Powell River Regional District Tsunami Report

September 2007

Contents

LIST OF TABLES

FIGURES

LIST OF APPENDICES

PLATES

Incorporated in the text

Executive Summary

The Powell River Regional District is not at significant risk from a devastating tsunami wave or series of waves. Four mechanisms that could generate tsunami waves in the Strait of Georgia have been identified but do not appear to generate wave heights that would cause significant physical damage to most Regional District beach areas, foreshore, protective sea walls or marinas. Maximum tsunami wave heights in the upper Strait of Georgia and Malaspina Strait appear not to exceed 1.0 meters and may be more likely 0.5 m for the presently identified events that could cause tsunami generation. A combination of extreme high tides, onshore winds and a concurrent tsunami wave would cause localized flooding in low-lying areas along some island and mainland foreshores. To the extent to which this would occur requires detailed survey of immediate foreshore areas. However, in some narrow island and mainland bays, their placement and relatively shallow water depths does not preclude significant increases in water levels and possible consequential damage in these locations.

Recreational use of beach areas during summer months coupled with very low tides has the remote potential for a concurrent tsunami wave to impact shallow water, beach and sand bar users. The impact would be greatest amongst those unable to withstand an unexpected or rapid increase in water depth associated with incoming wave action.

Other west coast jurisdictions have utilized foreshore signage to inform the public about this tsunami hazard. Typically these jurisdictions have a much higher tsunami exposure and the Regional District will wish to give careful consideration to whether or not tsunami signage is necessary in some low-lying areas. A number of supporting recommendations regarding emergency management planning and the need for more definitive information on inundation potential particularly around the periphery of the Regional District are made in this study.

Acknowledgments

This Report would not have been possible without the assistance of a number of agencies and individuals. In particular we would like to acknowledge the Regional District of Powell River for its direct assistance in facilitating and enabling this project to be undertaken.
Dr. Gary Rogers at the Pacific Geosciences Center of the Geological Survey of Canada, Natural Resources Canada provided invaluable assistance on the current status of research into tsunami threats in the upper Georgia Strait between the mainland and Vancouver Island.
A number off organizations have provided reference material for the study. In particular we would like to recognize The Cascadia Region Earthquake Workgroup, The Oregon and Washington Departments of Geology and Mineral Industries and the Currey County Emergency Services Emergency Manager; Mike Murphy.
D R Lister, P.Eng., Senior Geotechnical Engineer at Golder Associates Ltd. Victoria office provided the probable tsunami wave height and run–up assessments and these calculations were reviewed by RJ Atkins, **P.Geo.**, Senior Geomorphologist also at Golder.

This study is supported by a grant to the Powell River Regional District from the British Columbia Provincial Emergency Program without which this study would not have been possible.

1.1 Introduction

1.2 The events of Boxing Day 2004 in Indonesia, Sumatra and the Indian Ocean brought into sharp focus the devastation that low-lying areas and islands can experience following significant undersea earthquake activity. Sadly the Indian Ocean area had, at that time, no warning facility or sensor array, partly because the governments surrounding the Indian Ocean felt that it was not affordable and also because it was not deemed necessary based on recent historical experience . The last major tsunami in the Indian Ocean had been caused by the eruption of Krakatoa in 1883.

1.3 Historically, the Pacific has always been a far greater risk from tsunamis. As a result of the April 1946 Aleutian Island's tsunami which did extensive damage hundreds of miles away in Hawaii, most of the countries of the Pacific Ocean established a tsunami warning system that was completed in 1949. This warning system, utilizing seismometers to measure ground motion, sends signals in real time to operations stations as any seismic movement occurs, enabling undersea earthquakes or landslides to be recorded throughout the Pacific basin with great speed. Any ensuing tsunami is detected by a system of coastal tide gauges and deep ocean pressure sensors allowing "Warnings" or "Watches" to be established for likely affected areas. This system provides protection for the coastal areas of British Columbia and Alaska.

1.4 This system alone however, is only one part of an effective tsunami preparedness and response system. Moreover, the Powell River Regional District including its island communities are largely protected from major Pacific tsunami threats by their position toward the north and east of Vancouver Island. They are also separated from Vancouver Island by the Straits of Georgia and Malipina, which at the south end are protected, in turn, by the Strait of Juan de Fuca and the San Juan Gulf Islands complex and in the north by the upper Strait aggregation of islands and the narrow Johnstone Strait . While the known threat of tsunami wave action in the Strait of Georgia is not considered great, the Powell River Regional District, through an initiative of the provincial government, is undertaking a more substantive examination of the threat and risk to its foreshore areas. These areas encompass the inhabited islands of Lasqueti, Texada and Savory as well as the mainland coast stretching from Lund in the north to Jervis Inlet in the South.

