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An Assessment of the B.C. Tsunami Warning System and Related Risk Reduction Practices

Tsunamis and Coastal Communities in British Columbia

Canada

Acknowledgments

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Executive Summary

Tsunamis are large wave events generated by large surface impacts or sudden movements of the ocean floor that displace a large volume of water. The displaced water propagating outward from the source becomes a tsunami. Although usually associated with earthquakes, tsunamis can also be triggered by many other types of phenomena, including submarine or terrestrial landslides, submarine and terrestrial volcanic eruptions, explosions and even bolide (e.g. asteroid, meteor, comet) impacts.

Tsunamis have been responsible for enormous damage and loss of life in many coastal regions around the world. However, tsunamis are particularly threatening around the continental edges of the Pacific Ocean due to a greater frequency of large destructive earthquakes. The west coast of Canada is particularly vulnerable to earthquake-induced tsunamis due to the presence of both nearby and distant subduction source zones at the margin of the Pacific basin.

The threat of tsunami along the west coast of Canada has prompted the federal government and the Province of British Columbia to participate with other members of the international community in the Pacific Tsunami Warning System (PTWS). The B.C. Tsunami Warning System is, in effect, a regional component of the PTWS that consists of three functional subsystems for detection, emergency management, and public response. Together these critical links establish a three-stage detection and dissemination network to alert local populations along the B.C. coast to the threat of a potential or imminent tsunami.

British Columbia has an enormous coastal area that possesses an extremely diverse and productive environment in terms of the types of activities that can be accommodated in a temperate marine environment. Despite its rich environmental diversity, it is also a region plagued by systemic economic and environmental pressures, including high unemployment, dependence on declining primary resource industries, demands for increased environmental protection, conflicts associated with an increasing range of uses, and a declining public service sector.

Recently several new initiatives have been launched by federal, provincial, regional and local authorities, First Nations, conservation and private sector organizations to refine and direct economic growth in coastal regions. The most significant new areas of economic activity to emerge are aquaculture, recreation and tourism, and off-shore oil and gas exploration.

Under these dynamic economic conditions and compounded by ecological concerns, the composition of stakeholder groups involved with the B.C. Tsunami Warning System is rather large and evolving. In some cases, emerging sectors may have little regular contact with B.C. Provincial Emergency Program officials and may not fully appreciate the tsunami risk to their activities and investments. Communications links and capabilities also vary widely between and within these sectors.

These evolving fronts provide a backdrop for this study, which is intended to provide a baseline assessment of the B.C. tsunami warning system and related risk reduction practices in light of

socio-economic developments along B.C. coast, and evaluated according to recognized best practices and key principals and aims of Canada's National Disaster Mitigation Strategy.

While tsunamis cannot be prevented, levels of risk can be reduced and sometimes even eliminated. However, to be effective a tsunami mitigation strategy needs long-term support within coastal communities that are capable of implementing and maintaining local and regional tsunami preparedness programs, provided with essential planning tools, and willing to raise the awareness and commitment of individuals, businesses, emergency responders and government decision makers.

This study has attempted to show that an integrated tsunami warning system involves a wide range of considerations across all three stages of the dissemination network. Within this context, we offer a series of conclusions that could be used to strengthen key components of Canada's west coast tsunami warning system and related risk reduction practices.

Key finding: monitoring and detection

Canada's involvement in the Pacific Tsunami Warning System provides effective monitoring and alerting capability for telegenic tsunamis affecting the B.C. coast. Effective alerting for locally-generated tsunamis remains problematic.

Conclusions

There exists the need to:

- Maintain and strengthen where possible Canada's international commitments to the Pacific Tsunami Warning System;
- Consider the deployment of new communications technology where it provides identifiable enhancements to the current stage one activities; and
- Begin developing a warning and alerting strategy for local tsunamis throughout the B.C. coastal region.

Key finding: emergency management

Current inundation mapping and related mitigation efforts are focused primarily on selected communities on Vancouver Island.

Conclusions

Inundation mapping activities need to be:

- Expanded to include all populated and important economic coastal areas at risk in B.C.;
- Institutionalized under existing federal and provincial mitigation strategies to ensure longer-term sustainability.

Key findings: public response

Local warning capabilities are extremely limited in B.C. coastal regions. The capacity for broadcasting local warnings is extremely limited in many rural coastal areas and telephone-based notification schemes may also be problematic in small communities.

Conclusions

- A communications infrastructure audit needs to be undertaken to identify local capabilities and specific gaps in coverage. The audit would have to involve federal government departments, provincial agencies, the academic community, and the private sector.
- Regular reporting on exercises and meetings for the B.C. Tsunami Warning System needs to be established.
- The Pacific Regional Emergency Telecommunications Committee needs to become more actively involved in the further development and implementation of the B.C. Tsunami Warning System.
- A Universally Digitally Coded Warning system for public warning in B.C., with specific implementation for tsunami warning, is needed.
- A set of targets and corresponding incentives to ensure minimum warning capabilities for all communities along the B.C. coast is required.

Planning and response for tsunamis in transient and remote communities is evident in only a few cases where these have been developed on a voluntary, uncoordinated basis.

Conclusions

At the provincial level, officials need to work together with:

- Relevant ministries to develop a trailhead information campaign as part of a risk communication program for vulnerable recreational areas along the B.C. coast.
- Local authorities to encourage greater cross-membership in research, educational and training programs to support the formation of tsunami working groups.
- Local communities to develop a mechanism for continued assessment of coastal community needs and evaluation of the success of existing programs as part of broader national and provincial mitigation strategies. This is particularly important as the socio-economic profiles of coastal areas continue to change. In many coastal regions, there is an opportunity to build on broadly based processes already in place such as Rural Team British Columbia and the Coastal Community Network.

In the absence of an effective warning system for near-source tsunamis, a special awareness and education program about tsunami risk and appropriate response should be implemented. This would need to be communicated to residents, workers (seasonal and year-round), regional visitors (especially tourists), and transient populations, many of whom may have a different exposure to the tsunami hazard.

A successful mitigation strategy requires continuing commitment from local governments and other local authorities, as well as by individuals, industry and the recreational and tourism sectors in tsunami-prone areas.

Conclusions

- There exists the need to develop a standard provincial tsunami program assessment template, which could be based on the 1976 Foster and 2004 Anderson tsunami program reviews. This template should be administered regularly – every five or 10 years – to assess local, regional and provincial community readiness and to measure the utility of active tsunami program initiatives.
- B.C. PEP's Risk and Vulnerability Analysis (HRVA) Tool Kit is available to help a community make risk-based choices to address vulnerabilities, mitigate hazards and prepare for response to and recovery from hazard events. A specialized version of it to assist local planners in their preparation of tsunami mitigation strategies and response plans would be beneficial.
- Local authorities need to work together to develop a common public educational outreach program to ensure that local residents understand the procedures associated with tsunami watch and warning bulletins.
- Continued support from federal and provincial agencies and expanded access to tsunami information through existing websites is required.
- Current legislation needs to be reviewed to ensure minimum requirements for tsunami risk reduction practices are established and followed.

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. Scientific support may also be required when applying models and when interpreting inundation maps.

Conclusions

- The transfer of knowledge from the scientific community to local and regional tsunami risk management and mitigation efforts is important, but needs support from federal or provincial governments.
- A Canadian tsunami information clearinghouse to enable 'one-stop' access to tsunami information and planning resources would be helpful.
- Creation and maintenance of targeted tsunami educational programs in place for industry sectors such as tourism, fisheries, aquaculture and forestry is required.
- Specific training modules for tsunami hazards need to be jointly developed.

Much benefit can be gained from current mitigation efforts underway in neighbouring U.S. states that face similar challenges to British Columbia.

Conclusions

- To enhance information exchange and introduce stakeholders to each other, especially local planners, a regional mitigation conference and regular workshops should be planned. Possible venues include the annual Vancouver Emergency Preparedness Conference; Emergency Preparedness for Industry and Commerce Council annual forum (especially for industry planning); Union of B.C. Municipalities special events, and so on.
- Supporting the use and sponsorship of existing forums to reduce the effects of earthquake events would be helpful. Examples include the Western States Seismic Policy Council

(WSSPC), a regional earthquake consortium; and the Cascadia Region Earthquake Workgroup (CREW), a coalition of private and public representatives working together to improve the ability of Cascadia Region communities to reduce the effects of earthquake events.

While there is an ongoing need to support scientific research into tsunami hazard mapping for the B.C. coast, the study concludes by identifying three further areas for research based on what appear to be significant gaps in knowledge.

1.) Communications Infrastructure

An infrastructure audit should be undertaken to determine the communications capabilities of local populations along the B.C. coast. Findings from a study of this kind would provide important details for community planning and could make a valuable contribution to Industry Canada's Public Alerting initiative and to the future design of the B.C. Tsunami Warning System.

2.) Coastal Preparedness

Little is known about tsunami awareness within and the preparedness practices of coastal populations, particularly transient and marginal groups. A detailed assessment could provide an empirical basis for setting future targets, identifying priorities, and establishing quantitative measures for the effectiveness of mitigation and preparedness strategies.

3.) Duty to Warn

It may be prudent to undertake a formal review into federal and provincial legal obligations with respect to their 'duty to warn' residents and visitors of known tsunami hazards, as well as the minimum conditions that governments might be reasonably expected to establish when developing and maintaining a public alerting system.

Frequently Used Acronyms

B.C. PEP	British Columbia Provincial Emergency Program
B.C. TWS	British Columbia Tsunami Warning System
B.C. TWAP	British Columbia Tsunami Warning and Alerting Plan
CHS	Canadian Hydrographic Service
ECC	Emergency Coordination Centre
ICG-ITSU	International Coordination Group for the Tsunami Warning System in the Pacific
IOC	Intergovernmental Oceanographic Commission
ITIC	International Tsunami Information Centre
JEPP	Joint Emergency Preparedness Program
MCTS	Canadian Coast Guard Marine Communications and Traffic Services Division
NDMS	National Disaster Mitigation Strategy
NIF	New Search and Rescue Initiative Fund
NOAA	United States National Oceanographic and Atmospheric Administration
OCIPEP	Office of Critical Infrastructure Protection and Emergency Preparedness
PSEPC	Public Safety and Emergency Preparedness Canada (formerly OCIPEP)
PTWS	Pacific Tsunami Warning System
RCMP	Royal Canadian Mounted Police
RETC	Regional Emergency Telecommunications Committee
SFU	Simon Fraser University
UDCW	Universally Digitally Coded Warning
WC/ATWS	West Coast/Alaska Tsunami Warning System

Participants

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1.0 Introduction

On 27 March 1964, a series of tsunami waves travelled up Alberni Inlet and struck Port Alberni, raising water levels four metres above high-tide level and causing extensive damage to the town. Residents received no warnings about the incoming wave. Fortunately there were no casualties as a result of the tsunami, but direct losses were estimated at about $10 million. At the time, the British Columbia coast was a region dominated by a resource-based economy revolving around forestry, fishing, and to a lesser degree mining and agriculture. Populations beyond the lower mainland and east coast of Vancouver Island were primarily clustered in small communities and floating logging camps.

Much has changed along the B.C. coast since the 1964 event, and more change can be expected over the next decade as a result of economic upheavals. Since the mid-1990s, for instance, the forest sector's performance has declined significantly, resulting in mill closures and job losses. Similarly, salmon and herring fisheries declined significantly in the 1990s, as did seafood processing. Mining investment also fluctuated significantly throughout this period. Concerned about reliance on traditional forest and commercial fishing practices for employment, coastal residents now recognize that long-term survival of their communities rests on balancing sustainability of these industries with diversification of the coastal economy.

Recently several new initiatives have been launched by federal, provincial, regional and local authorities, First Nations, conservation and private sector organizations to refine and direct economic growth in coastal regions. The most significant new areas of economic activity to emerge are aquaculture, recreation and tourism, and off-shore oil and gas exploration. In the case of aquaculture, about 3,000 people are now employed directly and indirectly in B.C.'s salmon farming industry. Over 92 percent of the direct jobs are in coastal communities outside of greater Victoria and Vancouver. The British Columbia coastline is a sought-after location for aquaculture because of a coastline that is unique in North America with it's many fjords and protected inlets and bays, ice-free areas, and suitable water temperature for fish production. Salmon farms are primarily located in and around the northeast and west coasts of Vancouver Island.

Tourism has historically been a relatively minor component of the economy of much of mid and northern coastal B.C. and northern Vancouver Island. This was particularly the case up to the 1980s, due to the relatively small numbers of visitors to the area, lack of transportation and the dominance of primary industry. However, over the last two decades tourism has grown steadily due to several factors, including ferry and cruise ship runs to Prince Rupert and Alaska. Moreover, the tourism industry is expected to witness many significant changes in the new millennium. These changes are being brought on by such factors as much improved transportation, global economic conditions, and demographic shifts.

Offshore oil and gas exploration activities have identified four large basins with petroleum potential located in the Queen Charlotte Basin, Winona Basin, Tofino Basin and Georgia Basin. While these regions have been under a moratorium on further exploration since the 1970s, the decline in other industries along the B.C. coast in the latter part of the 1990s has once again brought calls for exploration to proceed. In 2001, the British Columbia government commenced a review of the moratorium, and in 2002 announced a goal to facilitate the development of an offshore oil and gas industry, expected to be up and running by 2010.

While some of these new economic activities are not expected to automatically replace other traditionally high-paying resource industry jobs, they are viewed as much more than minimum wage jobs. For many residents, these activities also offer additional opportunities, such as a chance to continue to reside in the community of their choice without having to move to find work and/or maintain a quality of life consistent with their values.

These trends also pose new challenges to effective warning systems along the B.C. coast. The areas in British Columbia most vulnerable to 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. These regions also correlate with most of the planned or emerging new socio-economic activities.

In addition to these social and economic changes, a revolution in communications technologies has transformed the potential of public alerting systems to generate more timely and more accurate warnings. Industry Canada is currently spearheading an initiative to develop standards for a national public alerting system that can maximize the value of new digital technologies in conjunction with more traditional analogue broadcast systems.

All of these developments are occurring at the same time as provincial and local authorities begin to adopt mitigation-oriented strategies for emergency management. Similarly, Canada's National Disaster Mitigation Strategy initiative coincides with an international trend toward building more resilient communities as a principal foundation for disaster management.

With respect to the future of the B.C. Tsunami Warning System, this report must therefore consider a number evolving fronts:

- The strategic shift in emergency management towards a more comprehensive model that includes preparedness, response and recovery, with a strong emphasis on mitigation;
- Improvements in understanding tsunami hazards, the associated risks, and our increasing vulnerability;
- Changing patterns in economic and social practices along the B.C. coast; and
- Emerging technologies and existing legacy systems for public alerting.

And to this list we might add a fifth evolving front:

- The inherent international scope of tsunami warning and Canada's reciprocal obligation to the international community.

Tsunami warning systems, as we shall describe in the later sections of this report, are necessarily international in scope, and thus require a high degree of multilateral cooperation and resource support. The B.C. Tsunami Warning System depends on these resources and infrastructures, and as the international components of this system evolve, the B.C. and Canadian governments must assume not only responsibility for ensuring that domestic warning capability continues to meet international standards but that, where feasible, Canada will continue to fulfil its reciprocal obligations to its international partners in the ongoing operation of the tsunami warning system, particularly in the Pacific region.

These evolving fronts have provided a backdrop for the study, the principal aim of which was to examine the current B.C. tsunami warning system in meeting the needs of present-day and projected future stakeholder groups. In addition, it sought to identify a range of strategies based on recognized international best practices for addressing these gaps and concerns in both short and long runs.

Results from the study are set out in this report, which is intended to provide a baseline assessment of the B.C. tsunami warning system and related risk reduction practices. These are evaluated against identified socio-economic developments along the B.C. coast and according to recognized best practices, as well as the key principals and aims of Canada's National Disaster Mitigation Strategy.

2.0 Measuring Success within the National Disaster Mitigation Strategy

In 2001, the federal government launched a series of consultations toward the development of a National Disaster Mitigation Strategy (NDMS). The NDMS (Canada, 2001b) defines disaster mitigation as:

> sustained actions to reduce or eliminate the long-term impacts and risks associated with natural and human-induced disasters. Mitigative measures are generally taken well in advance of a potential disaster situation to reduce the likelihood or frequency of the event's occurrence, or to avert or diminish the event's impacts.

The goals of the NDMS are to:

- Strengthen and develop resilient and sustainable communities in order to reduce social, environmental and economic impacts of disasters;
- Proactively create an environment in which capacity is built at all levels and risk management becomes a conscious element of decision-making; and
- Reduce risk to life, property, infrastructure, and economic activity from natural disasters.

Five guiding principles for an integrated, iterative strategy emerged from the consultations. The consensus was that the NDMS should:

1. Instill values of trust, equity and fairness at all levels of decision-making. It should be clearly based on the collective good and not transfer risk downstream;
2. Be integrated in all development planning, and be flexible and scaleable to different contexts and communities;
3. Be community-based with a strong national commitment;
4. Be knowledge-based and promote best practices in a living, ongoing process that is continually reassessed at all levels; and
5. Define clear roles and responsibilities, accountability and corresponding authority respecting established jurisdictions, in a context of transparency and public accountability.

Given these preconditions, what is an appropriate measure of "success" when considering the development and ongoing evolution of public warning systems? John Handmer (Handmer, 2002) has considered this problem in the development of flood warning systems, referring to it as "an ongoing critical issue" in assessment procedures. He lists a number of approaches, some as measures of loss reduction, others as measures against audience reach and response, or timing and accuracy in reporting of warnings. For our purpose, however, Handmer also identifies an approach that may serve as a definition of success within a mitigation framework. This approach, stated most succinctly, identifies and assesses "*the principles and assumptions underlying design and operation*…" of a warning system.

Success, by this measure, reflects the degree to which the design and operation of a warning system *effectively incorporates* the principles of a mitigation strategy. However, in his analysis of U.S. and European reviews on flood warning systems, Handmer also observed "the fundamental problem of designing warning systems so that they meet community needs was [consistently] ignored" (p. 22), suggesting that the principles and objectives of a mitigation strategy are not easily achieved:

> A serious omission of the U.S. and European material [on flood warning] is the failure to explicitly conceptualize the warning task as being about enabling the communities, enterprises and individuals at risk to take action to reduce their risk and property losses. (p. 17)

Success in the design of a warning system neither begins nor ends with the delivery of a message to an unknown public, but rather involves a much more extensive set of measures that consider the proactive development of local risk reduction practices, the deployment and upkeep of warning systems, and the enhancement of community coping capabilities appropriate to the specific needs of populations at risk. If this is the measure of success to be used, then Handmer's findings suggest from the outset that communities will need means and ways of becoming more directly involved in the design and ongoing evolution of public warning systems.

A number of practical questions follow from this determination, the most basic being concerns of community stakeholder involvement: who should be involved, and when and how should they be expected and permitted to participate in a public warning system and related risk reduction practices? Before we can address this question, however, a preliminary question must be answered: who is at risk from tsunamis and in what ways can the B.C. tsunami warning system contribute to the aim of long-term risk reduction for those populations?

It is the latter question that this study is intended to address most directly, but it attempts to do so while considering the wider question of stakeholder participation in the design and development of public warning systems in Canada.

2.1 Research design and the structure of this report

Research undertaken for this study has revealed that tsunami mitigation is a very broad area that has received minimal attention in Canada beyond natural scientific and technical studies. As such, there was little precedent on which to incorporate a broader social context, although many existing Canadian and foreign studies and reports were helpful in structuring the inquiry and analysis.

The purpose of this report is to serve as a baseline assessment of the B.C. tsunami warning system and related risk reduction practices along the B.C. coast. Therefore, one of its goals is to provide Canadian emergency planners and policy makers with a broader contemporary perspective of the nature of Canada's west coast tsunami hazard, associated risks, vulnerabilities, and the warning systems and strategies for improving warning and reducing risk. Another aim is to serve as a catalyst for more detailed studies and analysis.

For the overall conceptual approach, we adopted a functional model of warning systems (Mileti & Peek, 2000) and modified it into a communications-oriented model that portrays the B.C. tsunami warning system as a three-stage dissemination network. This modified model then served to focus our inquiry and direct our analysis during the study. Here it serves as a general framework for the design of the report and its findings.

Current stakeholder groups were identified as those directly involved in the B.C. system through formal connections in the B.C. Tsunami Warning and Alerting Plan and related documents. For instance, those groups listed in planning documents or on telephone contact lists, or directly involved in research activities or planning forums. Projected future stakeholders were identified in consultation with researchers and others working on socio-economic developments affecting the B.C. coastal region.

The performance review of the B.C. tsunami warning system was based on available sources from recent exercises and performance evaluations, and discussions with officials and participants, although more work will likely need to be undertaken in this area because of the relative lack of documented evidence currently available.

The section on best practices is based on a selective review of sociological studies on warning systems, drawn from a comprehensive bibliography kindly provided by Dennis Mileti from the Natural Hazards Research Centre at the University of Colorado (Boulder). Best practices in operational factors are drawn from the latest planning literature on warning systems currently available.

