, USA	United States (of America)
OR	Oregon, USA
UN	United Nations
WA	Washington, USA

Time zones used in British Columbia, as well as others used in tsunami bulletins, are often abbreviated.

GMT	Greenich Mean Time (also called Coordinated Universal Time in USA)
UTC	Coordinated Universal Time
Time + Z	Abbreviated form of expressing GMT/UTC. Other time zone abbreviations exist but should not be used (for clarity).
PDT	Pacific Daylight Saving Time (coastal BC time in summer)
PST	Pacific Standard Time (coastal BC time in winter)
ADT	Alaska Daylight Saving Time (as for BC)
AST	Alaska Standard Time (as for BC)

Appendix G
Glossary of Tsunami Terminology

G.1 Tsunami Classification

near-field or local tsunami: A tsunami from a nearby source, generally less than 200 kilometres away.

regional tsunami: A tsunami capable of destruction in a particular geographic region, generally within about 1,000 kilometres of its source. Regional tsunamis also occasionally have very limited and localized effects outside the region.

distant tsunami: A tsunami originating from a distant source, generally more than 1,000 kilometres away.

Pacific-wide tsunami: A tsunami capable of widespread destruction, not only in the immediate region of its generation, but across the entire Pacific Ocean.

tsunami earthquake: An earthquake that produces an unusually large tsunami relative to the earthquake magnitude. Tsunami earthquakes are characterized by a very shallow focus, fault dislocations greater than several metres, and fault surfaces smaller than for normal earthquakes. They are also slow earthquakes, with slippage along their faults occurring more slowly than would occur in normal earthquakes.

G.2 Surveys and Measurements

inundation area: Area flooded with water by the tsunami.

horizontal inundation: Distance between the inundation line and the shore, measured perpendicularly to the shore.

maximum inundation: Maximum horizontal penetration of the tsunami from the shoreline. A maximum inundation is measured for each different coast or harbor affected by the tsunami.

inundation line: Inland limit of wetting, measured horizontally from the mean sea level (MSL) line. In tsunami science, the landward limit of tsunami run-up.

leading wave: First arriving wave of a tsunami. In some cases, the leading wave produces an initial depression or drop in water level, and in some cases an elevation or rise in water level.

mean height: Average height of a tsunami measured from the lowest trough to the greatest height after subtracting the change in tidal level variation.

run-up: 1. Difference between the elevation of maximum tsunami penetration (inundation line) and the elevation of the shoreline at the time of the tsunami attack, corrected for the difference in shoreline elevation between the time of measurement and the time of tsunami attack. **2.** Elevation reached by seawater measured relative to some stated

datum such as mean sea level, mean low water, sea level at the time of the tsunami attack, etc., and measured ideally at a point that is a local maximum of the horizontal inundation. **3.** In practical terms, run-up is only measured where there is a clear evidence of the inundation limit on the shore.

run-up distribution: Set of tsunami run-up values measured or observed along a coastline.

maximum run-up: Difference between the elevation of the maximum tsunami penetration and the elevation of the shoreline at the time of the tsunami attack, corrected for the difference in shoreline elevation between the time of measurement and the time of tsunami attack.

tsunami amplitude: Usually measured on a water level record, it is: **1.** The absolute value of either the difference between a particular peak or trough of the tsunami and the undisturbed water level at the time. **2.** Half the difference between the adjacent peak and trough, corrected for the change of tide between that peak and trough. It is intended to represent the true amplitude of the tsunami wave at some point in the ocean. However, it is often an amplitude modified in some way by the response of the tide gauge.

maximum tsunami amplitude: Usually measured on a water level record, it is half the value of the maximum peak-to-trough excursion, corrected for the change of tide between that peak and trough.

tsunami period: Amount of time that a tsunami wave takes to complete a cycle. Tsunami periods typically range from five minutes to two hours.

dominant tsunami period: Difference between the arrival time of the highest peak and the next one measured on a water level record.

maximum water level: Difference between the elevation of the highest local water mark and the elevation of the shoreline at the time of the tsunami attack.