2.0 Description, Causes and Local Impacts of Tsunami

2.1 A typical description of tsunami is that it is a fast-moving, highly destructive wave or series of waves that steadily increase in height as they approach the shoreline and that they are generally associated with abrupt movement of the earth's surface under the sea caused by large earthquakes, volcanic eruption or by massive landslides both into the sea or undersea.

Tsunamis, once widely known as tidal waves although they have no link directly to tidal activity, are a natural phenomenon generated when the water in the sea or a large inland body of water is rapidly displaced on a massive scale creating forces such as those generated when the sea floor abruptly deforms and vertically displaces the overlying water, as was the case in Sumatra in 2004. Waves are formed as the displaced water moves under the influence of gravity seeking to gain its equilibrium and eventually radiating across the body of water or ocean like ripples in a pond. Unlike normal wave action where wavelength may be only a hundred and fifty meters long with a 10 to 15 second interval from one wave top to the next wave top, tsunami wave length can be up to several hundred kilometers long with extremely long wave intervals, ranging from minutes to a number of hours.

The actual height of a tsunami wave in open water is often less than 1 m and may go practically unnoticed by ships at sea. This is because the energy of a tsunami passes through the entire water column, from the seabed to the ocean surface. Again, this is unlike ordinary waves which typically reach down to depths less than 10 m. The speed at which a tsunami wave travels is also exceptional, traversing oceans and long bodies of water from 500 to 1000 kph. This speed may be maintained until the tsunami approaches land where the sea bed shallows and the waves can no longer travel at such high speeds. Instead, they begin to pile up and the wave front, which becomes steeper and taller, then yields less distance between the crests. As it approaches the shoreline existing shallow waters may well be withdrawn back from the beach and as the incoming tsunami wave slows its forward momentum decreases dramatically. As the wave compresses it can increase to heights in excess of 30 m if it has traveled long distances at high velocity through deep ocean water toward exposed coastlines. The first wave will collapse on the foreshore immediately inundating low lying areas with subsequent run up traveling inland as a flooding wave. It may be followed by succeeding waves. Shoreline configuration and bathymetric or seafloor features are known to influence wave intensity and dispersion. River or inlet mouths are similarly exposed to tsunami where they discharge to the sea. Since each causational seismic event is unique, every tsunami has unique wavelength, wave heights and directionality. From a tsunami warning perspective this makes the problem of forecasting and modeling tsunami activity extremely complex.

2.2 The Powell River Regional District situated in the southwest of British Columbia is situated in relatively close proximity to the active Cascadia subduction zone, with the trench axis about 150 km to the west of Vancouver Island. This setting makes the region subject to frequent seismic activity and contributes to a higher risk of large damaging earthquakes that can also cause tsunami, than is the case in any other part of Canada. Moreover, a number of seismic generated mechanisms have been identified that could cause what are now assessed to be fairly minor tsunami impacts on the Powell River Regional District island or mainland foreshores and beach areas.

Tsunami that could affect the Regional District have four potential sources:

- Plate-boundary earthquakes at the Cascadia subduction zone
- Plate-boundary earthquakes at other subduction zones on the Pacific rim
- Upper-plate faults in or close to the Strait of Georgia
- Sub-sea or terrestrial slides in or immediately adjacent to deeper waters of the Strait of Georgia

2.3 The tectonic plates that underlie much of the Pacific Ocean are being subducted beneath the continental margins around the perimeter of this large ocean basin. The interface between the converging oceanic and continental plates appears to lock for long periods of time generating an accumulated strain compressing and deforming the continental margins. This accumulated strain is released every few decades or centuries through large subduction earthquakes. As these earthquakes occur the seafloor above the locked zone may rise abruptly generating a tsunami while part of the adjacent coastal zone may suddenly subside causing flooding of the newly created low lying areas. This lock and release cycle is repeated, often with long time intervals between events.

2.4 Stretching from above the Brooks Peninsula on Vancouver Island to Cape Mendocino in California, the Cascadia earthquake subduction zone is where the heavier Juan de Fuca Plate meets and begins to push below the North America Plate along a 1300 km long line off the Pacific Coast. The two plates move relative to each other at an average rate of about 4 cm a year but are currently locked along a fault segment thought to be about 1100 km long and 100 km wide. Here, the North American plate is separated by a fault from the much smaller, eastward moving, oceanic Juan de Fuca plate.

This plate is bordered on the north by the smaller Explorer plate along the Nootka fault.
To the south, a similar fault separates the Juan de Fuca and Gorda plates. The Explorer and Gorda plates are thought to be breaking up as the North America plate overrides them. Since the Juan de Fuca plate subducts in a series of massive, earthquake generating jerks, the strain energy accumulating due to the locking of the main subduction fault will eventually release as a large earthquake. It is now known that Cascadia mega-thrust earthquakes and associated tsunamis occur at irregular intervals from a couple of hundred years to a thousand years apart with an average interval of between 500 and 600 years. The last mega-thrust earthquake occurred in January 1700 and created a tsunami wave that was hours later observed and recorded in Japan. It is only in recent times however, that this correlation has been discovered.