3.0 Tsunami Hazard Background

Tsunamis are large wave events generated by large surface impacts, or when the floor of a water body moves suddenly, displacing the water on top of it (Myles, 1985; Clague, 2001). The displaced water propagating from the source becomes a tsunami. Although usually associated with earthquakes, tsunamis also can be triggered by many other types of phenomena, including submarine or terrestrial landslides, submarine and terrestrial volcanic eruptions, explosions and even bolide (e.g. asteroid, meteor, comet) impacts (Clague, 2001; Paine, 1999).

Tsunamis have been responsible for enormous damage and loss of life in many coastal regions around the world. However, tsunamis are particularly threatening around the continental edges of the Pacific Ocean due to a greater frequency of large destructive earthquakes.

The term “tsunami”, pronounced, “soo-nah-mee”, is a Japanese word that embodies two characters: “tsu” and “nami”. The character “tsu” denotes harbour, and the character “nami” denotes wave (NTHMP, 2003). In the 1960s, the term was generally adopted internationally by scientists to describe long-periodic waves generated by a sudden displacement of the water surface (Clague et al., 2003). This was done, in part, to avoid confusing these events with “tidal waves”. In the past, tsunamis were often mistakenly referred to as “tidal waves”. Tides are the result of gravitational influences of the moon, sun, and planets. The causes of tsunamis are unrelated to the tides; although a tsunami striking a coastal area is influenced by the tide level at time of impact. As will be described below, however, even the term tsunami can be misleading because tsunamis don’t occur solely in harbour areas.

Several factors make forecasting tsunami impacts particularly challenging. First, because tsunamis are infrequent and generally unpredictable events, it is difficult to directly observe or measure their formation. Second, in deep waters, tsunamis are very tricky to detect. Their wavelengths are usually very long, sometimes hundreds of kilometres, and their amplitudes are usually less than a metre high (Clague, et al., 2003). The speed in which tsunamis travel is a function of the depth of the water they traverse; the deeper the water, the less resistance and the faster the wave (Myles, 1985). Those created in deeper parts of the Pacific can move at velocities similar to trans-Pacific commercial airline flights – that is, up to 1000 km/h (Clague, 2001), enabling them to travel from one side of the Pacific to the other in less than a day. This speed makes tsunamis dangerous as they approach shore lines. As the ocean floor rises towards land, friction slows the wavefront, causing the rest of the wave to push up behind it. Trailing waves pile into the waves in front of them pushing against the rising frontal wave. This phenomenon is referred to as “shoaling” (Clague, 2001). When one wave actually overtakes another, a very steep wall of water, known as a “bore” may be generated (Clague, 2001). Even though waves may be slowed considerably (down to 60 km/h or less), wave heights can reach up to 30 m or more in shallow water (Intergovernmental Oceanographic Commission, 2001; Clague, 2001).

However, not all tsunamis break when they reach the shoreline. They are usually turbulent, onrushing surges and not simple breakers (Clague, 2001). Some simply rush ashore like a sudden massive tide (Project Impact). It is important to note though, that it’s not always the wave crest that arrives on shore first. Often it is a trough that arrives first, and the first sign of a tsunami is what appears to be an extremely low tide. Tsunamis are typically characterized by alternate coastal flooding and then recession of water, often with several minutes to hours between successive flood periods. Local residents, first responders, and community leaders are sometimes unaware that the second and third waves are often the largest. Assuming the worst is over after the first wave, many place themselves at risk venturing too close to the shoreline only to be swept away by subsequent waves.

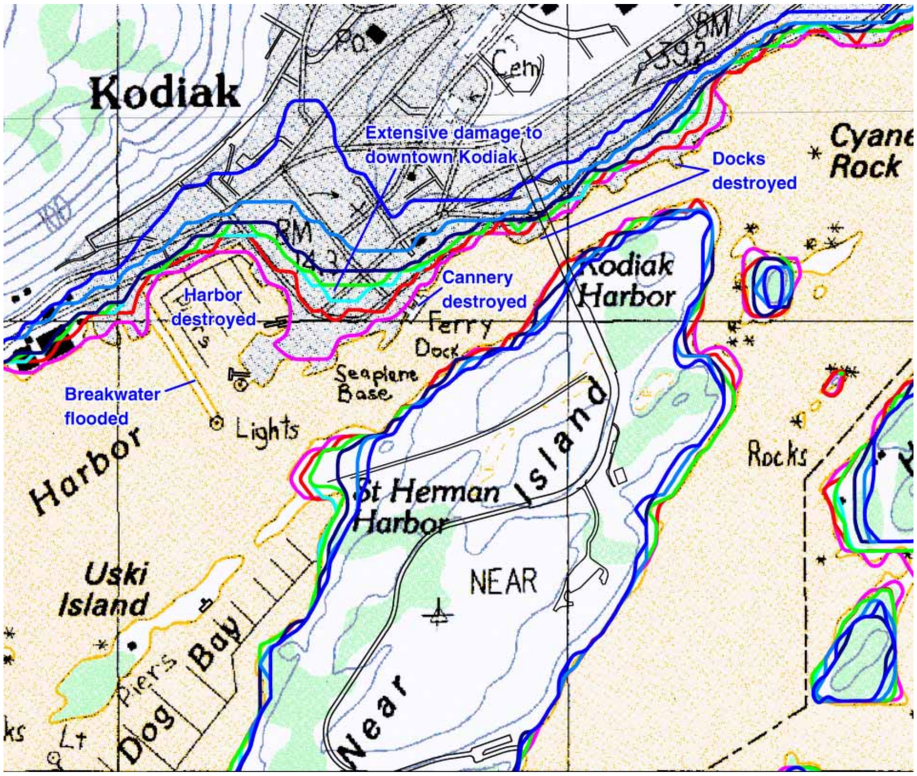
Unlike normal waves that have small volumes and quickly dissipate when they reach shore, tsunami wave series can last up to 24 hours and can push large water volumes far inland if the right conditions prevail. This phenomenon is described as 'inundation' and 'run-up' and the degree of inundation and run-up is a major determinant of a tsunami's destructiveness (Myles, 1985). Inundation is measured as the greatest horizontal distance reached by the waves and run-up is the greatest vertical height reached by the waves. So a tsunami impacting a high coastal cliff would exhibit high run-up with little inundation.

The degree of tsunami run-up and inundation, and therefore the degree of potential damage, is determined not just by wave size, speed, and approach angle but also by the coastal configuration at any one site. Influences such as shape of the coastline, water depth, ocean bottom shape, shoreline orientation, reefs, undersea features, and the adjacent land topography have a profound effect wave impacts. In general, the inundation is lower on straight, steep shorelines and higher at the heads of shallow, broad bays and inlets (Clague 2001).

The influence of tides on the potential tsunami risk is important. A two-metre tsunami occurring at low tide in a community where the tidal range is four meters will likely have a minimal impact on the community. The same two-metre tsunami coinciding with one of the community's highest tides of the year could be disastrous. It is usually inevitable that one of the waves will coincide with a high or rising tide. Other factors that may exacerbate the impacts of tsunami wave action include coastal erosion causing landslides or slumping, and storm surge which can lead to a significant rise in wave heights. Therefore, tidal and other factors need to be considered since tsunamis can be superimposed on existing local conditions.

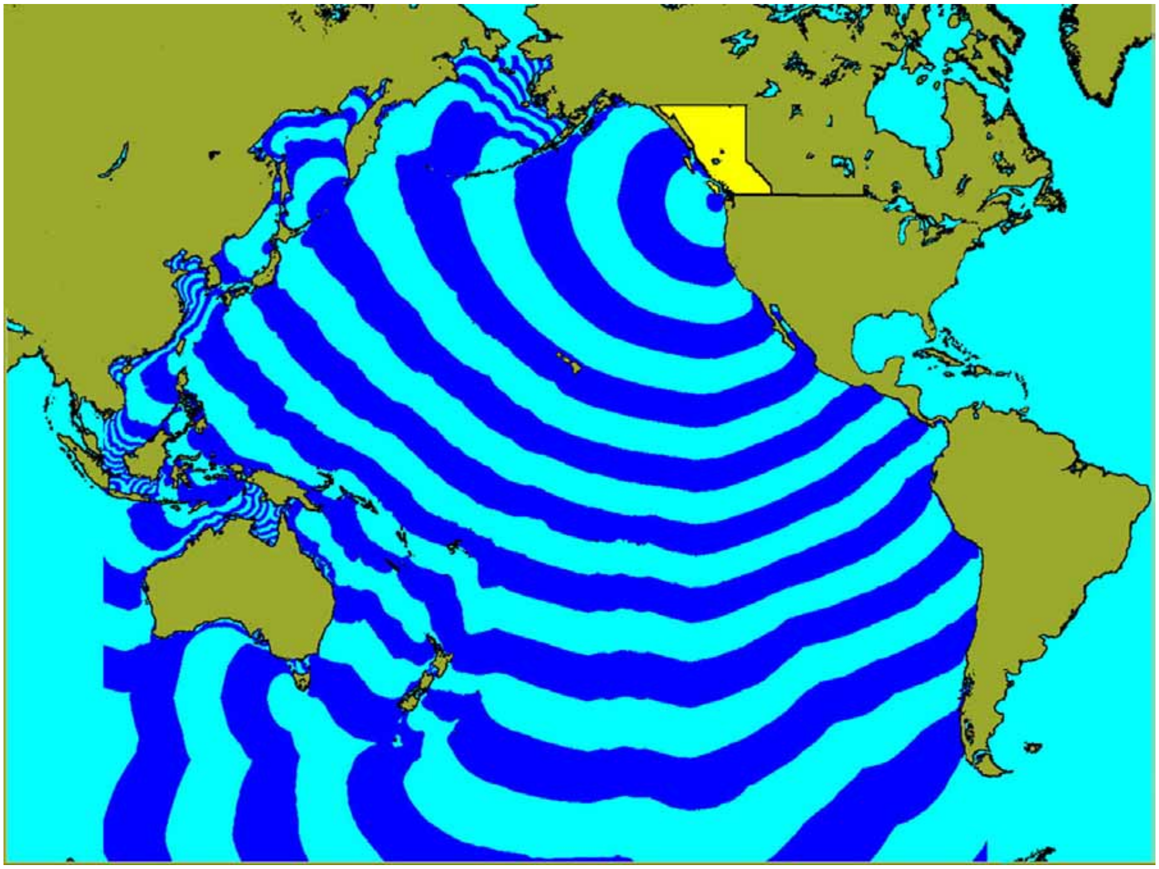
As seen, maximum water level may result from a combination of variables, from angle of impact, coastal configuration (both on and offshore), tide height, coastal erosion and slumping, to current weather conditions. Because each of these parameters varies along the coasts, inundation and run-up may differ considerably over even short distances, making it difficult to assess local hazard (Barlow, 1995). However, by carefully documenting many of these features, scientists are able to combine this data with past event records and/or mathematically model impacts to produce inundation maps that identify coastal populations and infrastructures at risk (see Figure 1).

Figure 1 Tsunami inundation scenarios for the City of Kodiak, Alaska
(Derived from: Alaska, 2004)



Combining this resultant information with the locations and times of the trigger events then enables scientists to mathematically predict when tsunamis will arrive, since the speed of the waves varies with the square root of the depth of water at any given point (NOAA; Clague, et al., 2003). This latter determination is crucial for public warning. Locally-generated tsunamis may impact coastal areas within minutes, leaving only the ground shaking (if seismically generated) as a means of warning people near the coast. However, distant or far-field generated tsunamis provide sufficient time (often hours) to alert threatened regions and enable them to initiate appropriate action, including evacuation. Canada's West Coast Tsunami Warning System is currently based solely on far-field tsunami events.

Figure 2 Tsunami Travel Time. Each colour band represents estimated a one-hour increment of travel time (Source data: NOAA, 2003)

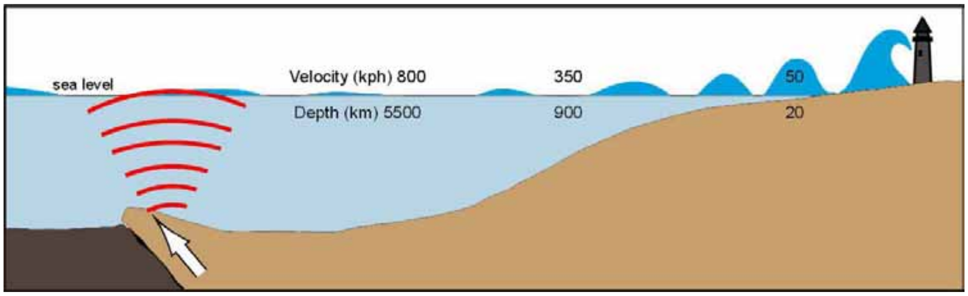


3.1 Causes of tsunamis

3.1.1 Earthquake-induced tsunamis

The most destructive and far reaching tsunamis are generally created by large, shallow submarine earthquakes (Intergovernmental Oceanographic Commission, 2001), sometimes described as "tsunamigenic earthquakes". The most frequently occurring of these earthquakes are located in the Pacific Ocean, primarily adjacent to continental boundaries where oceanic plates are subducted under the continental land mass, intermittently releasing large bursts of energy in the form of earthquakes (Dunbar, et al., 1989). Subduction earthquakes are particularly effective in producing tsunamis. By creating vertical (dip-slip) shifts of the ocean floor, earthquakes can displace, tilt or offset large areas from a few kilometres to in excess of 1000 kilometres. These sudden vertical displacements in turn deform the water surface and propagate waves outward from the source, generating potentially destructive tsunami waves (Intergovernmental Oceanographic Commission, 2001; Dunbar, et al., 1989). These types of tsunami waves are also known as "seismic sea waves."

Figure 3 Earthquake-induced Tsunamis
(Source:Clague, 2001)



The west coast of Canada is particularly vulnerable to this type of tsunami due to the presence of both nearby and distant subduction source zones at the margin of the Pacific basin (Clague, et al., 2003)

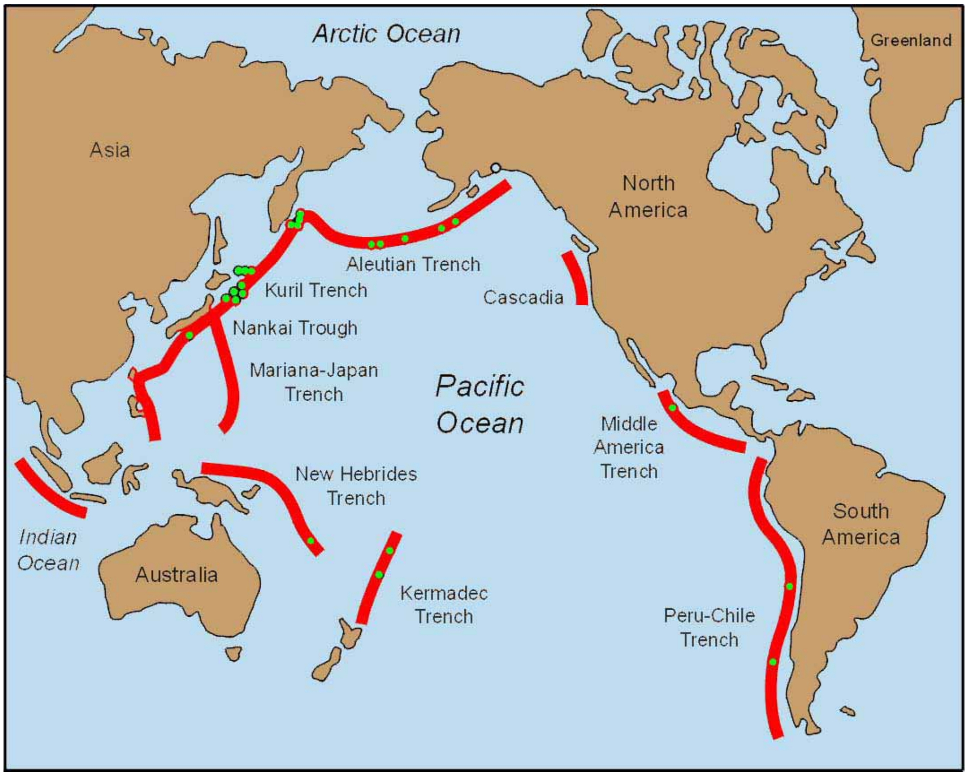
Not all earthquakes generate tsunamis, however. Many factors contribute to the tsunami generating process, including the earthquake's magnitude and depth, whether there is concurrent slumping of sediments, and the efficiency with which energy is transferred from plate crustal thrusts to ocean water. Because of these complicating factors, there is no simple answer as to how large an earthquake needs to be in order to create a tsunami. Generally, it is thought that an earthquake needs to be a magnitude 7.5 or greater to produce a tsunami capable of creating damage at great distances from the source (Intergovernmental Oceanographic Commission, 2001; Dunbar, et al., 1989). Earthquakes of much lower magnitudes, however, are capable of generating local tsunamis by triggering coastal and/or submarine slumping or landslides.

The first recorded earthquake-generated tsunami occurred off the coast of Syria in 2000 BC (NOAA, 2004a). Since 1900 (marking the beginning of locating earthquakes by instrument), most earthquake-induced tsunamis have been spawned in regions off the coasts of Japan, Chile, Peru, the Solomon Islands, and New Guinea. However, the only regions that have generated telegenic (remote-source) tsunamis sufficient to affect the entire Pacific Basin are the Aleutian Islands, the Gulf of Alaska, the Kamchatka Peninsula and the coast of South America. Island regions like Hawaii, centrally located in the Pacific basin, have experienced tsunamis generated in all parts of the Pacific (NOAA, 2004b).

Both the Caribbean and Mediterranean seas have small subduction zones and histories of locally destructive tsunamis. In the Atlantic, only a few tsunamis have been generated, largely owing to the fact that there are no large subduction zones at the edges of plate boundaries to spawn such waves except for small subduction zones under the Caribbean and Scotia arcs. In the Indian Ocean, the Indo-Australian plate is being subducted beneath the Eurasian plate at its east margin. Consequently, most tsunamis generated in this area are propagated toward the southwest shores of Java and Sumatra, rather than into the Indian Ocean (NOAA, 2004b).

Most large earthquakes in the Pacific Ocean have been triggered by earthquakes occurring within the subduction zones. During the past 150 years, the main sources have been at the Kurile Trench and Nankai Trough east and north-east of Japan, the Aleutian Trench south of Alaska, and the Peru-Chile Trench west of South America (Clague, 2001).

Figure 4 Pacific subduction zones
(Source: Clague, 2001)



Most large tsunamis in the Pacific Ocean have been generated by great earthquakes along subduction zone margins, shown in Figure 4 as red bands. The green dots locate the source of tsunamis larger than 10 cm in height that have been recorded at the Tofino tide guage on the west coast of Vancouver Island (Clague, 2001, figure 3.).

An example of the devastating power of a subduction-induced tsunami is the 16 August 1868 Arica Tsunami that was generated when a magnitude 8.5 earthquake struck an area of the Peru-Chile Trench just off of Peru's most southern coast. After the force of the earthquake had already severely damaged Arica, a 15 m tsunami wave swept across the city, followed by an even higher wave estimated to be 18 m (NOAA. 2002a). One navy ship was ripped from its mooring and smashed apart on the rocks of a nearby harbour island, while two others were pushed into the city and deposited some 400 m from the beach. Low-lying areas of the community were swept clean by the waves, removing all traces, including foundations of homes and other buildings that once existed there (USC Tsunami Research Group, 'The 1868 Africa Tsunami'). Some 25,674 perished as a result of the tsunami and earthquake (NOAA, 2002a). However, the damage did not stop there. Peruvian communities to the north of Arica, including Ilo/Pisco, Callao, Mollendo and Trujillo were also damaged by the tsunami, while Tambo was completely destroyed. South of Arica, the tsunami severely impacted the Chilean coastline, damaging ships in Caldera and completely submerging the City of Iquique (USC Tsunami Research Group, 'The 1868 Africa Tsunami').

Beyond the South American coastline, the tsunami waves swept north and west. In Hawaii, 4.5 m waves struck at Hilo's waterfront, while further west, 1.5-m waves flooded Yokohama's harbour. In New Zealand, run-ups of 4.5 m and 5.4 m reached the towns of Oamaru and Lyttleton, respectively. Other locations reporting the tsunami included Australia, Western Samoa, California and Oregon (USC Tsunami Research Group, 'The 1868 Arica Tsunami').

In the last part of the 20th century, five Pacific-wide destructive tsunamis occurred (1946 Alaska, 1952 Kamchatka, 1957 Aleutian Islands, 1960 Chile, and 1964 Alaska), while tsunamis in inland seas around the periphery of the Pacific were especially disastrous locally (Intergovernmental Oceanographic Commission, 2001).

Closer to Canada, on 4 April 1946, a 7.8 magnitude earthquake triggered a large tsunami in the Aleutian Islands. Of particular note was the 35-m run-up on nearby Unimak Island that was powerful enough to completely destroy the newly built five-storey Scotch Cap Lighthouse, killing five occupants. As the waves spread southwest across the Pacific Ocean, within approximately five hours they reached the Island of Hawaii. Run-ups reached 12 m in the Pololu Valley. However, Hilo received most of the damage where the run-up was measured at 8.1 m. Before the tsunami finally dissipated, 165 people perished and some US$26 million in damages (1946 dollars) were incurred (Clague, et al., 2003; University of Washington, 2003).