G.3 Tide, Mareograph, Sea Level

breaker: A sea-surface wave that has become so steep (wave steepness of 1/7) that the crest outraces the body of the wave and it collapses into a turbulent mass on shore or over a reef. Breaking usually occurs when the water depth is less than 1.28 times the wave height. Roughly, three kinds of breakers can be distinguished, depending primarily on the gradient of the bottom: (a) spilling breakers (over nearly flat bottom) which form a foamy patch at the crest and break gradually over a considerable distance; (b) plunging breakers (over fairly steep bottom gradient) which peak up, curl over with a tremendous overhanging mass and then break with a crash; (c) surging breakers (over very steep bottom gradients) which do not spill or plunge but surge up the beach face. Waves also break in deep water if they build too high while being generated by the wind, but these are usually short-crested and are termed whitecaps.

breakwater: An offshore structure such as a wall that is used to protect a harbour or beach from the force of waves.

low water: The lowest water level reached during a tide cycle. The accepted popular term is low tide.

mareogram or marigram: 1. Record made by a marigraph. **2.** Any graphic representation of the rise and fall of the tide, with time as abscissa, and height as ordinate.

mareograph or marigraph: A recording tide gauge.

sea level: 1. The height of the sea averaged over a long time compared to tidal fluctuations. Sea level can change over the years. **2.** The level of the surface of the sea, especially its position midway between mean high and low water.

mean sea level: The average height of the sea surface, based upon hourly observation of tide height on the open coast or in adjacent waters which have free access to the sea. These observations are to have been made over a considerable number of years. Along with mean high water, mean low water, and mean lower low water, mean sea level is a type of tidal datum.

tidal wave: 1. The wave motion of the tides. **2.** In popular usage, any unusually high and therefore destructive water level along a shore. It usually refers to either a storm surge or tsunami.

cotidal: Indicating equality in the tides or a coincidence with the time of high or low tide.

tide: The rhythmic, alternate rise and fall of the surface (or water level) of the ocean, and of bodies of water connected with the ocean such as estuaries and gulfs, occurring twice a day and resulting from the gravitational attraction of the moon (and, in lesser degrees, of the sun) acting unequally on different parts of the rotating earth.

tide amplitude: One-half of the difference in height between consecutive high water and low water; hence, half of the tidal range.

tide gauge: A device for measuring the height (rise and fall) of the tide. Especially, an instrument for automatically making a continuous graphic record of tide height versus time.

tide station: A place where tide observations are obtained.

water elevation: A height which water reaches.

probable maximum water level: A hypothetical water level (exclusive of wave run-up from normal wind-generated waves) that might result from the most severe combination of hydrometeorological, geoseismic and other geophysical factors that is considered reasonably possible in the region involved, with each of these factors considered as affecting the locality in a maximum manner. This level represents the physical response of a body of water to maximum applied phenomena such as hurricanes, moving squall lines, other cyclonic meteorological events, tsunamis, and astronomical tide combined with maximum probable ambient hydrological conditions such as wave level with virtually no risk of being exceeded.

G.4 General Tsunami Terms

tsunami: A series of traveling waves of extremely long length and period, generated by disturbances associated with earthquakes occurring below or near the ocean floor. (Also called seismic sea wave and, popularly, tidal wave.) An ocean wave produced by a submarine earthquake, landslide, or volcanic eruption. These waves may reach enormous dimensions and have sufficient energy to travel across entire oceans. They proceed as ordinary gravity waves with a typical period between five and 60 minutes. Tsunamis steepen and increase in height on approaching shallow water, inundating low-lying areas; and where local submarine topography causes extreme steeping, they may break and cause great damage. Tsunamis have no connection with tides; the popular name is entirely misleading.

air-coupled tsunami: Synonym for atmospheric tsunami.

atmospheric tsunami: Tsunami-like waves generated by a rapidly moving atmospheric pressure front moving over a shallow sea at about the same speed as the waves, allowing them to couple.

estimated time of arrival (ETA): Time of tsunami arrival at some fixed location, as estimated from modeling the speed and refraction of the tsunami waves as they travel from the source.

evacuation map: A drawing or representation that outlines danger zones and designates limits beyond which people must be evacuated to avoid harm from tsunami waves.

hydraulic model: A physical scale model of a basin or a harbour used to simulate effects of wave action or flooding caused by hurricane surge or tsunami wave activity.

hydraulic modeling: Mathematical formulations used in connection with a hydraulic physical model to simulate natural hydrologic phenomena which are considered as processes or as systems.

mechanism of tsunami generation: The theoretical problem of generation of the gravity wave (tsunami) in the layer of elastic liquid (an ocean) occurring on the surface of elastic solid half-space (the crust) in the gravity field. Also, tsunamis can be generated by other different mechanisms such as volcanic or nuclear explosions, landslides, rock falls and submarine slumps.

travel time: Time required for the first tsunami wave to propagate from its source to a given point on a coastline.

travel time map: Map showing isochrons of calculated tsunami travel time from the source outwards toward terminal points on distant coastlines.