Current studies of tidal marshes on the Pacific coast of North America that suddenly subsided during similar great earthquakes show that the Cascadia subduction zone has ruptured five times in the last 2600 years. Although direct evidence of tsunami impacts is not available an important computer model showing the probable propagation of tsunami waves from a great earthquake at the Cascadia subduction zone has been developed at the Institute of Ocean Sciences in Sydney, British Columbia. [See Links section of this Report] The model predicts that a great earthquake at the plate boundary will generate tsunami waves about 5 to 10 m high on the outer British Columbia coast. These large waves gradually diminish in height as they move through the Juan de Fuca Strait and the narrows between the San Juan and the Gulf Islands. The leading edge of the first wave is forecast to reach the southern portions of the Strait about two hours after the earthquake. Second and third waves are anticipated some three and five hours respectively following the first wave. South and east, areas such as Boundary Bay in Delta may experience wave heights in excess of 2 m. The predominant shoreline of the Fraser delta which lies parallel to the direction of wave travel however, is modeled to have maximum wave heights on the foreshore in the range of half a meter. By the time that the initial wave reaches the upper Strait, some two hours and a half following the major earthquake, its wave height is postulated to be in a similar range, with any succeeding waves in the Strait of Georgia most probably being somewhat less in height. Tsunami wave heights and behavior in the Strait of Georgia are the subject of ongoing research and, as the knowledge base expands, so too does the understanding of possible impacts on specific locations as is the case for the Powell River Regional District and its island jurisdictions.

2.5 Excluding the Cascadia subduction zone, of the other similar zones surrounding the North Pacific there is only the Alaska-Aleutian plate margin that represents a significant tsunami threat to the west coast of Canada. Great earthquakes have ruptured this subduction zone six times in the last 4000 years. On the last occasion in March of 1964 tsunami waves up to 6 m high devastated several communities on the outer coast of Vancouver Island and causing destructive damage as far south as Hawaii and California. The Hazard Preparedness section of the Provincial Emergency Program web site also provides a vivid description of the experiences in Alberni and Port Alberni that include measured wave heights of 4 meters from this same Alaska earthquake.

It has been determined that the island archipelagoes at the northern and southern ends of the Strait of Georgia, however, effectively moderate this type of tsunami in these inland waters. At the Northern end, Johnston Narrows might experience 6 meter waves that quickly diminish while at the eastern end of the Strait of Juan de Fuca the largest wave from the 1964 Alaska tsunami was one to two meters high and in the southern Strait of Georgia it had diminished to less than 0.5 m and by the time it had reached the upper Strait it had significantly dissipated . It is generally concluded that tsunamis triggered by distant plate boundary earthquakes do not constitute a significant source of hazard to the upper islands and coastline within Georgia Strait.

2.6 Crustal earthquakes within the North America plate are known to represent some tsunami hazard to coastal communities of the Pacific Northwest. Faults in central and northern Puget Sound are known to have experienced large earthquakes throughout the last century. Historic research also indicates that some tsunami inundation may have occurred in the last few thousand years, however, the narrow and relatively shallow channels in the Puget Sound suggest that significant tsunamis are unlikely to impact the Georgia Strait. Less well known however, is the tsunami potential posed by submarine faults beneath the Strait of Georgia. These faults appear to have an East West alignment. Were any of these faults to be active and vertical displacement of the seafloor to occur during a future earthquake then any ensuing tsunami might have some foreshore impacts but these would be diminished where the coast is at right angles to the fault zone or islands are protected by their position, orientation or adjacent reefs as is the case in the Regional District.

2.7 The Fraser River discharges millions of tons of unconsolidated sediment into the Strait of Georgia each year where much of the sediment accumulates on the steep frontal slope of the delta. Research dating back to 1956 in the Georgia Strait has suggested that both new sediment accumulations and seismic shaking could cause sub-marine slides at this Fraser River delta front. Small gravitational slides appear to be fairly commonplace and do not yield tsunami waves. Researchers have concluded that a large slide could generate a tsunami wave but that its greatest impact would be on Galliano and Mayne Islands and any waves at the shorelines to the north would have been significantly dissipated.

2.8 The upper Georgia and Malaspina Straits have a number of inlets or steep mountainous escarpments that have the potential for landslides that could plunge into the sea and produce tsunami waves. The most spectacular landslide triggered tsunami of the 20th century occurred in 1958 Litluya Bay, Alaska. This strong earthquake triggered a rock slide on the steep slope high above the head of the bay. The resulting 30 m high wave destroyed forest on high up on either sides of the valley.
No specific sites have been identified in the Regional District as a specific risk and since population is sparse in these types of narrow inlet locations, the impact of such terrestrial failures is not presently high.