The severe impact of this event served to raise awareness and concern about the need for a warning system to protect the Island population. On 12 August 1948, the Seismic Sea Wave Warning System was established. Its name would be changed later to the Pacific Tsunami Warning System (University of Washington, 2003).

3.1.2 Evidence of past tsunamigenic earthquakes

Despite the absence of locally written records of previous events, past tsunamigenic earthquakes have been identified using a combination of methods. In the late 1980s and throughout the 1990s, scientists began uncovering sheets of tsunami-deposited sand in peat and mud deposits in protected tidal marshes along the Pacific coasts of Oregon, Washington and western Vancouver Island, as well as at wave-exposed locations at the eastern end of the Strait of Juan de Fuca (Williams et al., 2003; Clague et al., 2003; Hutchinson et al., 1997). These sheets provide evidence of large Cascadia subduction earthquakes and associated tsunamis. For example, studies of tidal marshes subsiding from magnitude 8+ earthquakes in Washington and Oregon demonstrate that the Cascadia zone ruptured five times in the last 2,600 years (Atwater and Hephill-Haley, 1997; Clague 1997; Kelsey et al., 2002). Sand layering phenomena associated with tsunamis has also been verified through photographs and eyewitness accounts of historic tsunamis in Japan, Indonesia, Hawaii, Chile, and from uppermost sheets left by the 1964 Alaskan tsunami unearthed in marshes on Vancouver Island. Older, thicker and coarser grained sheets found at these same locations indicate impacts of older tsunamis larger than the 1964 event (Clague, 2001).

Although prediction of when the next "big one" will strike the west coast remains problematic, detailed studies of buried soils in southwestern Washington reveal that seven large earthquakes have struck that area in the last 3,500 years, giving an average recurrence rate of about 500 years. They also reveal, however, that intervals between successive events vary considerably. Three occurred between 3,320–3,500 and 2,400–2,800 years ago, the next between 1550–1700 years ago. Subsequently, two occurred 1130–1350 and 900–1300 years ago respectively, followed by an elapse of 600–1000 years before the most recent event 300 years ago (Clague, 2001).

The most recent event has been well-documented by scientists along the entire length of the subduction zone from California to British Columbia. Evidence includes discovery of plants and trees growing in marshes before the land subsided, and subsequent radiocarbon dating of samples to within 10–20 years. Corroboration of this event also comes from historical Japanese records that document damage along a 1000-km portion of the coast of Japan that occurred from a distant created tsunami arriving locally in excess of 3 m, but in the absence of any felt earthquake. Through a process of elimination, it was determined that the tsunami was probably generated by a great earthquake off the west coast of North America (Satake, K. et al., 1995).

This compelling evidence of large tsunamigenic earthquakes near the coast of British Columbia has prompted a need for greater understanding of associated tsunami run-ups and currents, particularly in light of the significant coastal settlement that has occurred in recent times. Much of the more detailed examination began in 1990. Using numerical hydrological models, Ng et al. (1990) computed the first tsunami travel times and sea surface displacements for different coastal regions of British Columbia. Simulated wave amplitudes were plotted for major tide gauge locations and some of the more densely populated coastal areas. The models showed, as in previous studies (Dunbar et al., 1989), that at each location wave patterns are affected strongly by local topography, bathymetry, shoreline configuration, amount of shoaling and excitation of resonance (Ng et al., 1990).

The most affected areas were shown to be along the west coast of Vancouver Island due to proximity to the sources. In particular, at the head of Alberni Inlet, waves were shown to be dramatically magnified through resonance; as much as three times those in Barkley Sound (5 m), the entrance to Alberni Inlet. Georgia Strait, even though sheltered by Vancouver Island and with waves attenuated by friction, would still experience amplitudes to up to one metre (Ng et al., 1990), sufficient potential to threaten densely populated areas along the Fraser River, especially if the tsunami arrives at high tide and during an annual freshet.

Currently, the Canadian Hydrographic Service is close to completing a three year modelling study to predict coastal sea level changes and currents in southern British Columbia harbours due to tsunami that may result from a megathrust earthquake in the Cascadia Subduction Zone. The study employs the same model as that being used by NOAA in the U.S. to study tsunami effects along the west coast of Washington, Oregon and California, and in the inland waterways contiguous to Canada and the U.S. Adopting a common model allows for data sharing (e.g. bathymetric data) and combining results so as to cover the entire Cascadia area. This latest modelling effort also uses bathymetric grids of several orders of magnitude finer than the previous studies done by Ng and others to give more accurate results and better insight into variations within harbours (ITSU, 2003).

Once fully completed, the study will have modelled those harbours on the west coast of Vancouver Island that are most susceptible to tsunamis originating in the Cascadia Subduction Zone. Intermediate coastal grids (50–100 m resolution) and the high-resolution grids (10–20 m resolution) for the harbours and harbour approaches are being produced to enable the effects of inundation to be more accurately modelled. In some cases topographic LIDAR is being used to produce even finer grids. Initial efforts have been directed at Victoria and Esquimalt Harbours on the south end of Vancouver Island, where much digital data was already available (ITSU, 2003). Both harbours are located approximately 110 km from the mouth of Juan de Fuca Strait. Results of the first model runs show that maximum amplitudes outside the harbours in Juan de Fuca Strait are about two metres, comparable with previous modelling studies. In the harbours, the response is quite different, however. The maximum amplitude in Victoria Harbour was shown to be about three metres, but in Esquimalt Harbour the maximum amplitude was nearly five metres. Maximum currents in both harbours exceeded five metres/second (ITSU, 2003).

3.1.3 Volcanoes and tsunamis

Volcano-generated tsunamis, although rare occurrences, are among the most spectacular. In 1490 BC, an eruption and collapse of the Santorini volcano, off the southeast coast of Greece, produced a gigantic tsunami that decimated most of the Minoan colonies of the Aegean Sea. It is speculated that the legend of Atlantis may well be based on this disaster. More recently, on 26 August 1883, one of the largest volcanic eruptions in history took place in Indonesia, resulting in the collapse of the crater of Krakatoa and tsunami waves reaching 40 m in height. Some 300 towns and villages were destroyed, causing the death of nearly 40,000 people on the islands of Java and Sumatra (Intergovernmental Oceanographic Commission, 2001).

3.1.4 Tsunamis generated by coastal landslides, ice and rock falls, and submarine slumps

Although the energy of their waves dissipates quickly as tsunamis travel across large bodies of water, tsunamis generated by sudden landslides and rock falls have the capability of being extremely destructive close to their source. In fact, the largest tsunami ever recorded was the result of a rockslide.

In the evening of 7 July 1958 a magnitude 8 earthquake shifted the land along the Fairweather Fault in Alaska that borders the bay beneath a steep rock face of rock. The intense shaking broke loose a massive rockslide along the east side of Gilbert Inlet that crashed into the bay, generating enormous waves sending water surging to a height of some 520 m on the opposite side of the inlet. The wall of water inundated approximately 13 km^2 of land along the shores of Lityua Bay, with water reaching as far as 1,100 m inland, knocking down millions of trees and stripping the shore down to bare rock. The rampaging wave overtook and killed two boaters fleeing to open sea. Other boaters anchored in the bay miraculously survived (USC Tsunami Research Group, ‘1958 Lituya Bay’).

Submarine landslides are also capable of generating large tsunamis. These can be set off by multiple natural and human-induced triggers, including earthquakes, undersea volcanic eruptions and construction works. Other causes include gases trapped beneath sediment layers at the edge of continental shelves, causing sediments to fail, slide downslope and trigger enormous waves (Clague et al., 2003).

A 1998 catastrophic event has caused scientists to pay much closer attention of this phenomenon. On the evening of Friday, 17 July 1998, about 20 minutes after a strongly felt local earthquake, a series of three large waves inundated the Aitape coast of Papua New Guinea. Waves 10–15 m high so completely destroyed three villages that they were left almost without trace. Some 2,200 were confirmed dead, another 1,000 were seriously injured, while a further 10,000 were displaced from their homes (International Tsunami Survey Team, 1998).

From the outset, experts were puzzled that such large waves could be generated by a moderate (M7.1) earthquake, and that the wave was so focused, with most energy directed at a narrow sector of coastline. After extensive post-event investigations, most scientists now believe that the tsunami was caused by a submarine slump or landslide, that presumably was triggered by the shaking of the initial earthquake. This finding has alerted communities around the world to the possibility that catastrophic tsunamis can arise from submarine gravity-driven mass movement, even without fault rupture (International Tsunami Survey Team, 1998).

3.1.5 Explosions and tsunamis

In the 20th century, a new category was added to the list of possible tsunami causes: tsunamis resulting from human-induced explosions. During World War I, on 6 December 1917, the munitions ship Mont Blanc carrying an equivalent of about 2,900 short tons of TNT collided with the relief ship Imo at the port of Halifax. A fire ensued, and as the cargo ship drifted to the Halifax side of the port, it exploded, killing an estimated 2,000 residents and injuring some 9,000 more. It is believed that many died from a resultant tsunami. Using historical narrative reports, tide predictions and tidal data from before and after the world wars, researchers were able to model the event and estimated the tsunami’s amplitude to be two to four metres in magnitude (Greenberg et al., 1993).

3.1.6 Bolide-generated tsunamis

While extremely rare, the fall of large meteorites and asteroids in the Earth’s oceans has the potential to generate cataclysmic scale tsunamis. It is estimated that an asteroid five to six kilometres in size impacting the Atlantic Ocean would be sufficient to wipe out coastal cities on both sides of the ocean. A similar size object impacting between Hawaii and the West Coast of North America could destroy the coastal cities of Canada, the U.S. and Mexico as well as most of the inhabited coastal areas of Hawaii (Intergovernmental Oceanographic Commission, 2001).

3.2 Tsunami hazard along the west coast of Canada

Canadian West Coast tsunami hazards are generally characterized by three types of tsunamis:

- Telegenic tsunami
- Local tsunami (marine)
- Local tsunami (terrestrial)

3.3 Telegenic tsunamis

Canada’s west coast is vulnerable to the effects of tsunamis generated at numerous locations along the subduction zones of the Pacific Rim. These events are rare and often cause little or no damage. For example, Clague (2001) reported that between 1906 and 1981, only two of 43 tsunamis recorded at the Tofino tide gauge, on the west coast of Vancouver Island, produced waves more than one metre high. However, occasionally, a great earthquake creates a large tsunami that can cause significant damage and loss of life. The largest recorded and most dangerous past century tsunami to impact the Canadian west coast was triggered by a magnitude 9.2 subduction earthquake in Prince William Sound, Alaska on 27 March 1964. Within a few hours, it reached the Queen Charlotte Islands and, two hours later, swept along the west coast of Vancouver Island entering bays and channels enroute. Many British Columbian communities were impacted, including Hot Springs Cove, Zebellos and Port Alberni. Damage was estimated to be around $10 million (1964 dollars). Fortunately, no lives were lost (Clague, 2001; Dunbar et al., 1989; White, 1966). Further details of this event will be described later in this report.

Unfortunately, preparing for these types of events in advance is problematic because accurately forecasting future earthquakes is not possible at present. Consequently, the travel time of the next tsunami is also unknown (Dunbar, et al., 1989). However, when a large earthquake does occur anywhere in the Pacific area, seismic waves are recorded by a network of seismic stations within minutes. Readings from these stations are correlated to determine the location of the earthquake. However, until the effect of a tsunami is reported by a tide gauge station, it is often not known whether or not a tsunami has actually been generated. Delays in detection can also occur because of the distance between the source of the event and the nearest reporting tide gauge (White, 1966).

Despite these uncertainties, based on analysis of historic event, local cultural and other records (McMillan and Hutchinson, 2002), analysis of cored and trenched tidal marsh sites (Williams et al., 2003), as well as current scientific data on tectonic plate movement, scientists have concluded that it is highly probable that large tsunami events will recur and that risks to lives and property are very real. Further, it is now possible, using advanced computing systems, to use this data to mathematically model tsunami wave generation and propagation effects and, thus, identify those regions around the Pacific Rim that are most likely to produce the greatest tsunamis along the British Columbia coast. This methodology permits flexibility in specifying tsunami source regions, generation mechanisms, as well as assimilation of complex bathymetry and topographical features of coastal waterways (Dunbar et al., 1989).

In 1989, a study was conducted to determine representative wave heights and current velocities along the British Columbia coastline that are likely to result from great earthquakes around the Pacific Rim (Dunbar et al., 1989). This was the first time that numerical modeling methods had been applied to this region on such a broad scale to approximate maximum tsunami wave heights. Previous estimates had been based solely on experience, intuition or statistical methods applied to historical tsunami records (Dunbar et al., 1989). Key stated objectives of the study were to:

- Derive a set of numerical models for tsunami generation and propagation from their point of origin to the heads of inlets along the British Columbia coast;
- Examine the sensitivity to tsunami water levels in inlets to different source locations (directional effect on water levels) and to source strength by varying the magnitude of bottom motions;
- Identify the source region that is likely to produce the largest tsunamis along the British Columbia coast from epicentres located in Alaska, Chile, the Aleutian Islands (Shumagin Gap) and Kamchatka;

- Determine the maximum expected water levels at each selected location along the British Columbia coast for earthquakes at the above sources and identify critical inlets where tsunamis are magnified by topography; and
- Identify areas in the modeled inlets where large current speeds will result from the passage of a tsunami wave (Dunbar et al., 1989).

Study of seismic activity in the Pacific Ocean was confined primarily to those zones where ocean plates, subducting under continental land masses, intermittently released large earthquakes. Other active areas, such as the Hawaiian Islands, were excluded on the basis that their earthquakes do not pose a destructive tsunami threat in British Columbia waters (Dunbar et al., 1989).

Four specific source regions were identified and simulated for ocean bottom displacements. These were the source regions of the 1960 Chilean and 1964 tsunamigenic earthquakes, and hypothetical earthquakes in the Shumagin and Kamchatka Peninsula regions. The study took into account that tsunamis arriving at British Columbia's outer coast propagate into all exposed inlet systems. Twenty of the more exposed inlet systems were studied employing detailed bathymetry and cross-sectional and surface area data. The 1964 Alaskan earthquake provided an opportunity to verify the modeling system using a well-documented tsunamigenic event (Dunbar et al., 1989).

The study produced a number of important findings:

- Tsunami wave crest generation and propagation to the heads of B.C.'s inlets can be modeled successfully. Based on simulation of the 1964 Alaska tsunami, wave arrivals were within an accuracy of two per cent; initial wave amplitudes within 20 cm; and subsequent wave amplitudes within 15 per cent.
- Tsunami wave heights are strongly influenced by source location and magnitude. Modeled earthquakes in the two closest areas, the 1964 Alaska earthquake and the Shumagin Gap regions of the Aleutian Islands, produced the largest waves and strongest currents.
- Maximum modeled water levels vary significantly from one region to another along the British Columbia coast. The six geographic zones summarized in Table 1 indicate critical areas that are subject to high wave amplitudes. With exceptions noted, the estimates were based on occurrence of a very large tsunamigenic earthquake in the Shumagin Gap region of the Aleutian Islands.
- Chile, the farthest source point, generated the smallest waves, and is not considered a probable source of tsunamis greater than 1.5 m amplitude in coastal inlets.
- The highest crest in a series of tsunami waves is often not the first to arrive. Consequently, the behaviour of a series of waves inside the inlets must be predicted, which demands, in turn, a realistic treatment of boundary conditions, most especially at the landward end.
- The principle limitation to estimating tsunami wave heights more accurately for particular sources is the uncertainty associated with specifying the final bottom displacements that will result for an earthquake occurring at the source.

Table 1 Maximum tsunami amplitudes resulting from subduction earthquakes in the North Pacific Ocean (Source: Dunbar, et al., 1989)

Zone	Location	Height (m)	Source area
North Coast	Near head of Khutzeymateen Inlet	3.5	Alaska
	Through Hastings Arm	3–3.5	Alaska
	Near Stewart	3.5–4	Alaska
North Central Coast	West of Princess Royal Island	3.5–4.5	Shumagan
	Cousins Inlet	4.2	Shumagan
	Head of Spiller Channel	7.2	Alaska
	Head of Laredo Sound	5.6	Shumagan
	Head of Surf Inlet	3.3	Shumagan
South Central Coast	Heads of Rivers and Moses Inlets	3.3–9.2	Shumagan
	Smith Inlet (increasing toward head)	6–9.3	Alaska
Northwest Coast of Vancouver Island	Quatsino Sound	5.5–7.2	Shumagan
	Neroutsos Inlet	up to 9	Shumagan
	Quatsino Narrows	8–8.5	Shumagan
	Head of Holberg Inlet	3.4	Shumagan
	Forward Inlet	6–7	Shumagan
	Klaskino	5–6	Shumagan
	Head of Quoukinsh Inlet	> 10	Shumagan
Central Coast of Vancouver Island	Nuchalitz Inlet	3.5–4.5	Shumagan
	Muchalat and Tlupana Inlets (increasing toward the heads)	4.5 – > 10	Shumagan
	South end of Tahsis Inlet	3.5–4.5	Shumagan
	Head of Tahsis Inlet	3	Shumagan
	Port Eliza and Espinosa Inlets	3.6–7.6	Shumagan
	Nootka Sound	3.5	Shumagan
South Coast of Vancouver Island	Sydney Inlet	3–4	Shumagan
	Pipestem and Effingham Inlets	4–8	Shumagan
	Alberni Inlet (increasing toward head)	3–8	Shumagan

These findings indicate that many British Columbia coastal inlets could be hit by very high tsunami waves, some even greater than 10 m, with maximum currents up to 5 m/s (Dunbar et al., 1989).

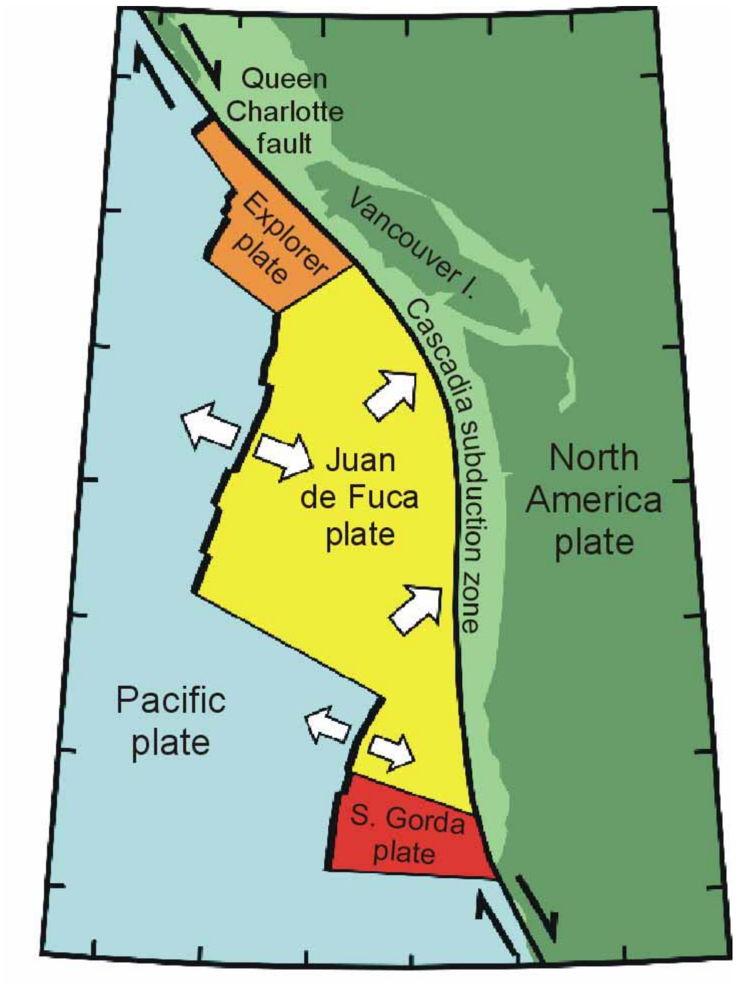
Outputs of the models were used to prepare maps and tables showing the largest wave heights and currents from each source area at several areas along the British Columbia coastline. These locations were chosen primarily on the basis of local human activity, including First Nations villages, townships, log-booming grounds and industrial development (Dunbar et al., 1989).

3.3.1 Local tsunamis – marine

Despite the serious threat posed by distant tsunamis, an even greater threat to British Columbia is posed by local tsunamigenic earthquakes. For British Columbian residents, conceiving such a threat is problematic because for many, these forms of tsunami impacts do not form any part of their contemporary cultural memories. Since post-colonial settlement of British Columbia, only one local earthquake-generated tsunami is recorded. In 1946, a strong (7.3 magnitude) earthquake occurred near Campbell River on the east coast of Vancouver Island. Associated with the earthquake was a displacement of ocean bottom of up to 3 m (Murty and Crean, 1986). It remains the strongest on-land earthquake recorded in Canada. While, no major tsunami was recorded, some minor water level displacement occurred due to landslides and slumping triggered by the earthquake. Numerical simulations of water level disturbances that occurred following the earthquake reported that while there was likely no major Strait of Georgia-wide tsunami, the water level disturbances would have been large enough to be noticeable and potentially destructive (Murty and Crean, 1986).