tsunami damage: Loss or harm caused by a destructive tsunami. More specifically, the damage caused directly by tsunamis can be summarized into the following: 1) deaths and injuries; 2) houses destroyed, partly destroyed, inundated, flooded, or burned; 3) other property damage and loss; 4) boats washed away, damaged or destroyed; 5) lumber washed away; 6) marine installations destroyed, and; 7) damage to public utilities such as railroads, roads, electric

power plants, water supply installations, etc. Indirect secondary tsunami damage can be: 1) Damage by fire of houses, boats, oil tanks, gas stations, and other facilities; 2) environmental pollution caused by drifting materials, oil, or other substances; 3) outbreak of disease of epidemic proportions which could be serious in densely populated areas.

tsunami detectability: Discovery or determination of the existence, presence, or fact of tsunami.

tsunami dispersion: Scattering of tsunami energy, particularly as a function of its period, as it travels across a body of water.

tsunami effect: The result, consequence, or outcome in the aftermath of a tsunami disaster.

tsunami generation: Tsunamis are generated primarily by tectonic dislocations under the sea which are caused by shallow focus earthquakes along areas of subduction. The upthrusted and downthrusted crustal blocks impart potential energy into the overlying water mass with drastic changes in the sea level over the affected region. The energy imparted into the water mass results in tsunami generation which is energy radiating away from the source region in the form of long period waves.

tsunami hazard: Danger from a tsunami on life and property.

tsunami simulation: Tsunami numerical modeling.

tsunami numerical modeling: Numerical models have been used in recent years to simulate tsunami propagation and interaction with land masses. Such models usually solve similar equations but often employ different numerical techniques and are applied to different segments of the total problem of tsunami propagation from generation regions to distant areas of run-up. For example, several numerical models have been used to simulate the interaction of tsunamis with islands. These models provide reasonable simulations of tsunamis for engineering purposes.

tsunami observation: Notice, observation or measurement of sea level fluctuation at a particular point in time caused by the incidence of a tsunami on a specific point on a coast.

tsunami preparedness or mitigation: Readiness of plans, methods, procedures and actions taken by government officials and the general public for the purpose of minimizing potential risk and mitigating the effects of future tsunamis.

tsunami propagation: Tsunamis travel outward in all directions from the generating area, with the direction of the main energy propagation generally being orthogonal to the direction of the earthquake fracture zone. Their speed depends on the depth of water, so that the waves undergo accelerations and decelerations in passing over an ocean bottom of varying depth. In the deep and open ocean, they travel at speeds of 500 to 1,000 kilometres per hour (300 to 600 miles per hour). The distance between successive crests can be as much as 500

to 650 kilometres (300 to 400 miles). However, in the open ocean, the height of the waves may be no more than 30 to 60 centimetres (1 or 2 feet), and the waves pass unnoticed. Variations in tsunami propagation result when the propagation impulse is stronger in one direction than in others because of the orientation or dimensions of the generating area and where regional topographic features modify both the wave form and rate of advance. Specifically tsunami waves undergo a process of wave refraction throughout their travel, as though they were shallow water waves. Tsunamis are unique in that the waveform extends through the entire water column from sea surface to the ocean bottom. It is this characteristic that accounts for the great amount of energy transmitted by a tsunami.

tsunami risk: Exposure to loss, or injury caused by the tsunami hazard.

tsunami source: Point or area of tsunami origin, usually the site of an earthquake, volcanic eruption, or landslide that has affected the sea floor or a body of water.

tsunamic: Having features analogous to those of a tsunami or descriptive of a tsunami.

tsunamigenic: Having the demonstrated or potential capability to generate a tsunami: a tsunamigenic earthquake, a tsunamigenic landslide.

tsunami zonation (tsunami zoning): Designation of distinctive zones along coastal areas with varying degrees of tsunami risk and vulnerability for the purpose of disaster preparedness, planning, construction codes, or public evacuation.

A.5 Wave Measurement

crest length: The length of a wave along its crest. May be called crest width.

wave crest: 1. The highest part of a wave. **2.** That part of the wave above stillwater level.

drop: The downward change or depression in sea level associated with a tsunami, a tide, or some long term climatic effect.

wave length: The horizontal distance between similar points on two successive waves measured perpendicularly to the crest.

overflow: A flowing over, inundation.

rise: The upward change or elevation in sea level associated with a tsunami, a hurricane, a tide, or some long term climatic effect.

significant (or characteristic) wave height: The average height of the one-third highest waves of a given wave group. Note that the composition of the highest waves depends upon the extent to which the lower waves are considered.

spreading: When reference is made to tsunami waves, it is the scattering and dispersion of the wave energy over a wider geographical area as the waves propagate away from the source region. The reason for this geographical spreading and reduction of wave energy with distance traveled, is the sphericity of the earth. The tsunami energy will begin converging again at a distance of 90 degrees from the source.