3.0 The **British Columbia Tsunami Warning and Alerting Plan**

3.1 Tsunami warning in the Pacific Basin is the subject of an international protocol established in 1946 by the United Nations Intergovernmental Oceanographic Commission. The warning system is managed by the United States Department of Commerce, National Oceanic and Atmospheric Administration [NOAA], and is designed to detect tsunamis and provide prompt notification to national jurisdictions bordering the Pacific Ocean.

3.2 The only part of Canada with a section of the Pacific Ocean on its coast is British Columbia. The tsunami risk areas of the province have been divided into five zones; A through E. Zones A, B and C which include the Queen Charlotte islands, coastal areas around Prince Rupert, the north central coast and the west coast of Vancouver Island are all considered as having significant tsunami risk. The Regional District is identified in zone E as part of the lower risk in Georgia Strait. The province through the Provincial Emergency Program [PEP] receives alerts and warnings from the West Coast and Alaska Tsunami Warning Center and relays these alerts and warnings along with interpretation for Canadian coast and tidal conditions in conjunction with the Canadian Hydrographic Service to all jurisdictions where the population may be at risk from tsunami wave action.

3.3 The Provincial Emergency Program, as British Columbia's representative recipient, can provide five types of B.C. Tsunami Advisory Bulletins. These are:

- **Tsunami Warnings:** this warning indicates that a tsunami exists, or may exist, and the travel time to any portion of the British Columbia coast is under three hours. A tsunami warning is intended to cause those receiving it to consider activating local evacuation plans including evacuation of low-lying areas.
- **Tsunami Watch:** a watch indicates that an earthquake has occurred which is capable of generating a tsunami however the travel time to any portion of the British Columbia coast will be greater than two hours. The tsunami watch is intended to cause emergency personnel to be placed on standby.
- **Tsunami Advisory:** these advisories are issued for an earthquake greater than magnitude 7.5R that has occurred in the Pacific Basin and which could generate a tsunami however, it would take over six hours travel time to the nearest point on the West Coast of Canada or to Alaska
- **Tsunami information:** these bulletins may be issued to advise that a major earthquake less than 7.1R on the West Coast or 7.5R has occurred in the Pacific Basin region but that a damaging tsunami is not expected to reach the coast of British Columbia.
- **Tsunami All Clear:** the provincial all clear indicates that no further tsunami waves are expected and local authorities may issue their own all clear announcements.
- **Tsunami cancellation:** this bulletin cancels all previous advisories and indicates that the threat of tsunami damage has ended

3.4 Provision of Tsunami Warning Information
Upon receiving alert or warning information from the Tsunami Warning Center the Provincial Emergency Program will then advise:

- All British Columbia coastal local governments in the risk areas, including the Powell River Regional District administration
- The Royal Canadian Mounted Police "E" Division
- The Canadian Coast Guard Vessel Traffic Management System
- Nav. Canada
- Public Safety and Emergency Preparedness Canada
- The Canadian Armed Forces Maritime Forces Pacific
- appropriate media networks and outlets

The information will thus be well dispersed to government and public safety organizations enabling them to further disseminate it within their own organizations. While public alerting through the media may have occurred it is also likely that an earthquake of sufficient magnitude to cause a tsunami affecting the Regional District will also have ground shaking motion that was apparent to the general public and property owners on the islands and along the coast.

3.5 Some confusion has arisen regarding the responsibility for the issuance of tsunami Bulletins. While the Pacific Tsunami Warning Center in Ewa Beach, Hawaii provides information for most of the Pacific Basin it does **not** provide information for the northern United States and Canada. Alaska, British Columbia, Washington, Oregon and California rely on the West Coast/Alaska Tsunami Warning Center for their updates. Additional information can be found at that Center's web site http://wcatwc.gov/.

4.0 Field Study of the Shorelines of the Powell River Regional District

The shoreline of the Powell River Regional District, including its principal islands, and the mainland foreshore including the Sliammon First Nation Indian Reserve, was visited to identify and photograph areas where any significant increase in sea heights might be of concern. A number of representative Plates on these findings accompany this Report in this Section. Some additional plates are found at the end of this report.