The absence of local earthquake-induced tsunamis in recent times, however, does not diminish the seriousness of their risk. In fact, historically, some of the largest North American earthquakes and associated tsunamis have occurred along a 1,100 km Cascadia subduction zone located approximately 100–150 km seaward of Vancouver Island where continental and oceanic plates meet. The zone extends from just north of Vancouver Island to a southern location off northern California. The zone is composed of three main segments: the Explorer, Juan de Fuca and Gorda South Plates (Ng et al., 1990).

Figure 5 Cascadia Subduction Zone
(Source: John Clague, SFU)



Two distinguishing features have been reported about this zone (Heaton and Kanomori, 1984; Heaton and Hartzell, 1987; Rogers, 1988; Dragert and Rogers, 1988): 1) the absence of any shallow-thrust earthquakes across the plate interface since European contact was established in the region over 200 years ago; and 2) the subducting segments are relatively young – some six to 10 million years old. These features are considered to favour strong coupling between the Cascadia and North American continental plates due to their high buoyancy, enabling a large force across the plate interfaces, and due to their flexibility, permitting a larger area of contact (Ng et al., 1990).

Studies over the past decade confirm that the shallow offshore parts of the fault zone are indeed locked, and that the accumulating stress ultimately will be released in a great earthquake (Dragert et al., 2001). In 1992, the Geological Survey of Canada began using Global Positioning System (GPS) instrumentation to monitor ongoing deformation of the southern coastal region of British Columbia to a resolution of 1 mm per year. Presently, some 40 GPS sites continuously monitor crustal motion along the Cascadia zone from northern California to southwestern British

Columbia. Studies of the data collected reveal average long-term movements of up to 15 mm per year due to fault locking on the shallow subduction zone (Geological Survey of Canada, 2003).

Further, monitored sites in northwestern Washington State and southwestern British Columbia have been shown to be converging as a result of strain building along the Cascadia subduction fault offshore. Through analysis of the GPS data, seismologists have also discovered that, in 1999, a cluster of seven sites briefly reversed direction through slippage with no concurrent detection of seismicity. These aseismic (silent) slip events appear to occur on the deeper Cascadia subduction interface and are theorized to play a key contributing role in the cumulative stress loading of the fault zone, with each event bringing the locked zone closer to failure (Dragert et al., 2001). The process of deep slippage leading to megathrust earthquakes is now thought to be responsible for the 8.4 magnitude 1944 and 1946 Nankai Trough, and 9.5 magnitude 1960 Chilean earthquakes, suggesting that enhanced seismic risk may accompany silent slip events) (Dragert et al., 2001).

Most recently, refinements in detection have revealed measurable tremor activity associated with slippage. Analyzing a sequence of events (1997–2003), sustained tremor activity on southern Vancouver Island was observed to coincide with slip occurrence (Rogers and Dragert, 2003), a phenomenon known as Episodic Tremor and Slip (ETS). Future study correlating GPS measured and seismic motion detection is anticipated to yield better understanding of subduction behaviour and accompanying seismic hazard, as well as enable movement towards real-time monitoring of the seismic potential of subduction megathrust events (Geological Survey of Canada, 2001).

Because of the differing ages of the Cascadia zone segments, there has been uncertainty expressed about whether or not all segments would rupture as a whole or independently. Assuming they rupture as a whole, Ng et al. (1990) forecast a magnitude of over nine and forecast magnitudes of about eight if they rupture independently. Rogers and Dragert (2003) indicated that in five of the six ETS events recently observed, tremor activity continued to move north along the axis of Vancouver Island, and then beyond the scope of diagnostic GPS coverage. At this point they have been unable to determine whether slip events occur everywhere along the Cascadia Margin, and if they do, whether they are identical in nature. If regional differences in recurrence interval and magnitude of slip events exist, then perhaps this ultimately may tell us something about the likelihood of rupture of individual segments (Dragert, 2004).

3.3.2 Local tsunamis – terrestrial

Locally generated tsunamis caused by terrestrial and submarine landslides also pose a hazard to people and property both in maritime and fresh water regions of British Columbia. For example, in 1975, a large submarine landslide at the head of Douglas Channel triggered a local tsunami with a wave amplitude estimated as large as 8 m and a water disturbance lasting for about an hour (Murty, 1979). The wave caused some $600,000 in damages (Clague, 2001) to boats, docks and other property in Kitimat Harbour.

Within the Lower Mainland region of British Columbia, tsunami hazard has traditionally been considered a low probability in community planning activities. Yet, many areas in the Fraser River Basin, especially sections of the Fraser Canyon, are prone to large landslides. Even within the Greater Vancouver Region, various forms of tsunami hazard exist. For example, on 28

February 1880, 27 acres of farmland, located on the north side of the Fraser River in Haney (now Maple Ridge), slid into the Fraser River. First-growth fir trees came down for over half a kilometre, still standing upright as they slid into the water. Earth and debris all but blocked the river, causing a displacement wave 12 m high. The force of the resulting wave swept across the river, downing trees as if they were matchsticks and stripping giant fir trees of their branches a full 6 m from their roots. The force of the wave picked up a man and flung him across his orchard. His son found his body in a tree (Waite, 2000). Today, the floodplains of the Lower Fraser Valley are home to an estimated 300,000 residents and many of the province's key industrial facilities.

Some 42 years ago, another, potentially even more significant source of local tsunami hazard was identified in the Georgia Strait. This area, located between the British Columbia Mainland and Vancouver Island is a basin which is underlain by thick sedimentation that reflects a history of intermittent slumping. Although this body of water is effectively sheltered from the largest tsunamis generated in the open Pacific Ocean, it may be prone to large internally generated tsunamis. Recently the Canadian Hydrographic Service (Intergovernmental Oceanographic Commission, 2003) conducted numerical modelling of landslide-generated tsunamis in the Strait of Georgia for two areas of potentially unstable sediment deposits suggesting the need for reassessing tsunami risk in community and regional economic and social planning throughout the Basin area.

3.3.3 Seiches

Another phenomenon, often mistaken for tsunamis because of their tsunami-like effects, are *seiches*: oscillations in enclosed bodies of water generated by seismic waves. An example is the local seiche on Comox Lake generated by the 1946 Campbell River earthquake that was sufficient to cause some damage and the death of a man whose dingy was overturned by one of the waves (Barlow, 1993).

They can also occur very far from the source of an earthquake. Following the 1964 Alaskan earthquake, reports of seiches in inland bodies of water were reported from a number of areas within British Columbia. Osoyoos Lake in the southern Okanagan region was observed to have risen about a third of a metre along its shoreline. A similar observation was reported on Sproat Lake near Port Alberni. Fracturing of ice was reported on numerous lakes in northwestern and north central British Columbia (White, 1966). A megathrust earthquake along the Cascadia subduction zone could generate numerous seiches throughout British Columbia.

3.4 Impacts of tsunamis

As reported earlier, several factors make tsunami hazard inappropriate to study using conventional statistical methods. Because they are not regularly occurring events and their actual impacts can vary considerably, the only reliable data is of events which have been recorded. Further, while numerical modelling of probable inundation, run-up and currents can be undertaken with an increasing degree of accuracy, the event record is the only reliable confirmation of the actual magnitude of tsunamis. As such, sand sheet, tree ring, radiocarbon dating and other analyses are vitally important for identifying, verifying and dating past physical impacts. However, the integration of human anecdotal and empirical evidence with this research is also crucial in order to qualitatively understand human, environmental and other impacts of tsunamis.

For example, the oral traditions of Northwest Coast First Nations peoples have recorded devastating impacts of tsunamis and earthquakes on coastal villages. Many have been confirmed through archaeological evidence of village abandonment associated with large earthquakes and tsunamis (Hutchinson and McMillan, 1997). Seismic experiences and perceptions are also incorporated into indigenous ritual performances, carvings and beliefs (McMillan and Hutchinson, 2002).

Although no catastrophic event has occurred in modern times along the British Columbia coast, historic records and geological data, combined with records of the 1964 Alaska tsunamigenic earthquake and those recorded elsewhere around the Pacific Rim, offer insight to the types of damage they can cause.

3.4.1 Tsunami damage

The damage and other resultant effects of tsunami events are generally a function of tsunami traits interacting with shore-based variables. However, since these interactions vary considerably from community to community, as well as within communities, determining the risk associated with a tsunami is an extremely complex process (Preuss, 1988). It is possible, however, to classify tsunami impacts into short-term or direct losses versus those impacts that may have long-term consequences.

3.4.2 Short-term tsunami impacts

Tsunami waves have been known to cause serious physical damage to coastal structures by pressure, scour and impact. In its simplest form, damage is caused by hydrostatic pressure from rising water, causing building collapse and bridge and building flotation (Barlow, 1993). Other damage results from hydraulic forces, such as water surging inland and drag forces created during both run-up and run-down (Preuss, 1988 in Dengler, 1998). High velocity currents associated with run-ups and run-downs greatly adds to the damage by causing scour (removal of sea and river bed). Scour can lead to the loss of support of structures such as pilings, as well as damage to dykes, railway tracks and roadways, and the removal of soil and fill. Scour due to high velocity currents may also destroy oyster and clam beds and salmon farms (Barlow, 1993).

Impact from debris such as docks, logs, boats, floating cars and houses also contribute to the damage and loss of life. The source of the currents which cause so much of this devastation is the change in water level of as much as 30–60 cm/minute. Coastal effects and damage due to inundation are directly related to run-up height, while damage due to impact and velocity drag on structures and objects is directly related to steepness of wave edges and their surface rise and fall speed (Barlow, 1993).

Within harbours and marinas, there may be serious damage to boats if there is insufficient time to evacuate them to deep water where tsunamis wave heights are insignificant. Normal mooring and anchoring methods are inadequate for the high currents experienced. As the 1868 Arica Tsunami demonstrates, vessels may be damaged by pounding, capsized, sunk, or even carried and beached a long distance inland. In addition to high water, retreating tsunami waves can also cause extremely low water levels, leaving vessels grounded and/or tipped on their sides and inevitably swamped by succeeding incoming waves (Barlow, 1993).

3.4.3 Indirect or long-term impacts

Damage to infrastructures caused by tsunamis can often trigger secondary effects such as fires, chemical spills, aerial releases and explosions, and sewage pollution. Associated human impacts can include lengthy evacuations, loss of use of critical infrastructure, extensive clean-up, repairs and reconstruction, unemployment and business disruption, as well as social disruption and trauma.

3.5 British Columbia and 1964 Alaskan earthquake

Although the 27 March 1964 (9.2 magnitude) Alaskan earthquake was widely felt, all of the damage in Canada was produced by the tsunami it propagated. At 11:00 p.m. that evening, B.C. residents learned of a tsunami proceeding down their coast. As the tsunami waves moved along the coast, they swept into the fiords of the islands and mainland. Some of the earliest and largest waves coincided with the natural high tide, causing crests to rise several metres above the high water line and to flood many low-lying areas (White, 1966).

Residents in the Alberni Valley thought the effects of the tsunami would not be felt since Alberni Inlet stretches so far inland. In fact, Alberni Inlet is a 40 km long fjord on the west coast of Vancouver Island with the twin cities of Alberni and Port Alberni situated at the head of the fjord. Historically, Alberni had been where the people lived, and Port Alberni the site of the mills, docks and wharves.

Although sheltered from ocean swell and wind waves, residents discovered that they were not immune to amplitude waves from the Pacific Ocean. At approximately 15 minutes past mid-night on March 28, the first tsunami struck the Alberni communities. This wave served as a warning and provided sufficient opportunity to alert emergency services and prevent loss of life to residents situated in low-lying areas. However, the second wave was much less forgiving. Arriving about 90 minutes later, and traveling at approximately 380 km/h on top of a tide created by the first wave, it smashed everything in its path, tossing enormous logs and other debris, including buildings, boats and automobiles. It then receded, followed by a recession of lesser waves over the next 18 hours (British Columbia, 1964 and White, 1966). Fortunately, the waves were traveling on a falling tide. The wave with the highest total water level was the second wave, estimated to be 4.4 m with a tsunami amplitude of 3.6 m. Although the third wave's tsunami amplitude was higher (4.1 m), it occurred at a lower tide, resulting in an overall wave height of approximately 4.1 m (Holden, 1995).

Tsunami impacts occurred mostly in the low-lying areas bordering the head of Alberni Inlet and along the north side of the Somas River. The greatest damage was recorded in the foreshore residential area of the City of Alberni, where the City Hall was partially flooded and buildings not bolted to their foundation were swept up to 300 m inland. Those with concrete block or wood frame construction fixed to foundations moved only a short distance. Many residents were caught in their homes, and as the fast-moving water knocked out residential electricity and outside street lighting, those who could waded chest-deep in the dark to higher ground. Others, including vehicle passengers, had to be rescued by boat (British Columbia, 1964).

Figure 6 Tsunami effects in Port Alberni, 28 March 1964
(Source: British Columbia, 2003a)

Log booms and boats in the inlet were carried high on shore, causing damage and providing obstructions to rescue operations. Logs also posed a secondary hazard. While it was undamaged, the sewage lagoon serving the cities was filled with logs. Dyke walls of the lagoon were further weakened as material washed away. The logs were removed and walls were rebuilt immediately, preventing sewage leakage. Another serious secondary hazard was the fire risk of propane gas escaping from storage tanks. The risk was lessoned by placing a ban on smoking. Fortunately, no fires or explosions ensued (British Columbia, 1964).

Heavy deposits of silt on all submerged objects contributed to damage and person-hours required for clean-up. Virtually all harbour industrial activity was halted until extensive clean-up and repairs could be carried out. Wharf structures were also damaged, due in part to decks rising in the waves and then hanging up on each other during recessions (White, 1966). Motels, car dealerships and other small businesses suffered extensive damage to stock, equipment and furnishings. Further business loss was experienced due to access restrictions to affected areas pending arrival of damage assessment and clean-up crews (British Columbia, 1964). Total damages were estimated to be approximately $10 million in 1964 figures (Barlow, 1993).

From a communications perspective, numerous problems surfaced. First, the damage occurred with little warning. At the time, no public warning system existed either regionally or provincially for civil disasters. The only system in place was the National Survival Attack Warning System, although some local officials had previously expressed concern that the role of Civil Defence in natural and human-made disasters was not stressed enough, as many people mistakenly believed it only had a role and responsibility in a nuclear attack (British Columbia, 1964). Secondly, even if a local public warning system was available, there was no system in place for conveying the necessary input warnings to local authorities. Due to the absence of serious tsunamis during the history of tidal recordings along the west coast, Canada had chosen to discontinue its participation in the Pacific Warning System in 1963. Consequently, there was no official warning of the first wave (White, 1996; Barlow, 1993).

Getting messages out of the area was also problematic. The City of Port Alberni had chosen to discontinue its participation in the Civil Defence program in 1963, while the City of Alberni had only maintained a small-scale organization. This lack of civil defence organization delayed alerting Provincial Civil Defence headquarters in Victoria about the disaster. Instead, initial reports came through news broadcasts (British Columbia, 1964). Alberni area communication was also hampered when the local radio station was knocked off the air. Although telephone services within unaffected parts of the community and to Victoria and other parts of the province were unaffected, local network congestion delayed calls (other than emergency calls) for about two hours on the first day (British Columbia, 1964).

While much of the public attention was focused on Port Alberni, many of the more remote regions were also impacted. A summary of the most significant reported impacts are contained in Table 2.

Table 2 Regions impacted by the 1964 tsunami
(Source: White, 1966; British Columbia, 1964; Barlow, 1993)

Location	**Impacts**
Hot Springs Cove	20 homes destroyed, residents evacuated to nearby community of Ahousat, 40 people evacuated and one woman injured during rescue, damage approximately $10,000 (1964 dollars)
Gold River	Elk River Company dormitories flooded
Zeballos	Main street flooded, buildings (including 30 homes) moved, extensive flood damage to homes and stores, damage approximately $150,000 (1964 dollars)
Fair Harbour	Bridges across mud flats damaged
Amai Inlet	Half of the houses at Jorgenson Brothers camp shifted, some carried up the river, radio telephone service knocked out; 37 people spend first two nights in the open.
Winter Harbour	W.D. Moore Logging Company booming ground piles completely destroyed by first wave. 9 m tender carried out of one inlet and carried up another inlet and deposited on beach
Port Alice	Log booms broken apart, small wharves swept away and some boats destroyed
San Joseph Bay	Large trees swept away from north river bank, clam denuded, and stream jammed at tree line with logs
Port McNeil	Pioneer Timber Company pilings and dolphins in booming ground snapped off

3.5.1 Lessons learned

Follow-up studies to the disaster revealed a number of deficiencies both in the warning systems and the organized response capabilities of the province and local communities. Soon after the incident, participation in a west coast warning system was restored. (Subsequent changes and improvements to this system will be discussed later in this report.) It was also apparent that local plans needed to be prepared that set forth responsibilities, authority, lines of communication and the means of coordination of local services in a disaster. A means of warning people in a disaster situation was also proposed that would not be confused with the National Survival Attack Warning System. Depending upon community resources, factory whistles, volunteer fire department signal systems, large bells, and loudspeakers were suggested (British Columbia, 1964).

4.0 The B.C. Tsunami Warning System

A study of the current British Columbia Tsunami Warning System (B.C. TWS) and related risk reduction practices requires the adoption of a model on which to represent the various functions and organizational connections involved. Mileti and Peck (Mileti & Peek, 2000) offer a well-respected functional model for warning system design that is helpful for categorizing major elements of the B.C. TWS:

- Detection subsystem
- Emergency management subsystem
- Public response subsystem

4.1 The detection subsystem: tsunami warning for the eastern Pacific region

The function of the detection subsystem is to identify the presence of a hazard or the existence of hazardous conditions. In the case of tsunami warning, this involves the monitoring and detection of certain seismic events, the anticipation and detection of tsunami generation, the tracking and monitoring of any generated waves, and the forecasting of wave arrival times and heights along the coast.

Since 1965 the detection subsystem supporting the B.C. tsunami warning system has been coordinated at an international level through the International Coordination Group for the Tsunami Warning System in the Pacific (ICG-ITSU) under the auspices of the International Oceanographic Commission. Canada is a member of this group, along with some 28 other member states located within the Pacific Rim. Responsibility for mitigating the effects of tsunamis in the Pacific region falls within the mandate of the International Tsunami Information Centre (ITIC), which routinely monitors and evaluates the performance and effectiveness of the Tsunami Warning System for the Pacific. ITIC issues recommendations in the form of reports presented at ITSU meetings, which in turn provide supplementary guidelines for national authorities in areas such as effective data collection, analysis, impact assessment, and warning dissemination.

The Pacific Tsunami Warning Center (PTWC) is responsible for overall operation of the system and works closely with member states, as well as with regional centres such as the West Coast/Alaska Tsunami Warning Center (WC/ATWC), which is responsible for issuing bulletins for British Columbia. The WC/ATWC in close coordination with PTWC monitors on a continuous basis for potential tsunamis and disseminates watch, warning, and advisory bulletins based on seismic and tidal data gathered from ITSU-member infrastructure located throughout the Pacific basin. Details of the system's operation at this level can be found in ICG-ITSU documents. The PTWC and WC/ATWC are also involved with NOAA's Deep-ocean Assessment and Reporting of Tsunami (DART) program.

Dissemination of bulletins is also a cooperative undertaking that requires international communication facilities to distribute messages to over 100 points across the Pacific Basin. These messages are sent on a formal basis to a single designated point per defined region but other local, regional, and international users as well as the media may be permitted to "eavesdrop" on these transmissions. The PTWC publishes a Communication Plan on a regular basis that provides general information about its operation and requirements (Intergovernmental Oceanographic Commission, 2001).

4.2 The emergency management subsystem: tsunami warning for the B.C. coast

The function of the emergency management subsystem is to determine the extent and magnitude of the tsunami threat to B.C. This includes assessment of public safety threat, property loss potential, environmental damage potential, and economic loss potential. In the event of a tsunami advisory, watch or warning bulletin issued by the WC/ATWC for B.C. coastal populations, the provincial government is responsible for coordinating response within B.C. It is important to note, however, that this subsystem is most effective in the case of far-field or telegenic tsunamis, where there is sufficient time to determine possible tsunami risk and affect a response along the coast. Locally generated tsunamis may pre-empt activation of this subsystem, as clearly indicated in the B.C. Tsunami Warning Plan:

> 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).

On behalf of the province, the Provincial Emergency Program (PEP) receives WC/ATWC bulletins at its Emergency Coordination Centre and contacts the Regional Tidal Superintendent for the Canadian Hydrographic Service (CHS) of Fisheries and Oceans Canada to have CHS staff assess the local tsunami threat based on ocean and tidal conditions at the time bulletins are issued. Communication between B.C. PEP and the CHS at this point is crucial to issuing a timely and accurate bulletin for local populations. The B.C. PEP Emergency Coordination Centre is staffed continuously, but CHS staff members may be off-duty or otherwise away from the office when a bulletin is issued and so need to carry a pager or mobile phone. Office telephones may also be call-forwarded to home or mobile phones when staff members are off-duty.

The current communications arrangement between B.C. PEP/ECC and CHS is through CHS “tsunami telephone,” home telephone, and pager. This is backed up by radio communications through Coast Guard (Pacific Region) – Marine Communications and Traffic Services. CHS plays a twofold role in the B.C.TWS insofar as it provides an assessment of local threats based on bulletins received from WC/ATWC, and it provides a local detection function through a data network with three dedicated tsunami warning stations along the B.C. coast.

When a bulletin is received via B.C. PEP, CHS staff then use tsunami travel time charts and other sources of coastal information to determine the local threat. These procedures include active monitoring of three tsunami warning stations along the B.C. coast (located at Tofino, Winter Harbour, Langara Island). Data communication between these stations and CHS is designed for Supervisory Control and Data Acquisition (SCADA) applications facilitated by telephone modem, with satellite telephone (MSAT Packet Data Network) backup.[1] Future enhancements to the SCADA system (according to Canada’s report to ITSU-XVIII in 2001)

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[1] In the January-March 1990 issue of *Emergency Preparedness Digest*, an article describes the installation of what appears to be these monitoring stations, stemming back to a pilot project in 1983 for the Institute of Ocean Sciences. The monitoring stations were built by Sierra-Misco Environment Ltd., and were reported as using ‘Meteor Burst VHF radio’ for communications link with a base station on Saturna Island (Jervis, 1990).

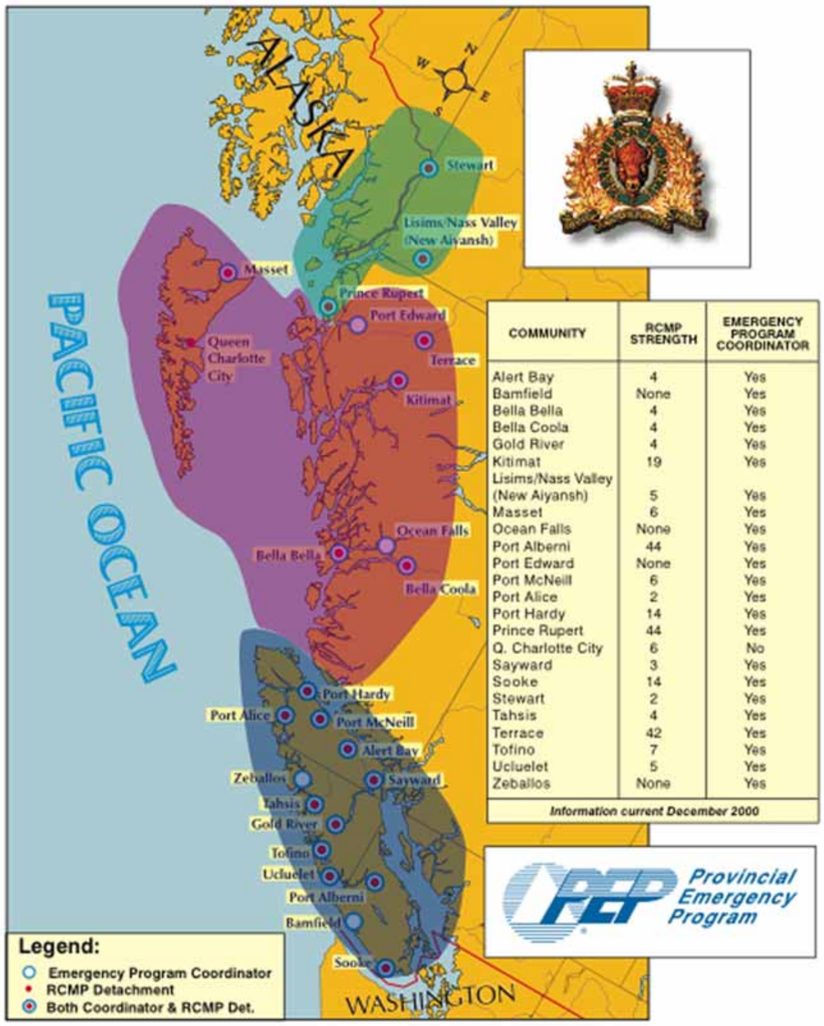
“will provide the capability to access the IOS tsunami computer by laptop or palmtop computer using a cellular phone. This will provide immediate access to the data and station parameters, including ability to change the station parameters.” A related enhancement described in this report is “to have incoming data placed on a website for reference by selected users” (Canada, 2001, 2003).

The B.C. Tsunami Warning and Alerting Plan is principally concerned with the emergency management subsystem and establishing a warning network between B.C. PEP and those organizations and agencies that it intends to contact for issuing B.C. Tsunami Advisory Bulletins. These organizations include federal government agencies: PSEPC (B.C./Yukon), National Defence (MARPAC), the Canadian Coast Guard, NAVCAN, and RCMP ‘E’ Division. B.C. PEP is also to contact provincial government agencies, although the list of specific contacts is not included in the Plan. The Plan also calls for dissemination of bulletins to RCMP detachments along the coast and to local authority emergency program coordinators, as well as broadcast media. It is assumed but not detailed in the Plan that these organizations will then inform local populations and coordinate community-wide protective action response.

The Plan defines four regions along the B.C. coast for referring to tsunami advisory bulletins. These are a simplified version of the “breakpoint” methodology employed by the WC/ATWS (British Columbia. Provincial Emergency Program, 2001). These regions provide logical boundaries for comparative assessment of communications requirements and warning capabilities along the B.C. coast. This includes:

- The entire B.C. coastline;
- Prince Rupert north to Stewart on the Alaska border;
- The Queen Charlotte Islands and the mainland coast from Queen Charlotte Strait north to Prince Rupert; and
- The west coast of Vancouver Island from Port Renfrew north, and coastal areas bordering Queen Charlotte Strait and Johnstone Strait.

Figure 7 Coastal Warning Zones
(adapted from B.C. PEP source map)



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

Coastal Communities at Risk and Local Warning Capabilities
(from British Columbia Tsunami Warning and Alerting Plan 2001)

According to the B.C. Tsunami Warning and Alerting Plan, warnings are issued as "Tsunami Advisory Bulletins" by B.C. PEP to local authorities and may take the form of one of five specific types of notification, establishing a hierarchy of priority for communication and each with distinct implications for subsequent public warning and protection action response:

- Warning – tsunami wave verified; activate local emergency plans.
- Watch – tsunami wave not verified but possible; local authorities on standby.
- Information – no immediate tsunami threat; report on other regions for clarification.
- Cancellation – threat over; all previous bulletins cancelled; terminates advisory episode.
- All Clear – threat over; may be issued by local authorities and other agencies in accordance with B.C. PEP advisory.

4.3 The public response subsystem: tsunami warning for coastal communities

B.C. Tsunami Advisory Bulletins are issued by B.C. PEP to a list of contact points for local communities along the B.C. coast. These Bulletins are issued to all points but may be of higher priority for one or more warning sectors (noted previously). The role of the public response subsystem is to inform local populations of a potential or imminent threat to the area and to initiate and coordinate protective-action response measures, such as evacuation. It is important to note, however, that B.C. PEP is not responsible for community preparedness. Provincial legislation stipulates that communities must plan and prepare for emergencies and must maintain an emergency management organization.

Local warning activities are undertaken by a range of organizations and agencies, depending on the plan established within each community. Where there is an RCMP detachment or emergency program coordinator, they will be responsible for issuing warnings to members of the public. Where there is a large employer in the area (e.g., Norske Canada Paper Mill), warnings may be issued at the worksite.

Local areas falling outside provincial jurisdiction should receive warnings through the most appropriate channels. The marine community along the B.C. coast is served by Coast Guard Marine Communications and Traffic Services Division (MCTS), responsible for providing warning broadcast and subsequent communications service for ships at sea, in port or at anchor. Coastal shore-based populations may also intercept and monitor marine communications activity. Tsunami-related messages are routed through Prince Rupert MCTS, which is designated as primary Coast Guard link between WC-ATWC, Coast Guard Operational Sites, and B.C. PEP. Comox MCTS serves as an alternate site. Coast Guard communications may also serve as backup to PEP when requested by local PEP coordinators as part of an individual Stations contribution to their community plan (Department of Fisheries and Oceans–Coast Guard (Pacific Region), 2004).

There do not appear to be any published standards for the dissemination of Advisory Bulletins to the public by local authorities.

The public response subsystem can be extended to include planning and mitigation measures taken well in advance of a tsunami event. In fact, there are several identifiable stages of local warning:

- Residents and visitors first need to know if they are in or about to enter into an area at risk of tsunami.
- Individuals and other groups then need to know how they should expect to receive tsunami warnings (there may be more than one method depending on their location) and how to obtain additional information and interpret the messages that accompany them.
- Individuals and other groups need to know what responses are required in the event they receive a warning.
- Local dissemination points must be capable of receiving, possibly editing, and then issuing tsunami warnings (notifications) on a timely and consistent manner through appropriate (possibly multiple) channels.

- Local authorities must be prepared to answer questions and respond to requests for additional information from members of the public and local populations.

The first three points might be interpreted as part of a regional risk communication strategy rather than the warning system proper. A recently issued report on public warning for backcountry avalanche hazards in Canada may provide important insights for further work in these areas (O'Gorman, Hein, & Leiss, 2003).

The latter two points are more typically associated with tsunami warning and alerting as conceptualized in the B.C. Plan. Yet the B.C.TWS does not include this “last mile” in the warning system. The limits are clearly indicated in the Warning and Alerting Plan:

> [This Plan] 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 into local plans (p. 1-1).

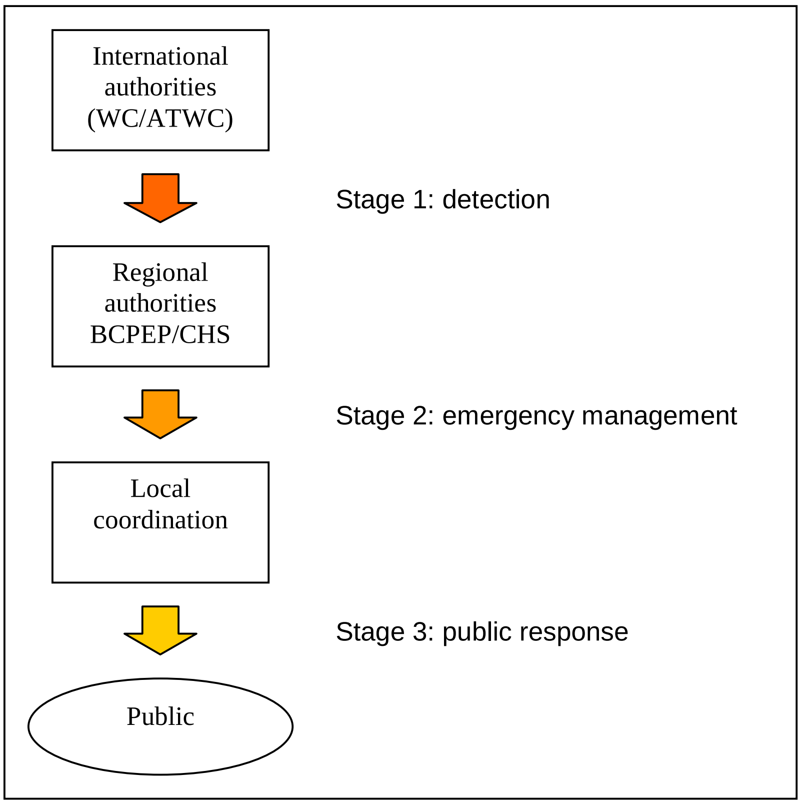
The Plan does advise, however, that B.C. PEP will assist in the preparation of local plans and will work to make educational material available for distribution. B.C. PEP has identified this role as a “Priority Work Action Issue” within its Strategic Objectives, listing three outstanding needs: improving local tsunami preparedness, maintaining a regular validation exercise schedule, and develop a planning strategy for emergency public warning in B.C. (British Columbia. Provincial Emergency Program, 2002a). It is not clear to what extent these needs have been addressed to date, although B.C. PEP did conduct a small-scale mitigation project with a select group of local communities in 2002 following a major exercise to test the B.C. Tsunami Warning and Alerting Plan (“Seaswell 5”) (British Columbia. Provincial Emergency Program, 2002b).

Under the Emergency Preparedness Act, Industry Canada is also assigned a lead role in the “the provision of advice and planning assistance to provinces and municipalities with respect to emergency telecommunications and related warning systems,” although no formal programs appear to be in place to facilitate this function. Industry Canada is currently sponsoring a public alerting initiative at the national level, which eventually may contribute significantly to this lead role through the development of guidelines, infrastructure, and financial support for implementation (Industry Canada, 2003).

4.4 The B.C. Tsunami Warning System: a three-stage dissemination network

From a communications perspective the B.C.TWS consists of three functional subsystems linked through a set of interfaces. It is thus helpful to adopt a complimentary model that recognizes these critical links as a three-stage detection and dissemination network (see Figure 8).

Figure 8 Dissemination Network Model (source: authors)



Each stage of the dissemination network model can be disaggregated into several focal points for study, from which we have derived a set of preliminary observations for this study:

- Focus on infrastructure;
- Focus on organizations and procedures; and
- Focus on policymaking, regulation, and resources.

4.4.1 Preliminary observations: stage 1

Infrastructure	• Multiple paths needed for communication redundancy but relatively modest data requirements.
Organizations and procedures	• Small network (few nodes), high reliability in following procedure likely. • Relies heavily on international cooperation for detection; Canada contributes tidal data through a network of stations along the B.C. coast. • Canada/B.C. does not contribute to tsunami detection. • Canada/B.C. can assess travel times; can NOT predict wave heights. • State/province tsunami communication links are weak and untested.
Policymaking, regulation and resources	• International agreements through IOC, federal government lead role in detection support and international liaison.

4.4.2 Preliminary observations: stage 2

Infrastructure	• Relies on public telephone or provincial PBX for voice and fax; may be suited to automated notification system; Internet is a possible option. • Internet and Web could provide follow-up information to compliment bulletins. • May require means to handle unexpected call volumes from public and/or local authorities (e.g., toll free number, call centre).
Organizations & procedures	• Medium-sized network, some diversity among stakeholders (e.g., federal, provincial, local). • Contact lists must be updated on a regular basis; multiple contact points at local level may create confusion. • Serial telephone calls are labour intensive and possibly time consuming; may require a policy for confirmation of receipt. • Two-stage process (including CHS consultation) that may be time consuming. • May require procedures and training for handling follow-up calls including provision of additional information (inundation maps, etc.) to local authorities.
Policymaking, regulation and resources	• Provincial government jurisdiction, but relies on and must liaise with federal government departments in certain areas and international agencies. • while federal, provincial agencies can predict arrival times and estimate tides along the coast, no Canadian agency can estimate tsunami wave heights at time of impact along the B.C. coast. This is critical emergency management information, imperative in deploying scarce resources to the highest impact areas to minimize

	life, property, and economic losses. • Resourced through B.C. Minister of Public Safety & Solicitor General; competes internally with other concerns (earthquake, flooding, etc.) • B.C. Tsunami Warning and Alerting Plan is key reference • B.C. TWA Plan does not address authorities or declarations of emergency – critical to evacuating people. • B.C. TWA is not a response plan – response plan required. • Preparedness and Recovery plans also required. • B.C. Emergency Response Management System (B.C.ERMS); provincial plans, strategies, guides, legislation, regulations; B.C. Inter-Agency Emergency Preparedness Council (IEPC).

4.4.3 Preliminary observations: stage 3

Infrastructure	• Infrastructure will vary depending on community; door-knocking; loudspeaker/siren (one system only in B.C.); media broadcast; marine radio; amateur radio; telephone; automated call notification system. • Inadequate communications and gaps in coverage remain a problem in many regions. • New technologies may improve communications capabilities at reasonable cost.
Organizations & procedures	• Large and diverse network of stakeholders; reliability of procedure may be low; remote or small communities may not have a 24/7 capabilities for receiving B.C. PEP issued advisories. • Possible lack of coordination between media and emergency coordinators; requires some familiarity with community and trust among population. • Possible gaps with First Nations, transient populations, and less visible members of the community and remote operations (logging camps/sorts; fish farms; recreational lodges; oyster farms; etc.). • Opportunity for advanced preparation and exercises. • Private industry and recreation facilities may require special arrangements for communications. • This stage is most affected by changing activities along coast.
Policymaking, regulation and resources	• Mitigation begins with local planning and development policies. • Resource constraints prevalent but duty of care obligation remains. • JEPP, NIF possible funding sources.

Our preliminary observations suggest that many of the challenges to B.C. TWS reside predominantly with the Stage 3 dissemination network. This is because of a number of related factors that will be explored further in this study:

- High diversity in stakeholder groups leading to uncertain reliability in the successful implementation of warning and alerting procedures and protective action responses.
- High infrastructure costs and resource constraints create a challenge for establishing effective communications or for upgrading current system.
- Changing composition of local communities along the B.C. coast creates higher percentage of transient, tourist, and other populations that pose unique challenges for warning and alerting.
- Emergency planning authority and capabilities vary considerably among coastal regions.

5.0 Stakeholder Groups along the B.C. Coast

British Columbia has an enormous coastal area that possesses an extremely diverse and productive environment unparalleled in Canada, and in many respects the world, in terms of the types of activities that can be accommodated in a temperate marine environment (Dobson, 2002). The region boasts enormous ecological wealth and diversity. It encompasses a variety of unique biophysical and ecological conditions. It supports hundreds of species of marine fish, internationally significant seabird colonies, herons, shorebirds, eagles, and migratory waterfowl. It is internationally renowned for its sea and land mammal populations, most notably the orca whale and the grizzly bear, as well as elk, mountain goat, and many others. Some of the largest and oldest forests in the world grow here (Dobson, 2002).

Despite its rich environmental diversity, it is also a region plagued by systemic economic and environmental pressures, including high unemployment, dependence on declining primary resource industries (e.g. forestry, fishing and mining), demands for increased environmental protection, conflicts associated with an increasing range of uses, and a declining public service sector. The search for new economic alternatives includes finfish and shellfish aquaculture, tourism and oil and gas, each with their own challenges (Dobson, 2002).

As one might expect from such an extensive range of economic activities and ecological considerations, the composition of stakeholder groups involved with the B.C. Tsunami Warning System is potentially quite large. In this section we have classified stakeholder groups using the three stage dissemination model. Current stakeholder groups are those identified explicitly in the existing B.C. Tsunami Warning and Alerting Plan or otherwise indicated by B.C. PEP staff.

5.1 Stakeholder groups at stage 1

- ITIC / ITSU
- West Coast/Alaska Tsunami Warning Centre
- Pacific Tsunami Warning Centre
- Canadian Hydrographic Service
- Coast Guard (Pacific Region) – Marine Communications and Traffic Services Division (MCTS)
- B.C. Provincial Emergency Program (Emergency Coordination Centre / Provincial Emergency Coordination Centre / HQ staff)

5.2 Stakeholder groups at stage 2

- RCMP “E” Division and Detachments
- Coast Guard (Pacific Region) – MCTS
- Maritime Forces Pacific (MARPAC) Operations Centre, Canadian Forces,
- B.C. Central Coordination Group
- B.C. Interagency Emergency Planning Council (IEPC)
- B.C. PEP Regional coordinators
- B.C. PEP Volunteers – SAR, Road Rescue, Radio, ESS, PEP Air
- B.C. Provincial Ministries, Crown Corps and Agencies – Ferries

- Neighbouring Provincial Emergency Management Organizations
- Public Safety and Emergency Preparedness Canada (PSEPC)
- Industry Canada
- Indian and Northern Affairs Canada
- States of California, Oregon, Washington and Alaska
- Navigation Canada (NAVCAN)
- Port Authorities
- Local Authorities/ Emergency Coordinators
- First responders (Fire, police, ambulance)
- Radio and television news agencies

5.3 Stakeholder groups at stage 3

While the current B.C. Tsunami Warning and Alerting Plan (p. 1-2) does not list specific stakeholder groups at the local level, it does identify five types of contact points that fall within the Stage 3 dissemination network:

- Local governance
- Industry
- Recreation
- Tourism
- Individuals

In some cases, these sectors may have little regular contact with B.C. PEP officials and may not fully appreciate the tsunami risk to their activities and investments. Communications links and capabilities also vary widely between and within these sectors. Moreover, social and economic changes along the B.C. coast are likely to most affect the specific composition of these groups over the next several years.

A more detailed assessment of these Stage 3 stakeholder groups will need to be undertaken because of the importance of these groups in providing the “last mile” of the B.C. tsunami warning system and because of the relative lack of information about them in the current B.C. TWAP. This section presents a preliminary overview of several of these stakeholder groups, focusing on industry, recreation, and tourism. Local governance is an important issue, particularly with respect to land claims issues and contested jurisdictions. Individuals living and working along the B.C. coast are often a special case in risk communication and will not be dealt with in this report; however, we recommend that interested readers consult a recent report on backcountry avalanche hazard for further information on dealing with individuals and personal risk (O’Gorman et al., 2003).