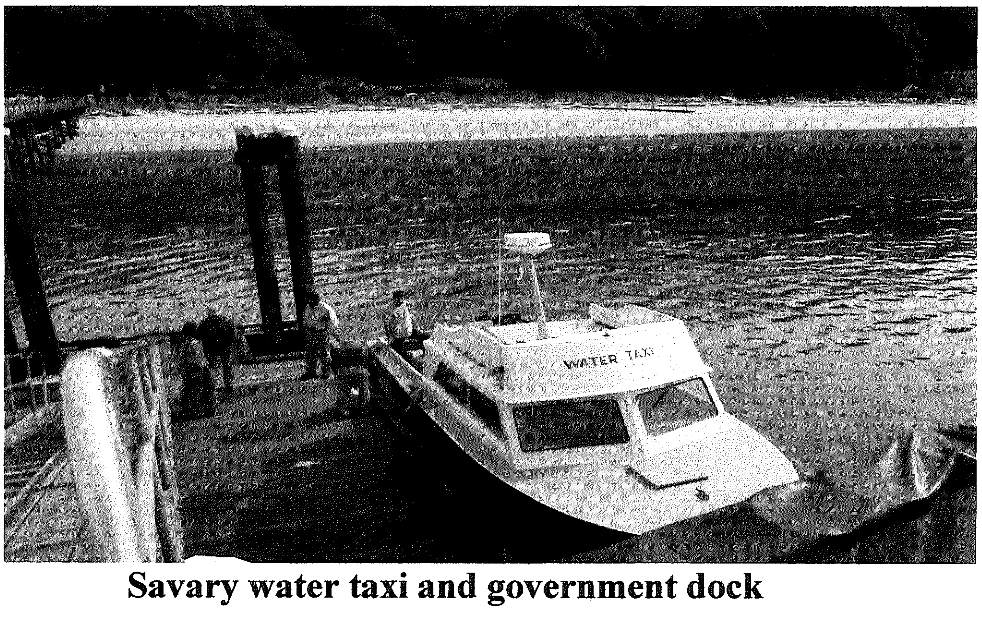
Three factors, probable tsunami wave heights, onshore winds and high tides influence shoreline exposure. There is substantial mitigation of any likely impacts that would occur even from the most significant modeled tsunami wave or series of waves that might otherwise impact other jurisdictions immediately south of the Regional District throughout much of its area due to its more northerly location in the Strait of Georgia, protection afforded by some rocky banks and shoals, rock banks at the shoreline in many locations, and the northwest southeast orientation of much of the coastline.

4.1 Savary Island

Savary Island, with a resident population of less than 100 but a summer population of up to 2000, is approximately 8 km long and less than a kilometer wide. Due to its predominantly low beaches, west to east orientation and debris on the upper tide line any significant high water might well cause inland damage since run up distances could be as great as 100m .

Increased water heights would move debris inland from these shallow Savary beaches

Savary Island is served by float plane or water taxi from Lund at the northerly terminus of the mainland highway. Administratively it is part of Electoral Area A in the Regional District.



Savary water taxi and government dock

4.2 Lasqueti Island

Lasqueti Island is approximately 5 km wide and 21 km long. The island's ferry terminal is located at False Bay and is served from French Creek on Vancouver Island. The island supports a resident population of approximately 400 and a summer population up to 1000. Administratively the Island is designated as: Area E: Lasqueti Island and small surrounding islands.

Lasqueti False Bay dock

Much of Lasqueti Island is endowed with significant rock bank around its shore line with the exceptions shown in Table 3.

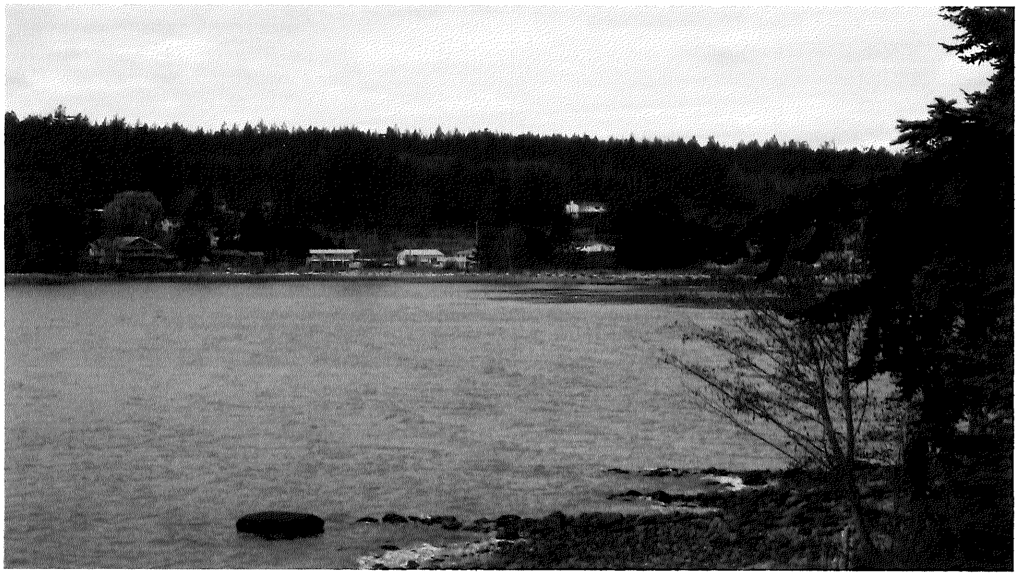
Some bays and beaches have only scattered rock outcrops

4.3 Texada Island

Texada Island is approximately 50 km long and 10 km wide. It has two small communities at Van Anda and Gillies Bay.

Van Anda benefits from high bank protection

Texada island presently supports a resident population of about 1200, however, future mining expansion is anticipated.