5.4 Industry stakeholder groups

5.4.1 Forestry

Forestry remains the number one economic contributor to British Columbia's overall economy. With 600 mills across the province, B.C.'s forest industry supports 260,000 direct and indirect jobs in more than 150 communities. It accounts for one quarter of B.C. provincial economic activity and supports vital public services. However, since the mid-1990s the forest sector's performance has been declining. This decline has resulted in forest workers losing their jobs and mills closing. More than 26 mills have closed and 13,000 forest jobs have disappeared. Government income has declined by more than $600 million. Major contributors to this decline are growing competition from around the world and trade disputes (British Columbia, 2003c).

Currently most of the coastal forest activities are located on Vancouver Island, the Queen Charlotte Islands and on the northern coast near Prince Rupert and Kitimat. A number of areas along the B.C. coast are protected from logging, specifically within the central coast and the Queen Charlotte Islands areas. During the past five years the British Columbia government has carried out a number of studies on sustainable economic and forest management practices on the coast with a view to restructuring the forestry economy. For example, while the central coast (Great Bear Rainforest) remains under a commercial logging restriction of one million hectares until June 30, 2004, recommendations from studies recently undertaken may lead to increased logging within the area. Within the Queen Charlotte Islands, the government is working with the First Nations to develop land use recommendations in order to manage the timber harvesting within the area. Smaller and innovative local forest companies will be given the opportunity to open up in British Columbia – the goal being to allow 45% of the allowable annual cut in B.C. to the open market and doubling the allowable annual cut available to First Nations (British Columbia, 2003c).

5.4.2 Commercial fisheries

The commercial fishing industry is British Columbia's fourth largest industry, behind forestry, mining, and agriculture. However, it is also the primary industry that is geographically located along the coast of B.C. British Columbia exports 90 percent of its fish and seafood products, making it one of the most important generators of foreign exchange in the province (PricewaterhouseCoopers, 2001). The industry produced over $1 billion in revenue in 2002 (British Columbia, 2002b). While salmon and herring fisheries declined significantly in the 1990s, ground fish, shellfish harvests and aquaculture have increased significantly.

Seafood processing in 2002 was comprised of 186 companies with 213 facilities and directly employed 5,700 (British Columbia, 2002a). This is a significant decline from the 1990s when the industry employed an average of 11,000 workers. The majority of the processing plants are located along the east and west side of Vancouver Island and the southern coast of British Columbia. Fish processing increased on Vancouver Island by 35% during the 1990s, while it declined proportionately on the lower mainland. Drastic declines in fish processing were also experienced within the Queen Charlotte Islands (77%), central and northern coast, and the Sunshine Coast (90%) regions (British Columbia, 2001).

As such, both commercial fishing and fish processing have been in decline for some time. Despite this trend, the seafood industry continues to expand, but into different specialty fishing markets – salmon farming, squid, sardines, tanner crabs, spiny dogfish, arrowtooth flounder, sea cucumbers, and red sea urchins (British Columbia, 2002a).

5.5 Changing profile of the B.C. coast

Concerned about this reliance on traditional forest and commercial fishing practices for employment, coastal residents now recognize that long-term survival of their communities rests on balancing sustainability of these industries with diversification of the coastal economy. Over the past decade several new initiatives have been undertaken by federal, provincial, regional and local authorities, First Nations, conservation and private sector organizations to refine and direct economic growth in coastal regions. The most significant new areas of economic activity to emerge are aquaculture, recreation and tourism. While these new economic activities are not expected to automatically replace traditionally high-paying resource industry jobs, they are viewed as much more than minimum wage jobs. For many residents, these activities also offer additional opportunities, such as a chance to continue to reside in the community of their choice without having to move to find work and/or maintain a quality of life consistent with their values.

5.5.1 Aquaculture

Although small compared to many other components of the Canadian West Coast fisheries sector, the aquaculture industry has shown dramatic growth during the last two decades. In 1984, the industry's annual output was estimated at $2.3 million, less than one percent the size of the commercial fishery. However, by 2001, shellfish and finfish farming activities in the province were contributing over $287 million to the province's total GDP. Aquaculture now accounts for nearly one-fifth of the total revenue originating in the fisheries and aquaculture sector, and is now comparable in size to the fish processing industry. The expansion of the aquaculture industry is largely due to the maturity of the salmon farming industry. Shellfish farming has also made significant gains, but is no longer the dominant force in this industry (British Columbia, 2001).

Some 3,000 people are now employed directly and indirectly in B.C.'s salmon farming industry. Over 92% of the direct jobs are in coastal communities outside of greater Victoria and Vancouver. The British Columbia coastline is a much sought after location for aquaculture because of a coastline with many fjords and protected inlets and bays, ice-free areas, and suitable water temperature for fish production. Salmon farms are primarily located in and around the northeast and west coasts of Vancouver Island (Dobson, 2002).

5.5.2 Oil and gas exploration

Interest in oil and gas development in western Canadian coastal waters dates back over 40 years with drilling of exploratory wells in the Queen Charlotte basin, along with others off the west coast of Vancouver Island. A federal moratorium on further exploration has been in effect since the early 1970s. However, with the decline of other coastal resource industries in the 1990s, both federal and provincial governments have recently chosen to re-examine options for resuming exploration (Vodden, et al., 2002). In 2001, the British Columbia government commenced a review of the moratorium, and in 2002 announced a goal to facilitate the development of an offshore oil and gas industry to be up and running by 2010.

5.5.3 Tourism and recreation

While aquaculture and oil exploration promise new employment opportunities for some communities, many will see significant opportunities related to tourism and outdoor recreation.

At the start of the new millennium, tourism was firmly established as the number one industry in many countries and the fastest growing economic sector in terms of foreign exchange earnings and job creation. International tourism is now the world's largest export earner and an important factor in the balance of payments of most nations, including Canada. According to the World Tourism Organization, 2002 worldwide receipts for international tourism amounted to US$474 billion (€501 billion), corresponding to US$1.3 billion a day or some US$675 per tourist arrival. Canada’s share of the international market is significant. In terms of tourist arrivals, Canada ranked seventh in overall world tourism destinations with some 20.1 million tourist arrivals, and ranked second in the Americas in terms of international tourism receipts (US$9.7 billion) (World Tourism Organization, 2003).

Despite the effects of September 11, 2001, the World Tourism Organization has forecast that international arrivals are expected to reach over 1.56 billion by the year 2020, more than double the 2002 level of 703 million. This accelerated growth is fueled by a number of changes that were already underway in the industry. Low-cost airlines are anticipated to continue growing in North America. The Internet is playing an increasingly key role not only as a strategic means of accessing local destination information, but also as an effective means of organizing and booking trips. Non-organized, individual and small group travel is proliferating, while large tour operators are facing more difficult times. ‘Do-it-yourself’ is becoming more and more common, particularly for the mature and experienced travellers, vigorously stimulated by the possibilities offered by low-cost airlines and other special travel and local event booking discounts offered through the Internet (World Tourism Organization, 2003).

Changes in the tourism industry also reflect new consumer preferences and tastes. Many new tourists visiting the B.C. coast are more experienced, better educated, independent, conservation-minded and quality conscious, but also harder to satisfy and much more adventurous in their activities (Poon, no date). Risk-taking behaviour is also likely to increase in certain segments of the industry. Among the most significant changes in tourism is an increasing interest in getaway vacations, ecotours, cultural tourism (so-called ethnotourism) and combining business trips with pleasure. There is also a shift in emphasis from passive enjoyment to active learning and quality, and authentic outdoor visitor experiences have become crucial for successful rural tourism. Concerned about impacts of large-scale tourism activities, many are seeking low impact tourism facilities consistent with environmental values. Further, these changes are occurring amidst shifting demographics in Europe and North America, where the baby boomer population (50 and older) is growing significantly and is more affluent, more demanding, more discriminating and able to spend more time travelling than previous generations.

British Columbia is well positioned to take advantage of these changes. With its reputation for abundant and pristine wilderness resources, wide diversity of wildlife and its image as an unspoiled region, British Columbia's coastal regions are rapidly becoming favoured national and international destinations for adventure and eco-tourism. Among other favoured attributes, the coast is rich in cultural resources associated with First Nations and non-aboriginal peoples, and can take advantage of a milder climate to expand the duration of the tourism season beyond that found elsewhere in rural Canada (except for winter recreation and tourism). The establishment of federal and provincial parks and ecological reserves has increased awareness of the coast's offerings and resulted in a dramatic increase in the number of recreationists, tourists and commercial tourism operators visiting destinations all along the coast. The goal has been to draw visitors off the beaten path to some of British Columbia's most spectacular and lesser known wilderness and scenery.

Consequently, numerous tourism and recreation products are being marketed along coastal regions. An emerging trend is a growth in adventure land recreation and "people-powered" water activities. The activities detailed below provide a small sample of current offerings:

Water-based activities

- Sea Kayaking – traditionally viewed as a young person's activity, kayaking is gaining greater acceptance among families with older children, mixed-sex single groups and older adults.
- River and ocean snorkelling
- Scuba diving – very popular in inlets and narrows.
- Marine cruising – usually associated with other marine activities such as fishing, scuba diving and/or wildlife viewing. The activity can be undertaken by any age. Very popular in sheltered inlets all along the coast.
- Wildlife viewing – very popular among European tourists who wish to see natural landscapes. On many cases, to avoid visible logging roads and recently harvested areas, long distances have to be travelled along coastal areas.
- Wind and regular board surfing – very popular along the west coast of Vancouver Island.
- Salt water fishing – by far the most popular activity for recreationists and tourists. The fish resource (salmon, halibut, ling cod and snapper) is world class and attracts a large numbers of international visitors.

Land-based activities

- Camping – provides natural outdoor environment, peace and quiet, opportunities for outdoor adventure sports and recreation, and benefits of a family activity. Undertaken as a destination activity at designated campsites, or increasingly, as part of another activity such as backpacking or sea kayaking at informal or undeveloped coastal sites.
- Caving or karst exploring – growing in popularity. British Columbia is blessed with an abundance of world-class karst, particularly on Vancouver Island, central coast mainland and Queen Charlotte Islands. The high concentration of karst features on Vancouver Island, combined with a long history of cave exploration and the unique association of karst with the coastal temperate rain forest, has focused a great deal of international attention on these coastal forest karst ecosystems. While sites are often reached by road; many others, especially along the coast of Vancouver Island, are accessible only by boat.

- Backpacking/day hiking – increase in adventure tourism, overcrowding of established coastal trails and desires by adventure tour companies to offer new destinations are factors contributing to growth of the activity into more remote coastal regions. For example, the West Coast Trail, an arduous 77 km wilderness trail along the west coast of Vancouver Island is so much in demand that a reservation and quota system is in effect.
- Cultural and Heritage viewing – First Nations people have occupied and utilized coastal areas for thousands of years. While very ancient cultural infrastructures, such as traditional longhouses and totems, have disappeared because of wood deterioration, remnants of centuries old structures have remained while news ones have been built on First Nations lands. Cultural tours to contemporary and ancient communities are featured in many coastal regions. Other significant viewing features include: petroglyphs and pictographs; archaeological sites; culturally modified trees and trade routes. Non-First Nations points of historical interest include old canneries, abandoned logging and fishing communities and lighthouses. Heritage and cultural viewing is viewed as low impact, non-consumptive activities often associated with ecotourism, especially in remote regions.
- Beachcombing – popular secondary coastal activity.
- Natural history/photography – usually undertaken in conjunction with other activities such as marine cruising and sea kayaking.
- Rock climbing – highly technical and growing niche market for extreme adventurers. British Columbia's rugged coast line offers spectacular climbing challenges.
- Storm watching – a popular winter activity in locations along the west coast of Vancouver Island.
- Special events/festivals – used to market or showcase a region through associated media exposure. Examples include fishing derbies, sea festivals, conferences and workshops, triathlons and sea kayak races (Nicolson, 1998; British Columbia, 2001b).

5.5.4 Cruise ship industry

Cruising is increasingly popular among tourists visiting the B.C. coast. Vancouver, Victoria, Prince Rupert, and other coastal cities such as Nanaimo, Campbell River and Alert Bay are now ports of call for both luxury and pocket cruise ships working the waters along the west coast during the cruising season (which lasts from May to October). During the summer months, B.C. Ferries also provides services through the Inside Passage for passengers traveling between Port Hardy and Prince Rupert who opt for a more modest mode of travel (British Columbia, 2003b).

The largest B.C. port cities also serve cruise ships en route to or from Alaska. North American destinations have been the prime beneficiary of growth in the cruise ship industry over the last few years, as northern cruise vacations have become more popular. Alaska recently surpassed the Mediterranean area to become the second most popular cruise ship destination in the world, after the Caribbean. Alaskan cruises, while already in vogue before September 2001, have become even more attractive to North Americans who prefer to stay closer to home and, as much as possible, avoid flying on their vacations (British Columbia, 2003b).

For more remote regions like mid and northern coastal B.C. and northern Vancouver Island, tourism traditionally has been a relatively minor component of their economy due to the relatively small numbers of visitors to the area, lack of transportation and the dominance of primary industry. However, since the late 1980s, ferry and cruise ship runs to Prince Rupert and Alaska have generated considerable new tourist activity along these remote coastal regions. Further, the tourism industry is expected to continue to witness significant changes in the new millennium brought on by such factors as much improved transportation, vastly improved technology, world economies, and demographic shifts (Dobson, 2002).

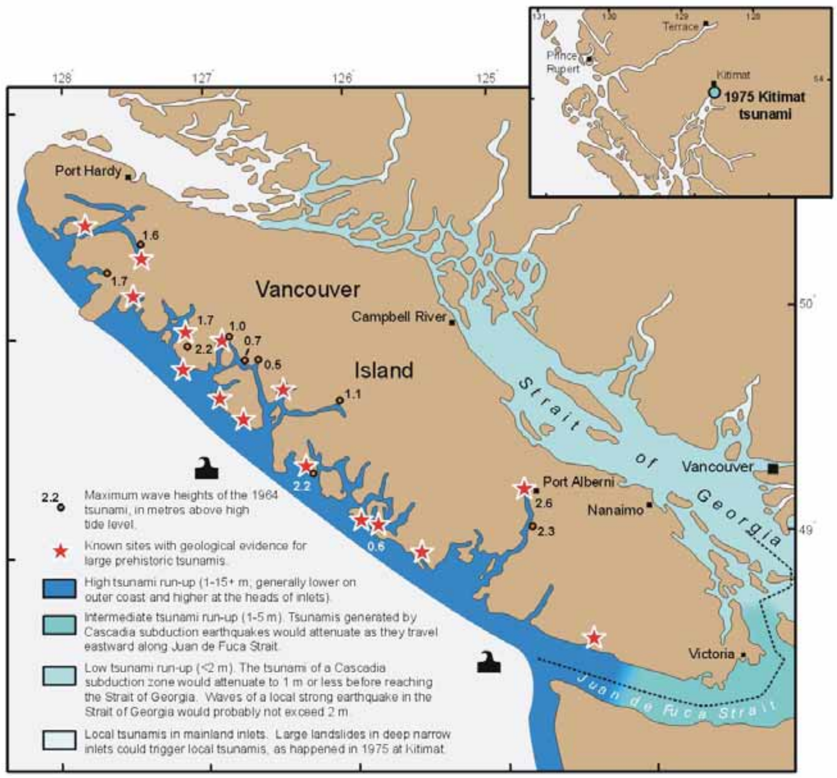
The nature of cruising is also changing in fundamental ways. Like land tourism, people are looking for a quality and more diverse on board experience combined with local recreational, cultural and learning encounters. Accessible cruise ports and more remote destinations are thus becoming vital. This trend is reflected in the overlap between cruising and ecotourism and outdoor adventure. While most coastal shoreline remains inaccessible by road new nautical charts are being produced allowing boaters to take lesser traveled routes through the vast collection of islands and inlets. Accompanying this cruising/ecotourism is the establishment of ‘gateway’ communities, lodges and marinas to serve as launching points for a variety of coastal recreational and cultural activities with people now regularly visiting or residing in previously unpopulated areas (Dobson, 2002).

Where tourism has become established, changes in the demographic and economic make-up of communities have followed. The increase in tourism and outdoor recreation has provided opportunities for local entrepreneurs to promote support services such as accommodation, real estate, banking, automobile and marine refuelling and repairs, restaurants, arts and crafts, equipment and boat rentals and charters, local tours and outdoor recreation training. Many communities have also become homes to writers, artists and craftspeople.

5.6 Changing coastline activities and new vulnerabilities

The areas in British Columbia most vulnerable to 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 (see Figure 9). As figures 10, 11 and 12 illustrate, these regions also correlate with most of the planned or emerging new socio-economic activities.

Figure 9 Identified locations of large tsunamis
(Source: Clague et al., 1999)



Large recent tsunamis

1700 British Columbia outer coast. A large subduction earthquake on the Cascadia subduction zone triggered a tsunami that deposited coarse sediment in tidal marshes and low-lying lakes on western Vancouver Island. The distribution of deposits indicates that this tsunami was much larger than the 1964 tsunami.

1960 British Columbia outer coast. A magnitude - 9.5 earthquake in Chile produced a tsunami that travelled the length of the Pacific Ocean. A 1.2 m wave was recorded at the Tofino tide gauge, and run-up was higher in many other areas. Log booms along the west coast of Vancouver Island and on the Queen Charlotte Islands were damaged.

1964 British Columbia outer coast. A magnitude - 9.2 earthquake in Alaska produced a tsunami that caused about 10 m damage on Vancouver Island. The amplitude of the highest wave at Port Alberni was over 6 m, damaging 260 buildings in the community. The maximum wave height at the Tofino gauge was 2.4 m.

1975 Kitimat. A large submarine landslide near the head of Kitimat Arm in April 1975 generated sea waves that caused $600,000 damage to wharves and other shore facilities at Kitimat.

Figure 9 is a Tsunami hazard map portraying four generalized hazard zones, as well as sites with evidence for large prehistoric tsunamis, the location of the 1975 Kitimat tsunami, and maximum wave heights of the 1964 Alaska tsunami. Details on four important recent tsunamis are given at the bottom. Southwestern British Columbia is the only region along the western Canadian coastline where sufficient information exists to produce such a map.

Figure 10 Aquaculture sites within southern coastal regions of British Columbia
(Derived from British Columbia, 2001b)

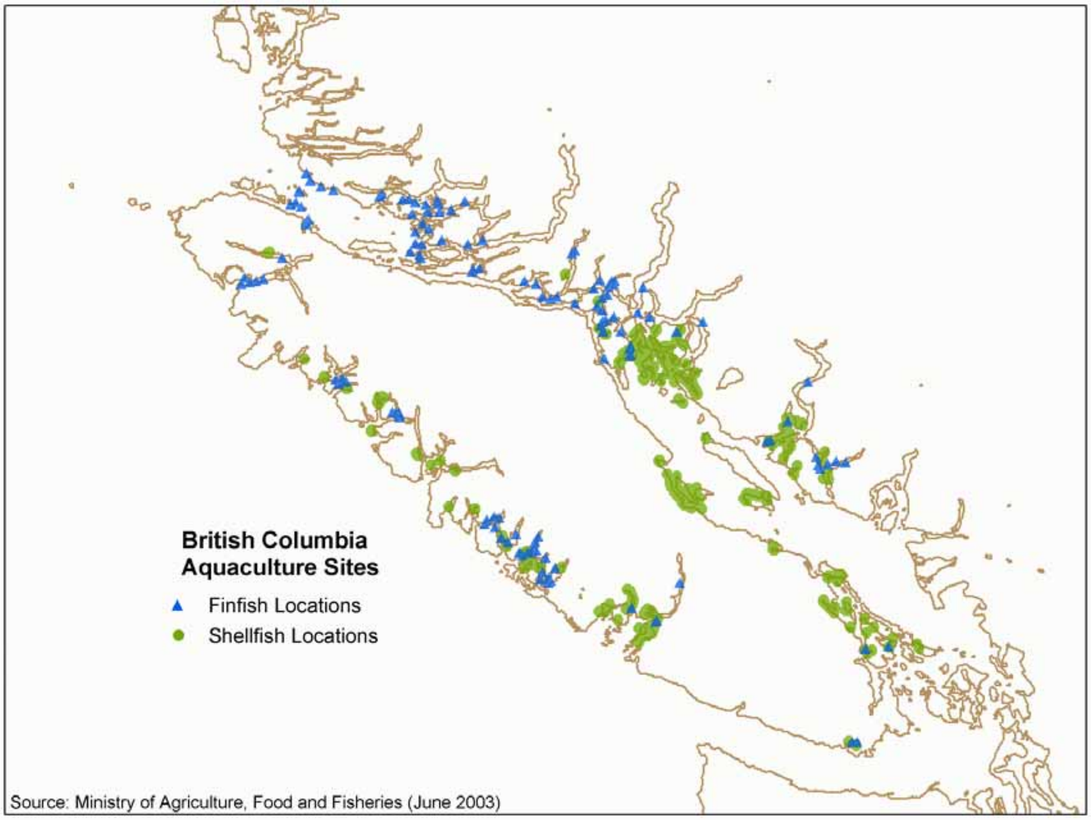


Figure 10 shows aquaculture operations on west coast of Vancouver Island. The green squares indicate locations of finfish farms; purple squares shellfish farms; and blue dots licensed processors.

Figure 11 Tourism activity along the west coast of Vancouver Island

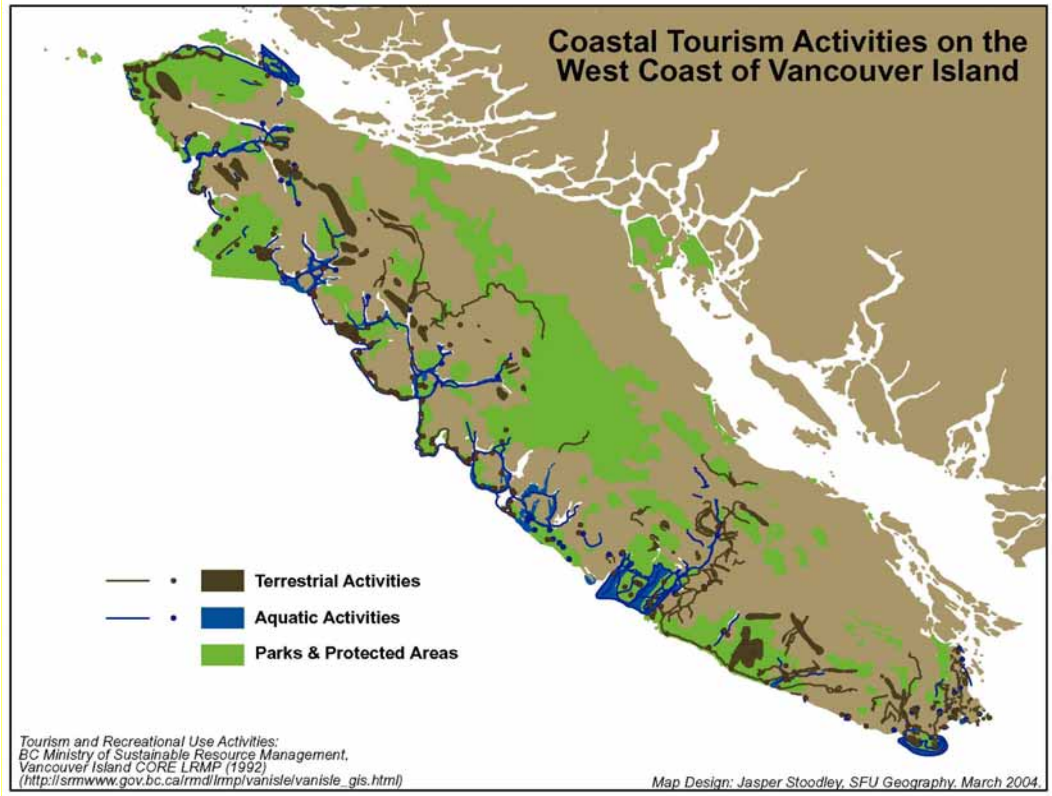


Figure 11 highlights important tourist features, routes and activities around Clayoquot Sound on the west coast of Vancouver Island.

Figure 12 Offshore Oil and Gas Exploration along the B.C. Coast

Figure 12 shows areas of interest for future offshore oil and gas exploration along the B.C. coast.

6.0 Performance of the B.C. Tsunami Warning System

With respect to assessing performance, the current B.C. Tsunami Warning and Alerting Plan (2001 edition) ("the Plan") cites a need "to enhance tsunami detection, warning and alerting systems, and communication techniques" although it does not specify where such enhancement is most needed. However, the Plan does set out six components of the B.C. Tsunami Mitigation Strategy. These six components can serve as the basis for a performance assessment of the current Warning System based on discussions with key stakeholders and a review of reports from past exercises and events:

- Improved detection
- Tsunami models and mapping
- Local preparedness planning
- Local warning and alerting
- Local response tactics
- Public awareness and education

While the aim of this study is in part to identify known problems or concerns with the current B.C. warning system, we will focus principally on two components: local warning and alerting; and public awareness and education. While the other components should be considered integral to the success of the B.C. TWS overall, this study emphasizes the Stage 3 dissemination network, for which components four and six are most relevant.

The earliest published (and most complete) evaluation of the B.C. TWS we have come across is from 1976, published by two University of Victoria geographers, Harold Foster and V. Wuorinen (Foster & Wuorinen, 1976). The overall conclusion at that time was that the B.C. TWS was decidedly "inadequate" based on a number of findings:

- Excessive delays in issuing warnings for local generated tsunamis;
- Lack of testing of the TWS "beyond the PEP level";
- Over-reliance on "blind transmissions" to disseminate warnings;
- Communications deficiencies in small and isolated settlements;
- Poorly prescribed response plans and lack of resources among local communities; and
- Jurisdiction gap over use of existing siren systems.

At the time the report stated that "no attempt has been made to draft [local response] plans for Vancouver Island communities" despite obligations set out in Canada's role in the PTWS (p. 121). Local level planning was hindered by a lack of warning systems, inundation maps and pre-planned evacuation routes (p. 121). At the time only one B.C. coastal community (Port Alberni) had a tsunami warning plan (p. 118).

In many small or isolated communities along the B.C. coast, there was lack of effective communications support, or in some cases no individuals appointed to monitor and disseminate warnings. Available communications technologies listed in the report were telephone, radio-telephone, and the "Raven" network, which was described as "an independent Indian-owned and operated radio-telephone system" based near Courtenay on the east coast of Vancouver Island (p. 116, 118). Furthermore, so-called blind (one-way) transmission of warnings to communities created potential problems for confirming the receipt of warning messages, and siren systems at that time fell under federal government jurisdiction and were authorized only for nuclear alert and were thus unavailable for tsunami warning (p. 122).

The report states that findings from other areas that had experience with fairly recent tsunamis around that time (Hawaii, Crescent City California) had

> …shown that, unless the public has been fully informed about potential tsunami hazards and has detailed information readily available describing how to respond to warnings, many will not evacuate threatened areas, even if inundation is virtually certain. (p. 122)

Findings from a survey taken following the Hilo, Hawaii tsunami in 1960 corroborate this statement, indicating that 59 per cent of the local population did not evacuate the threatened area after a siren warning was issued in advance of the tsunami. Major reasons given were that the siren was thought to be a preliminary signal and not a warning to evacuate; that the meaning of the siren was unclear; or it was simply unknown. In such cases, people actively chose not to evacuate (Beaulieu, 2001).

The 1976 B.C. study (p. 122) concludes that detailed information for local populations at the time “is not sufficiently available” and that greater efforts needed to be given over to increasing appreciation of the tsunami threat and appropriate protective action response to warnings. It closes by stating that until such an “appreciation” is achieved the B.C. TWS “can never be considered effective.”

The 1976 study presents a historical baseline for evaluating the local alerting and public awareness functions of the B.C.TWS. Have these fundamental concerns been addressed in the intervening decades? Have new concerns come to light? How do changes in local conditions present an ongoing challenge to addressing these concerns?

We have classified the findings from what might be termed the “Foster-Wuorinen Assessment” of 1976 into related categories for the purpose of assessing the current situation:

- Communications deficiencies (including detection systems)
- Preparation and Testing of Community Warning and Alerting Plans
- Jurisdiction Gaps

6.1 Communications deficiencies

The advent of new communications technologies over the past decade, including terrestrial broadband and satellite, would seem to suggest that many of the deficiencies reported in the Foster-Wuorinen Assessment are a thing of the past. However, with respect to Stage 2 and 3 dissemination networks, it is not clear that local broadcast radio and television coverage to many remote communities along the B.C. coast is much better off than it was in 1976. Much of the over-the-air radio programming reaching into rural communities is carried via network feeds to local transmitter sites with no provision for local content insertion. Many coastal regions are poorly served, if at all, with local or regional radio or television service. Direct-to-home (DTH) satellite service may be available in many communities but may not be reliable in dissemination of tsunami warnings because much of the programming over these systems originates from major urban centres and does not report on local conditions.

Access to the public switched telephone network may have improved in many remote communities, although the extent of this needs to be further examined from the perspective of both coverage and capabilities. Local infrastructure and capacity in some small communities may present problems for providing landline-based warning solutions (e.g., automatic call notification). Commercial cellular service is not available in many remote communities and Telus' marine VHF radiotelephone service appears to be in a slow state of decline on its way to disappearing as satellite telephones are adopted for remote voice and data communications.

Marine radio remains an important means of communication along the B.C. coast, although it is not clear how reliable the service will be for alerting transient and tourist populations unfamiliar with its operation and with the Coast Guard MCTS.

Recent performance assessments for the Stage 1 dissemination network have reported it as good. Tests between WC/ATWC and B.C. PEP, for instance, demonstrate response times under 10 minutes (Canada, 2001, 2003). Enhancements made to the Stage 1 (detection) dissemination network to incorporate Internet and mobile access technologies (to compliment existing telephone modem and satellite links) promise to further enhance performance, creating new possible points of failure. However, such issues are likely to be raised and dealt with at the regular IOC/ITSU meetings held every two years (next will be 2005).

6.2 Preparation and testing of community warning and alerting plans

The Plan states that governments at all levels are responsible for being educators to the public, which entails risk assessment on a local scale and preparing aids to enhance individual preparedness and support community emergency planning. While B.C. PEP produces a number of public education aids – including information on the PEP website, signage, and information brochures dealing with tsunami preparedness – risk assessment at the local, provincial and federal scale is expensive. Only at the federal scale is any coordinated local risk assessment taking place. In 2003, CHS completed wave amplification models for two harbours on the B.C. Coast – Victoria and Esquimalt. Contingent on continued funding, Sooke and Ucluelet harbours are scheduled to be completed in 2004.

The Plan also states that the provincial system is to be exercised every eight to 10 months. These exercises produce reports, including consolidated reports that are intended to identify shortcomings in the warning system and make recommendations for its improvement (D-1). According to the Plan, reports are to be mailed to the PEP office, although it may be the case today that email or Internet is replacing traditional postal service.

It is important to note that the provincial exercise regime does not include "internal local authority" or coordinating agency-level activity, unless these communities or agencies provide their own resources and personnel.

According to a number of participants we spoke with, community-level plans appear to be exercised infrequently, there are no apparent baseline standards against which to assess results, and deficiency reports are not readily available for review.

In addition to regular exercises, regional planning and working groups are involved in assessing various aspects of the B.C. TWS on a less regular basis. Two important groups are the B.C. Earthquake and Tsunami Working Group and the Regional Emergency Telecommunications Committee (Clague, et al., 2003, p. 451), which appear to meet on an occasional basis. A comprehensive review of published minutes from RETC (Pacific Region) meetings over the past eight years indicates that the B.C. tsunami warning system has never been included as a specific agenda item.

A number of potential deficiencies may need to be considered further. For instance, while B.C. PEP makes somewhat regular visits to communities, it does not appear to have established a clear strategy for extending its efforts to include economic and recreational interests along the B.C. coast to provide education and consultation for tsunami risk reduction. This situation will likely need to be addressed as socio-economic changes along the coast will require renewed efforts at risk assessment and the development and distribution of related information products.

6.3 Jurisdiction gaps

The provincial government undertakes periodic large-scale exercises to test the B.C. TWS. These are known as Seaswell exercises, the last being held in 28September 2001. These assessments report on the performance of the Stage 2 dissemination network (from B.C. PEP/ECC to regional points of dissemination). The results of Seaswell 5 prompted B.C. PEP to conduct a pilot community project to gain experience with, among other things, complex jurisdiction issues in the Stage 2 dissemination network.

The initiative consisted of a B.C. PEP-led presentation and consultation with local government councils, and other agencies with identified jurisdictional responsibility (e.g., Parks Canada in the Tofino region). Five communities were selected for the initiative, which suggests they may also represent important regions for future developments of the B.C. TWS:

- Tofino (nearby federal parks and high tourist draw)
- Ucluelet (federal Coast Guard facilities)
- Port Alberni (large community, suffered a tsunami in 1964)
- Alberni-Clayquot Regional District (unique governance challenge)
- Port Renfrew (high transient population, First Nations, coastal lowlands)

As noted in the B.C. TWAP, local communities are not part of routine provincial testing and so it is not clear at present the extent to which the Stage 3 dissemination network (from local authorities to members of the public) has been assessed systematically, if at all, along the B.C. coast. It is also important to note that current B.C. TWAP and related exercises are primarily designated for far field tsunami events, meaning that locally generated tsunamis remain a special case that local communities will need to consider in planning.

7.0 Best Practices in the Design of Warning Systems

This section reviews current consensus on best practices for the design of effective warning systems based on sociological and operational considerations. Generally speaking, sociological studies have found that the response to warnings among individuals has been found to relate to three factors:

- Individual risk perception;
- Nature of the warning information; and
- Social context and personal traits of the recipient.

Successful design of a warning program must take into account such variables as individual risk aversion, effective message design, and the social context in which warning messages are received. Much work has been done in this area and best practices have been incorporated into a number of documents, including a recent report produced by a panel looking into risk communication concerns faced by Parks Canada with respect to the backcountry avalanche hazard in western Canada (O'Gorman et al., 2003).

The report offers some perspective on best practices in risk communication and the design of hazard warnings in general, and presents some interesting parallels to the risk of tsunami along the B.C. coast. Among these are the often complex analysis that is required to determine the extent of risk presented by a hazard, the need for continuous vigilance, and the wide and varying range of people that may be at risk from the hazard. In the case of avalanche, the range of groups entering into the backcountry encompasses novice and expert tourists, as well as seasonal workers. The risk communication approach presented in the report offers important insights gained when we reconceptualize the tsunami warning system as part of a wider B.C. coastal development risk management strategy.

7.1 Risk assessment

- Is there uniform collection and reporting of relevant data, so that the planners and the public may get a clear sense of comparative risk based on local conditions?
- Is there consistency and robustness in methods used to summarize data into local warnings and notifications?

7.2 Risk management

- Is there a consistent understanding and reporting of the risk assessment findings to different local authorities and for similar situations?
- Is the division of responsibility for managing risks (as between federal, B.C. PEP, local authorities, private sector) clearly presented to and understood by those at risk?

7.3 Risk communication

- Are the different types and magnitude of the relevant hazard presented to members of the public in ways that enable them to make informed judgements about risk taking?
- Is the full range of information presentation formats used to convey danger being used effectively?
- Are the "most vulnerable" categories of users reachable by clearly understandable warnings?

Although the report notes that questions of risk assessment and management are clearly applicable to the overall effectiveness of a hazard warning system, the authors focus on three key best practices in risk communication that are relevant to the design of a tsunami warning system, particularly within the Stage 3 dissemination network.

The first of these deals with the matter of "duty to warn" and states that there must be clearly defined objectives behind when warnings are issued. The duty to warn may have different objectives depending on circumstances. In some cases, a warning may be issued to discourage actions absolutely (e.g., "keep out"); in other cases the duty to warn must strike a balance between creating awareness and informed understanding among the public while not "inappropriately discouraging the activities" (p. 35).

The second consideration sets out the basic test for determining effectiveness of hazard warnings, focusing on three key components (quoted directly): (1) whether or not the least sophisticated user comes away with (2) an adequate awareness of the risks (3) at the time when the activity is about to be undertaken. [emph. in original] (p. 36). The authors suggest that focus group testing is the best way to evaluate these components in the design of warning messages. "Awareness" in this context refers to presence of mind at the appropriate time and place.

The third consideration in best practice deals directly with message content of warnings, noting that they consist of two basic elements, text and symbols (p. 36); text can either be written or spoken word in the case of broadcast radio, and symbols can be both visual and aural (e.g., siren wail); to these we would add context and timing, insofar as message design must take into account the setting in which a warning is to be delivered as well as the moment in time when it is to be delivered, each with a potential influence on text and symbolic content. Much work has been done in this area and the report cites at least two sources that can serve as points of reference for the design of visual warning messages (p. 36), leading to the possibility of improved and more standardized warnings.

Two examples of published best practices for the design of public warning messages are:

- Wogalter et al. (1999). Warnings and Risk Communication. Taylor & Francis.
- 'Natural Hazard Safety Signs,' prepared for Parks Canada, Western Region by Western Ergonomics Inc. and Paul Arthur, VisuCom Ltd., 1996.

7.4 Special populations at risk

Handmer (Handmer, 2002) has found that past research reports have given considerable attention to vulnerable and visible groups, but that much less work has been done concerning less visible but potentially high-risk populations, noting the following categories:

- Anyone who may be mobile at the critical warning time
- Tourists
- Business travellers
- Seasonal workers
- Socially isolated individuals (homeless, reclusive, and undocumented)

He identifies a further group that tends to occupy high risk areas on a casual basis, these being nomadic aborigines (bushwalkers, in the case of his Australian study), and independent adventure recreationists. Among the largest numbers at risk at any one time, according to Handmer, are campers and organized groups of recreationists – groups that have "contributed significantly to flash flood death tolls" in Europe and other places (p. 21). To complicate matters, organized groups may be aware of hazards and even warnings, but may exhibit poor decision-making processes.

7.5 Tourists

Sociologists have examined the ways in which tourist businesses deal with the protection of tourists from natural hazards through the use of emergency evacuation and other measures (Burby & Wagner, 1996). Looking at hotels in the United States, findings in this area of investigation suggest that while most hotels may have written emergency plans, as few as half may have a plan for the evacuation of guests. Many hotels were reported to have failed to revise or test their emergency plans regularly, and a high proportion of plans had been prepared and filed without the participation of those who would be called to implement them, leading in some cases to a false sense of preparedness among staff and management.

The size of the establishment is reported to have a bearing on preparedness, where smaller, independent hotels found it easy to ignore planning in the face of other resource constraints. However, firm size did not predict well to preparedness to evacuate, as this was more closely correlated with the individual perceptions and experience of hotel managers.

Not wanting to assume responsibility for guests beyond their walls, some hotels were discovered to have avoided a policy of formal guided evacuation for guests, opting instead to keep guests informed of the hazard through posted updates.

A number of potential problems with mandatory evacuations have also been noted, including the problem of providing transportation for large numbers of hotel guests leaving at the same time, as well as inadequacy of municipal emergency plans to deal with the evacuation of potentially thousands of tourists residing in hotels, resorts, and other commercial lodgings at risk.

A number of suggested best practices have emerged from findings in this area, emphasizing several considerations: smaller establishments need support from industry associations or local authorities in preparing and revising emergency plans; managers are best prepared when having participated in evacuation exercises and with other community organizations.

A key line of defence in this regard is to increase awareness and appreciation among hotel management and staff of the hazard through an information campaign and at regular workshops or industry events. This could be undertaken through industry associations while working in conjunction with provincial planners. Local authorities are advised to work closely with individual firms to assist in the preparation of evacuation plans; or, alternatively, local authorities could prepare and distribute emergency planning and evacuation manuals for smaller firms and lodgings. The report also recommends that local authorities need to establish and maintain through regular exercises direct lines of communication with larger tourist establishments as part of a long-term risk communication strategy.

7.6 Advisory bulletins and compliance

Among many sociological studies of warning phase of disasters, the issue of compliance within the population has been a dominant concern, particularly among special populations of socially isolated individuals, including elderly and transient groups.

An early study on tsunami warning reports on findings from two American communities following the Alaskan earthquake on 27 March 1964 (Anderson, 1969), raising a number of points still worth considering today. First, the wording of emergency bulletins is a critical factor in preventing delay among local officials when making decisions about evacuation. Ambiguous information as to the existence of a threat can create inconsistency and delays in implementing local emergency plans. Second, in the case of tsunamis – in contrast with some other hazards – there may be no danger clues present in the environment. As a result, local authorities must depend on outside information regarding the threat, placing a greater demand on timeliness of updates, and for clarity and completeness of the bulletins. Where there is lack of either, local officials and residents may resort to unofficial sources, creating the possibility of misinformation, confusion, or indecision in taking action. A case report from the Sanriku event of 1989 corroborates this finding, noting that low rates of compliance among the public coincided with the “lack of a coordinated and coherent emergency plan” among government authorities (Yoshii, 1990).

Sociological research conducted over the past three decades into elderly populations appears to have spawned an erroneous hypothesis within emergency management planning that special populations may present problems during for public warning because they tend to be reluctant to take protection action response when advised to do so by authorities. Further research in the area, however, has found non-compliance with disaster warnings may be more closely related to timely reception of a warning message from a trusted source, and the ability to voluntarily comply with a warning message by taking protection action response (Perry & Lindell, 1997).

7.7 Warning dissemination networks

Sorensen's review (Sorensen, 2000) covering two decades of research into warning systems differentiates between short-term and long-term warning systems, contrasting activities such as forecasting and modelling (long-term) and issuing advisory bulletins or alerts (short-term). Among his findings, forecasting and prediction of tsunami hazards has shown little significant improvement over the past 20 years (p. 119), although we would call this into some question by noting that communications links and computing capabilities have certainly improved dramatically within the past decade. It may be more accurate to suggest that the potential for forecasting has improved dramatically while implementation may be lagging behind that devoted to other natural hazards.

A key principle in the design of warning systems according to Sorensen is integration between the three subsystems in Mileti's model (p. 120). Sorensen does not address how we might measure or assess integration, but simply stresses that all three subsystems must be effectively coupled in order to ensure timely and accurate warnings. Among the most significant challenges to integration is at the third stage dissemination network, where Sorensen reports that up to 50% of initial warning notification can come through informal social networks rather than official channels. Handmer (Handmer, 2002) has also noted the importance of understanding links between informal and official networks as a step toward enhancing overall warning system design.