As Table 3 suggests, run up would be more pronounced in long shallow bays as in Gillies Bay

Administratively Texada is designated as Area D. There is daily regular ferry service from the City of Powell River to the Texada Island ferry terminal at Blubber Bay.

Texada ferry dock and ramp

4.4 Mainland

The largest portion of the Powell River Regional District is located on the mainland of British Columbia 140 km northwest of Vancouver. Jervis Inlet separates the District from the adjacent Sunshine Coast Regional District. British Columbia Ferries provide service to both the Sunshine Coast and to Saltery Bay, below, at the south end of the mainland portion of the Powell River Regional District.

To the west lies the Strait of Georgia and Vancouver Island. The region is rural in nature, with a population of about 23,000 and a land area of about 1,260,160 acres, and has boundaries that stretch from Jervis Inlet in the south to Toba Inlet in the north. The area encompasses several small mainland rural communities, including

Sliammon Creek Bay

the Sliammon First Nation, a small section of the Sechelt Indian Government District Lands, the City of Powell River itself and also the two larger islands of Texada, Lasqueti, and the smaller Savary Island discussed above.

The City of Powell River, as a separate legal and jurisdictional entity, has developed its own Emergency Program and Tsunami Plan. Powell River has regular ferry service to Little River Terminal at Comox on Vancouver Island.

Administratively the mainland is comprised of three Electoral Areas :

Area A: North of the municipal boundary and including Sliammon First Nation, Lund and, as noted above, Savary Island.

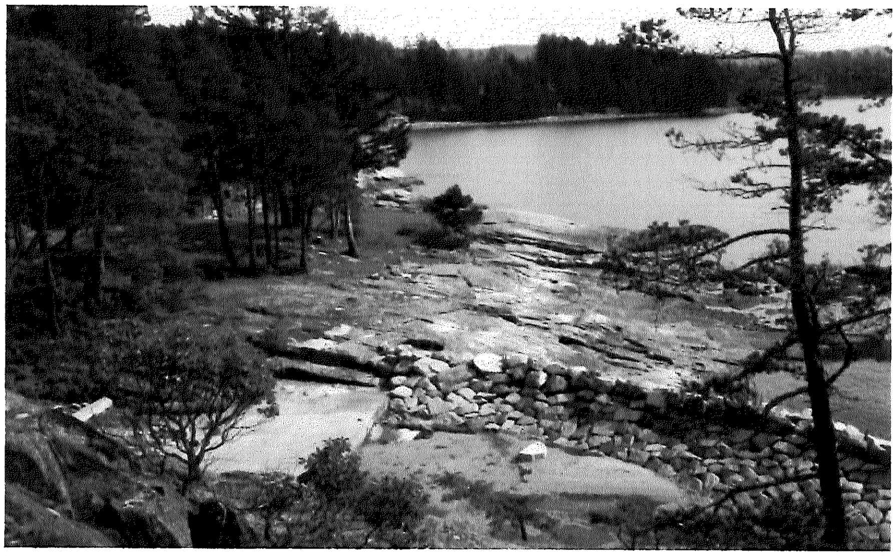
Lund marina at the terminus of Highway 101

Area B: South of the municipal boundary to Whalen Road including Paradise Valley, and properties outside the city municipal boundary along Nootka, Covey and Tanner Streets.

Area C: from Whalen Rd. South to Saltery Bay, including Black Point, Kelly Creek, Lang Bay and Stillwater.

In total Highway 101 stretches some 81 km facing the Malaspina Strait and the shoreline waters of the Algerine and Shearwater Passages from the ferry terminal at Saltery Bay in the south to Lund at the northerly terminus of the paved road.

Heading north to south from Lund, a variety of beach and waterfront conditions were observable in the waterside residential areas.



From Emmonds Road with its beach and Revida Road with approximately 16 low bank homes one moves to Stuart Road which leads to Macadam Place where all but one of the houses, of new construction, is located on high bank.

Along Highway 101 most is high bank until Klahanie Drive North where approximately 38 homes range from lower to higher bank. Along Waterfront Road in the Sliammon First Nation no houses are built between the road and the foreshore although the bay might present an opportunity for run up as noted in Table 3.

Further south Stevenson road is largely high bank as is Pebble Beach Road. On the other hand the Myrtle Point Resort is on the beach.

McCausland Drive to Alta Vista is high bank as is Garnet Rock Camp with mobile homes. On McGuiness Road to Amour Road and Patricia Road the shoreline returns to low bank. By contrast Whalen to Fleury roads return to high bank conditions. The same holds true for Reave Road down to Stittle as well as Black Point road.

On Zielinski to Brew Bay there is a pretty beach shoreline. And at Lang Bay Road there is a motel and housing close to the beach followed by the Palm Beach Road and RV park. Loubert Road leads to Scotch and then to Hollingsworth with new housing on relatively high bank as similarly with Fir Point Road. There is little housing at present from Thunder Bay south until Saltery Bay where housing is largely on semi-high bank.


Saltery Bay shingle beach and rocky foreshore

An exception is the low bank in the Provincial Park in Saltery Bay.

Rip Rap has been used to in the Park to curtail beach erosion

5.0. Tsunami Hazard Assessment

Golder Associates Ltd.(Golder) was asked to prepare a preliminary assessment of the Tsunami hazard to the coastal portions of the Powell River

Regional District. For the purposes of the study, the areas of interest are the Mainland coast between Lund and Saltery Bay not including the Municipality of Powell River, and the three islands Savary, Texada and Lasqueti (See Figure 1).

5.1 Methodology

5.1.1 Review of Existing Information

A review of existing information was undertaken in a previous study by Golder for the BC Ministry of Transportation to determine likely Tsunami characteristics in British Columbia. A bibliography is presented in Appendix I. From the existing information four potential Tsunami hazard zone areas were developed for the British Columbia coast.

- The Strait of Georgia and Inlets;
- Juan de Fuca Strait and Haro Strait and Inlets;
- The west coast of Vancouver Island and Inlets; and,
- The north and central coasts, and the Queen Charlotte Islands and Inlets.

For this assignment only the information for the Strait of Georgia is relevant

5.2 Tsunami Wave Height determination and Run – Up Calculations

Potential maximum Tsunami wave heights were estimated through the literature review and through dialogue with staff from the Pacific GeoScience Centre and Simon Fraser University. In particular, papers by Ng *et al.* (1990, 1991) and Dunbar *et al.* (1989) that describe wave model results were used to develop potential maximum wave heights for each of the geographic locations as outlined in Table 1. TABLE 1: Modeled Wave Heights

Geographic Location	Height (m)
Strait of Georgia	
Port Hardy	1.5
Bellingham	2.0
Burrard Inlet	1.0
Comox	0.5
Delta/ Richmond	0.75
Discovery Passage	1.0
Johnstone St	1.0

Geographic Location	Height (m)
Nanaimo	0.5
Point Atkinson N. Vancouver	0.5
Sidney	1.75
White Rock	1.0

Using these modeled wave heights an assumed maximum wave height was developed for the Strait of Georgia. The modeled wave heights in the literature reviewed assumed the occurrence of a large (> 7 M_R) subduction zone earthquake in the Aleutians, near Alaska and in the Cascadia Subduction Zone. Therefore the maximum wave heights used in this study may be considered representative of the waves generated by large (> 7 M_R) subduction zone earthquakes such as may occur in the Pacific Ocean and impact the BC Coast.

A tsunami wave of a given amplitude or wave height will produce a wave run-up on shore to an elevation greater than the amplitude. This run up elevation is dependant on a number of factors primarily related to the slope morphology and roughness. For a preliminary study we have assumed a run up elevation of twice the wave amplitude. Discussion with staff from the Pacific GeoScience Centre indicated that assumed tsunami wave run–up elevations of two times the modeled wave height are a reasonable, conservative estimate.

Potential tsunami wave run-up distances were calculated using a simple trigonometric formula. Wave run up elevations, as determined above, were divided by the tangent of the beach slope to determine wave run–up distances (Appendix I). Therefore wave run-up elevations of two times the wave height were used to determine the hazard zone along the shoreline. The effects of friction on the wave crossing the beach and inundating the terrestrial area were considered to be negligible to provide a conservative estimate of run-up distance.

5.3 Mapping

As no detailed topographic mapping of the Regional District is available, British Columbia TRIM mapping with 20 metre contour intervals was reviewed as the best available topographic mapping for the study area. Average slopes were computed by measuring the distance between the coastline and the 20 m contour. Typically these average slopes ranged from 1.5 degrees in bays and inlets to > 10 degrees in cliff area.

As the contour spacing is 20 m it is possible to have a relatively low-lying shallowly sloping area adjacent to the shore followed by a steeper sloped area inland within the first 20 m of elevation.

In order to attempt to refine the topography of the shoreline, the Ministry of Environment Website Coastal Resource Information System was reviewed together with the British Columbia Physical Shore-zone Mapping System. The mapping classifies the coastline into the various substrates and types. It also provides slope ranges.