Measures in the third stage system might include reach, compliance, and time to respond (p. 121). Sorensen's review also found that specialized devices are capable of faster dissemination than mass media and that these systems are most effective when they incorporate both indoor and outdoor components. Among standard warning system technologies, telephone and tone alert systems are reported to reach the widest numbers in the shortest time, followed by sirens and mass media (p. 122).

Sorensen's review claims that there is no conclusive evidence to suggest that public education leads to a significant increase in response rates to warnings (p. 121). This claim is supported by other studies (Handmer, 2002). However, it also notes that a modest education program will not necessarily lead to poorer response rates, suggesting that beyond a certain level, greater investment in public education will not bring significant returns in the form of greater compliance to warnings when they occur.

Sorensen's overall conclusions in his review are that warning systems can reduce death and injuries among at-risk populations, but they have not demonstrated a significant effect on reducing losses to property or infrastructure or economic disruption (p. 123). In some cases, the deployment of a warning system may increase risk by encouraging long-term occupancy of high risk areas in a community. This suggests that emphasis should be placed on long-term dimension of warning to improve forecasting and modelling as a means of enhancing community planning and zoning restrictions.

Three recommendations are made in Sorensen's report aimed at improving the integration of warning subsystems into a more effective system. The first advocates a national strategy for warning that can also support models for local community implementation. The second advocates improving existing warning systems in two ways: through low or no-cost measures such as improved management practices in combination with the acquisition of "better equipment." He adds, however, that "better local management and decision making about warning processes are more critical than promoting advanced technologies" (p. 124). This means, in effect, that the criteria for equipment upgrading should be *appropriateness* to the needs of a local community, rather than simply selecting state of the art. Third, Sorensen advocates closing the knowledge gap between detection, forecasting, and impact assessment to promote long-term risk reduction as a complementary (perhaps dominant) strategy to local warning and alerting.

7.8 Best practices in the design of warning systems

The U.S. Working Group on Natural Disaster Information Systems published a document titled "Effective Disaster Warnings" in 2000 (United States. National Science and Technology Council, 2000). Among its various findings and recommendations, the document establishes a set of guidelines for the design of warning systems, from which we have derived six key principles:

- Relevance
- Timing
- Redundancy
- Clarity
- Credibility
- Action-oriented

It is reasonable to assume that the design of contemporary warning systems in the United States and other regions, including Canada, are being developed based on these principles of best practice.

A high order of relevance is achieved when warnings are delivered to those at risk and who are capable understanding and evaluating the level of risk to their community or to themselves. Relevance is achieved through the ability to target specific communities and through the education of members of those communities in order to establish a continuous "presence of mind" related to risk and response to warnings.

Designs with low order relevance create several potential problems. Repeated false alarms or warnings issued to communities not at risk may lead to people passively ignoring bulletins, to actively disabling warning devices that have come to be considered a nuisance. For instance, individuals or communities that are repeatedly awoken in the night by false alarms may decide to remove or otherwise incapacitate a local warning system.

The principle of timing suggests that there are appropriate windows of opportunity to capture the attention of people in order to encourage appropriate action. In the case of quick onset hazards – such as a locally generated tsunami – warning information must be provided well in advance through an education strategy that informs those potentially at risk how to respond to warning signs that may be present in the natural environment (e.g., earthquake, rapidly receding tide, etc.). In the case of slow onset hazards, such as a distant tsunami, timing considerations will vary depending on the specific community and local response requirements.

Redundancy refers to the delivery of warning messages across a variety of technological systems, such that bulletins are more likely to reach people according to their activities, be they indoor or outdoor, overnight or during the day. A high order of redundancy is achieved when a warning message can be delivered to all potential warning devices within an identified region and has been tested against a representative range of target populations.

Clarity is needed in two dimensions. The first is the need for warning messages to clearly convey key pieces of information: the type of hazard, its probability, affected areas, estimated time of arrival, and instructions for further action. Information may consist of a variety of visual or auditory symbols (both text and non-verbal forms) that are organized in a logical and coherent structure. Clarity also includes the need in some instances to issue warnings that can be understood by many different people across a range of diverse coastal communities, including transient and seasonal populations. Language and cultural barriers are primary considerations.

Credibility refers to recognition and acceptance of the source of the warning message. A high order of credibility will include the organization that has detected the hazard, the organizations that are conveying the message, and trust in the information about the hazard that is being conveyed, including any instructions for protective action response. Contradictory messages or misinformation may threaten credibility in both the short and long terms but best practices also indicate that unwarranted withholding of information can be equally problematic. Social research has found that this is not easily achieved under some circumstances, where informal social networks may play a significant role in establishing the credibility of warning messages.

The final principle of designing effective warnings is that they should be response-oriented. This means that warnings need to alert and to provide follow-up information and protective action response. A well-designed warning will clearly alert a local population to the hazard and provide for clear instructions on what measures are to be taken and under what circumstances. This response orientation also includes an emphasis on all-clear notifications, which may be of significance for tsunami hazards when multiple waves often occur over several hours.

7.9 Design recommendations

A number of basic design recommendations can be derived from the best practices embodied in this basic set of six principles and recommended by the U.S. Working Group on Natural Disaster Information System. The principles stated above suggest at least four design recommendations:

- Develop a standardized terminology for warnings.
- Identify and implement a single, consistent set of variables (fields) to be included in all warning messages.
- Develop consistent method for routing warnings to populations at risk.
- Develop consistent method for targeting populations at risk.

The principle of variety and clarity, however, also suggests that standardized terminology may need to consider differences between different types of dissemination networks, most notably that between Stages 1, 2, and 3. Further differentiation within the Stage 3 dissemination network may also be necessary for certain populations. This suggests that a standardized terminology may need to consider non-specialist populations as well as non-english language speakers. One possibility is the adoption of official synonyms to augment the core terminology.

When seeking to identify a set of variables for warning messages it is important to coordinate this undertaking between local, regional, national, and international initiatives and conventions to maximize consistency and interconnection across warning systems and to reduce disintegration of warnings as they pass between dissemination networks.

Development of a consistent method for routing warnings to populations at risk adheres to the principle of credibility as it reduces the potential for false alarms and conflicting messages. It may involve a range of organizations within the Stage 3 dissemination network. Currently it involves B.C. PEP, RCMP, Coast Guard, and others. Is current policy clear and comprehensive?

Development of a consistent method for targeting populations at risk adheres to the principle of relevancy as it would provide for greater precision and accuracy in the delivery of warnings, reducing complacency and disabling of warning devices. Such a method could also improve dissemination strategy by highlighting communications capabilities and deficiencies in specific regions. The degree of precision and method for coding coastal areas will need to be determined; however, it should take into account possible future developments along the coast when deciding regional coding schemes.

7.10 Putting best practices into practice

The aforementioned principles and design recommendations are widely accepted and now provide the foundation for current initiatives and trends in the design of warning systems in North America and other areas.

7.10.1 Universally Digitally Coded Warning (UDCW)

By adopting a standardized terminology and an identified set of fields for digital warning messages, a UDCW system could enable a diversity of warning devices to be activated with single message format. This is recommended in the report by the Working Group on Natural Disaster Information Systems, and is currently being developed in the United States with the Common Alerting Protocol (CAP) initiative.

In Canada a similar initiative appears to be underway, led by Industry Canada – Emergency Telecommunications, with the involvement of both public and private partners. Authority to develop such a system in Canada comes from the Emergency Preparedness Act. It designates Industry Canada as having a lead role in this area. Participation can range from simple adoption of received standards to ongoing involvement in the standards making process.

7.10.2 Warning dissemination capabilities and strategy

Warning dissemination capabilities and strategy are mentioned in a number of documents dealing with the design of warning systems. Multiple technologies are now available for dissemination, and best practice suggests that a constellation of systems be considered based on local conditions (Beaulieu, 2001; Molino, 2002a, 2002b).

The principles of variety and credibility suggest that dissemination strategy should consider the use of multiple systems with clearly defined jurisdictional responsibilities in place and protocols for activation. Multiple systems may require partnerships involving commercial operators, local, provincial, or federal authorities (e.g., telephone based call notification systems, local siren systems, provincial broadcasting, marine radio). A comprehensive review of current delivery systems and associated planning issues can be found in Beaulieu (2001).

A multi-mode dissemination strategy at the Stage 3 level may need to be established on a preliminary policy that clearly defines communications responsibilities in order to prevent duplication of warnings, false alerts, and misinformation.

7.10.3 Geo-coding warnings

The development of a Universal Digitally Coded Warning regime makes it possible to improve precision and accuracy in the delivery of warning messages to those at risk. The principle of relevancy suggests this is an important development to pursue in order to increase effectiveness of warnings.

Improved precision in warning dissemination, however, may require some form of geo-coding for local communities along coastal regions. The degree of precision required and exact method(s) of geo-coding should be established in consultation with other organizations to ensure maximum consistency and integration across the three Stage dissemination network.

7.10.4 Local planning

The principle of response orientation in the design of warnings suggests the need to provide local communities with the information and support they will need to effectively plan a response to the range of warnings that may be issued. This consideration includes not only local permanent settlements but key entry points into provincial and national parks, as well as seasonal and transient commercial undertakings (tourism, etc.).

8.0 Building Best Practices into the B.C. System

While tsunamis cannot be prevented, risks presented by them often can be reduced and sometimes even eliminated. To be effective, a tsunami mitigation strategy needs to support long-term risk reduction within coastal communities by implementing and maintaining local and regional tsunami mitigation programs, providing essential mitigation tools, and raising the awareness and commitment of individuals, businesses, emergency responders and decision makers at the local, provincial, and federal levels.

Tsunami mitigation has many similarities to approaches applied to other natural hazards in that it requires knowledge of the hazard, its likely effects, and what can be done to reduce those effects. However, in many other ways the tsunamis present their own set of unique challenges:

- Destructive tsunamis are very rare events. Since the last destructive Canadian event in 1964, an entire generation has never experienced one.
- The lack of documented local tsunamis effects along most B.C. coastal regions makes it difficult for residents to conceptualize tsunami impact risk and determine associated vulnerabilities.
- In contrast to seismic design and engineering, there are no Canadian standards for the design of tsunami-resistant structures.
- Current national mitigation and warning priorities are targeted at urban areas. Even though sparsely populated, the potential loss of life, property and infrastructure to tsunami is large.
- B.C. coastal regions have different tsunami exposure and histories, diverse populations and cultures, and different economies, institutional structures and issues. No single mitigation strategy is likely to fit the needs of all areas.

Historically, Canadian tsunami mitigation efforts have been inconsistently proactive and more often reactive. For example, a year before the 1964 Alaska Earthquake, Canada chose to withdraw from participating in the Pacific Warning System while, at the same time, many communities were withdrawing from participation in local civil defence programs. The 1964 Alaskan tsunami resulted in reinstatement of Canada’s participation in the international Pacific Warning System, recognition of the near-source tsunami hazard and (along with B.C. PEP) subsequent participation in the west coast subsystem coordinated by the West Coast/Alaska Tsunami Warning Centre. Over time, however, the experiences of local populations and governments have tended to gradually under-prioritize the tsunami threat in many cases.

Overall, evidence seems to suggest that the public response subsystem presents some of the most difficult challenges in terms of infrastructure, organizational, and policy considerations. However, as noted in the best practices literature, a properly integrated tsunami warning system involves a wide range of considerations across all three stages of the dissemination network. This report therefore offers a series of recommendations, classified according to the three-stage dissemination model but emphasizing a mitigation-oriented approach aimed at strengthening system integration overall.

8.1 Stage one: monitoring and detection

Gradual improvements in monitoring and detection of distant-source tsunamis have occurred since the last damaging event of 1964. For example, the Canadian Hydrographic Service has installed a small number of tidal gauges on the B.C. coast that can be read remotely in real-time to monitor the arrival of tsunami waves on land. This network contributes to warning systems for distant-source tsunamis, but Canada still relies primarily on international partners for wide area monitoring and detection. Local tsunamis continue to be problematic for issuing timely alerts.

Conclusions

There exists the need to:

- Maintain and strengthen where possible Canada's international commitments to the Pacific Tsunami Warning System;
- Consider the deployment of new communications technology where it provides identifiable enhancements to the current stage one activities; and
- Begin developing a warning and alerting strategy for local tsunamis throughout the B.C. coastal region.

8.2 Stage two: emergency management

At present, inundation maps are not readily available to community, regional or provincial planners. Current inundation mapping efforts are focused primarily on selected communities on Vancouver Island. Because of the specialized technical knowledge required, it is unlikely that local communities will possess all of the necessary expertise to produce their own inundation maps without expert assistance.

The majority of the B.C. coastline at risk of tsunami flooding is rural and, in many cases, sparsely populated. These regions generally have difficulty competing with more populated areas for scarce mitigation resources and will likely require additional assistance in order to conduct mitigation efforts.

Conclusions

Inundation mapping activities need to be:

- Expanded to include all populated and important economic coastal areas at risk in B.C.;
- Institutionalized under existing federal and provincial mitigation strategies to ensure longer-term sustainability.

8.3 Stage three: public response

Local warning capabilities are extremely limited in B.C. coastal regions. Only one community uses a siren for mass warning. Aside from marine radio, there is no common coastal warning system to ensure all populations at risk can be warned and to confirm that warnings have been received and understood.

The capacity for broadcasting local warnings is extremely limited in many rural coastal areas, and telephone-based notification schemes may also be problematic in small communities due to overloading of the local telephone systems during major incidents. Telephone systems generally are not scaled for community-wide emergency events, especially during tourist seasons.

Conclusions

- A communications infrastructure audit needs to be undertaken to identify local capabilities and specific gaps in coverage. The audit would have to involve federal government departments, provincial agencies, the academic community, and the private sector.
- Regular reporting on exercises and meetings for the B.C. Tsunami Warning System needs to be established.
- The Pacific Regional Emergency Telecommunications Committee needs to become more actively involved in the further development and implementation of the B.C. Tsunami Warning System.
- A Universally Digitally Coded Warning system for public warning in B.C., with specific implementation for tsunami warning, is needed.
- A set of targets and corresponding incentives to ensure minimum warning capabilities for all communities along the B.C. coast is required.

No response techniques are in place for transient and remote communities other than those developed on a voluntary, uncoordinated basis. The west coast tourism industry brings in many thousands of transient visitors (not all of whom speak English) and temporary workers who will likely be vulnerable while in the area and should know what to do if a tsunami occurs.

Information about the tsunami risk and appropriate response needs to be communicated to residents, workers (seasonal and year-round), regional visitors, and transient populations, all of whom have different exposure to tsunami hazard.

Conclusions

At the provincial level, officials need to work together with:

- Relevant ministries to develop a trailhead information campaign as part of a risk communication program for vulnerable recreational areas along the B.C. coast.
- Local authorities to encourage greater cross-membership in research, educational and training programs to support the formation of tsunami working groups.
- Local communities to develop a mechanism for continued assessment of coastal community needs and evaluation of the success of existing programs as part of broader

national and provincial mitigation strategies. This is particularly important as the socio-economic profiles of coastal areas continue to change. In many coastal regions, there is an opportunity to build on broadly based processes already in place such as Rural Team British Columbia and the Coastal Community Network.

In the absence of an effective warning system for near-source tsunamis, a special awareness and education program about tsunami risk and appropriate response should be implemented. This would need to be communicated to residents, workers (seasonal and year-round), regional visitors (especially tourists), and transient populations, many of whom may have a different exposure to the tsunami hazard.

Mitigation ultimately cannot succeed without the support of local populations. Therefore, a successful mitigation strategy requires continuing commitment from local governments and other local authorities, as well as by individuals, industry and the recreational and tourism sectors in tsunami-prone areas.

Longer-term mitigation goals need to embrace better land-use practices and be incorporated into Official Community Plans of municipalities and in regional district development plans for unorganized regions. Successful mitigation practices will also recognize that every community is different. Some are isolated. Some are locally governed, while others are administered by a regional district office situated many kilometres away. Some have emergency services while others do not.

Conclusions

- There exists the need to develop a standard provincial tsunami program assessment template, which could be based on the 1976 Foster and 2004 Anderson tsunami program reviews. This template should be administered regularly – every five or 10 years – to assess local, regional and provincial community readiness and to measure the utility of active tsunami program initiatives.
- B.C. PEP’s Risk and Vulnerability Analysis (HRVA) Tool Kit is available to help a community make risk-based choices to address vulnerabilities, mitigate hazards and prepare for response to and recovery from hazard events. A specialized version of it to assist local planners in their preparation of tsunami mitigation strategies and response plans would be beneficial.
- Local authorities need to work together to develop a common public educational outreach program to ensure that local residents understand the procedures associated with tsunami watch and warning bulletins.
- Continued support from federal and provincial agencies and expanded access to tsunami information through existing websites is required.
- Current legislation needs to be reviewed to ensure minimum requirements for tsunami risk reduction practices are established and followed.

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. Because tsunamis are infrequent natural events, individuals require constant education to substitute for personal experience.

Scientific support may also be required in applying modeling concepts, as well as in learning how to interpret inundation maps and approach areas not covered by mapping.
A potential problem for emergency preparedness in many small communities is the dual role played by many emergency managers who often have multiple responsibilities (e.g., fire department, search and rescue, public works, etc). Under these circumstances, certain public warning responsibilities may be unclear to these individuals or its importance may go unrecognized amidst competing responsibilities.

Conclusions

- The transfer of knowledge from the scientific community to local and regional tsunami risk management and mitigation efforts is important, but needs support from federal or provincial governments.
- A Canadian tsunami information clearinghouse to enable 'one-stop' access to tsunami information and planning resources would be helpful.
- Creation and maintenance of targeted tsunami educational programs in place for industry sectors such as tourism, fisheries, aquaculture and forestry is required.
- Specific training modules for tsunami hazards need to be jointly developed.

Much benefit can be gained from current mitigation efforts underway in neighbouring U.S. states that face similar challenges to British Columbia. Two noteworthy initiatives are: 1) the National Tsunami Hazard Mitigation Program coordinated by NOAA which provides funding for the production of tsunami inundation maps, development and implementation of education and preparedness programs, and improvement of warning guidance through the installation of new seismic stations and deployment of an array of real-time deep-ocean tsunami detectors; and 2) TsunamiReady, a National Weather Service (NWS) initiative that promotes tsunami hazard preparedness as an active collaboration among federal, state and local emergency management agencies, the public, and the NWS tsunami warning system.

While the development of a U.S. tsunami mitigation strategy is underway and while the results are being shared with Canadian federal and provincial agencies, much less collaboration and interaction seems to be occurring among local authorities and industries across jurisdictions and borders.

Conclusions

- To enhance information exchange and introduce stakeholders to each other, especially local planners, a regional mitigation conference and regular workshops should be planned. Possible venues include the annual Vancouver Emergency Preparedness Conference; Emergency Preparedness for Industry and Commerce Council annual forum (especially for industry planning); Union of B.C. Municipalities special events, and so on.
- Supporting the use and sponsorship of existing forums to reduce the effects of earthquake events would be helpful. Examples include the Western States Seismic Policy Council (WSSPC), a regional earthquake consortium; and the Cascadia Region Earthquake Workgroup (CREW), a coalition of private and public representatives working together to improve the ability of Cascadia Region communities to reduce the effects of earthquake events.

9.0 Suggestions for Further Research

This section lists three broad areas for further research based on various findings from this study. These suggestions are limited to those areas where there appears to be significant gaps in knowledge, and are detailed in the conclusions drawn from this study.

In addition to these three areas, there will likely be a need for expanded support of scientific research into tsunami run-up modelling and inundation mapping for B.C. coastal regions. Such research provides foundational knowledge necessary for planning and preparedness initiatives across all levels of government and in the private sector.

9.1 Communications infrastructure

Few details are known about communications capabilities throughout the B.C. coastline. Recent developments in technology and changes in communications policy in Canada have created both new possibilities and potential constraints for public alerting. As such, there is an urgent need for research into this area to determine the most appropriate means of delivering warning messages to local populations.

Findings from such research would provide valuable information about the communications capabilities of local populations along the B.C. coast, contributing to Industry Canada's Public Alerting initiative and to the future design of the B.C. Tsunami Warning System.

9.2 Coastal preparedness

Little is known about tsunami awareness and preparedness practices of coastal populations, particularly transient groups and emerging business initiatives. As such, there is a need for a comprehensive empirical assessment of risk reduction practices that would consider such factors as local emergency planning capacity and exercise schedules, the existence and maintenance of written action plans, local public warning and educational strategies, evacuation planning and designated safe sites, vulnerability of critical and essential infrastructure, and potential economic impacts.

The results of such an assessment could provide detailed information for setting future targets, identifying priorities, and establishing measures for the effectiveness of mitigation and preparedness strategies.

9.3 Duty to warn

It may be prudent to undertake a formal inquiry into federal and provincial legal obligations with respect to a 'duty to warn' residents and visitors of known tsunami hazards, as well as the required minimum conditions that governments might be reasonably expected to take in developing and maintaining a public alerting system.

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