TABLE 2: Powell River Regional District Coastal Slopes

Location		Average slope 0 – 20 m elevation from TRIM mapping (°)	Slope based on MoE Coastal Resource Information Systems (°)
Savary Island		2 – 3	1 – 4
Lasqueti Island		5 – 10	> 5
Except	False Bay	3 – 4	1 – 4
	Scottie Bay – West Point	2 – 3	1 – 4
	Tucker Bay	2 – 4	1 – 4
	Jenkins Cove, Richardson Cove, Old House Bay, Boat Cove	2 – 4	1 – 4
Texada Island		5 – 10	> 5
Except	Blubber Bay, Limekiln Bay, Crescent Bay	2 – 5	1 – 4
	Vananda Cove, Sturt Bay	5 – 10	1 – 4
	Gillies Bay, Mouat Bay	1.5 – 5	1 – 4

Lund – Powell River		5 – 10	> 5
Except	Finn Cove and Lund	4 – 5	1 – 4
	Sliammon IR	2 – 3	1 – 4
	Lund – Sliammon IR	4 – 5	1 – 4
Powell River – Saltery Bay		5 – 10	> 5
Except	Myrtle Point, Brew Bay, Lang Bay, Stillwater Bay	2 – 5	1 – 4
	Frolander Bay, Thunder Bay	4 – 5	1 – 4
	Saltery Bay	2 – 5	1 – 4

Slopes obtained from the TRIM mapping and slopes obtained from the Coastal Mapping for the various parts of the Regional District are presented in Table 2.

5.4 Results

5.4.1 Wave Run-Up by Area

In the Strait of Georgia it was determined that the maximum Tsunami wave height would be approximately 1 metre with a run-up to elevation of 2m The wave height increases to two metres at the heads of long narrow inlets greater than 15 km in length.. In this study area there are no long inlets under consideration.

Using the slope angles developed above in section 5.3 a range of run up distances for the various coastline section of the Regional District have been produced as Table 3. Assuming a beach slopes ranging from one degree to 10 degrees and a beach friction of zero, a Tsunami wave run–up distances ranging from 10 to 100 metres from the shoreline was used to determine hazard zone widths.

TABLE 3: Powell River Regional District Potential Tsunami Run Up Distances

Location		Run up Range (m)
Savary Island		30 - 100
Lasqueti Island		10 - 20
Except	False Bay	30 -100
	Scottie Bay – West Point	30 -100
	Tucker Bay	30 -100
	Jenkins Cove, Richardson Cove, Old House Bay, Boat Cove	30 -100
Texada Island		10 - 20
Except	Blubber Bay, Limekiln Bay, Crescent Bay	30 -100
	Vananda Cove, Sturt Bay	30 -100
	Gillies Bay, Mouat Bay	30 -100
Lund – Powell River		10 -20
Except	Finn Cove and Lund	30 -100
	Sliammon IR	30 -100
	Lund – Sliammon IR	30 -100
Powell River – Saltery Bay		10 -20
Except	Myrtle Point, Brew Bay, Lang Bay, Stillwater Bay	30 -100
	Frolander Bay, Thunder Bay	30 -100
	Saltery Bay	30 -100

Based on this table, two zones of potential tsunami run up distance have been developed for the coastline of the Regional District.

5.5 Hazard Maps

In view of the limited estimated run up distances developed and the lack of detailed mapping available it was determined that plotting of the hazard zones was not reasonable. Instead maps showing the locations of coastline within the Powell River Regional District with one of the two ranges of run-up developed in Section 2.1, were prepared. These maps are reproduced as Figures 2.1 to 2.7. at the end of the report.

5.6 Discussion

5.6.1 Potential Tsunami Wave Run - Up Distance

As indicated in Appendix II the potential Tsunami wave run up distance is significantly affected by the beach slope angle. As the beach slope increases the potential Tsunami wave run–up distance decreases. For example a Tsunami with a wave height of 1 metre has a potential run–up distance 115 metres on a beach with a one degree slope. However, a Tsunami with a wave height of 1 metre has a potential run–up distance of only 11 metres on a beach with a slope of 10 degrees.

A second factor in potential Tsunami wave run–up distance is loss of wave energy due to friction with the beach, lowland areas and roughness elements (e.g. trees, boulders, buildings). To calculate beach friction site specific information such as beach substrate, detailed lowland topography, vegetation (species and size e.g. species, diameter and spacing of trees), anthropogenic structures, type and roughness of bedrock would be required to estimate the frictional losses to the wave and corresponding reductions in run-up distance. This information is beyond the scope of this study, therefore friction was ignored in the calculations resulting in a more conservative run–up estimate.

5.7 Further Investigation

This study is based on available literature and available mapping. A better estimate of the effects of a large tsunami on the shoreline of Powell River Regional District can be developed using the following information:

- Topographic mapping of the coastal zone or at least the areas noted to have run up distances in excess of 20 m, with contour spacing of 1 m;

- Air photo review of population centres to review coastal landforms; and,

- Development of a more accurate relationship between wave height and wave run up including an assessment of beach and shore friction and potentially using numerical simulations of wave shoaling to predict tsunami wave run-up heights at the shore.

5.8 Closure

None of the Tsunami hazard zones identified in this preliminary study were field verified. Since the evaluation of wave run-up is highly sensitive to local topography, beach slope and lowland conditions in areas adjacent to any buildings and infrastructure, field verification of all hazard segments would need be carried out.

The estimates of wave run-up were developed by best judgment using available data. If additional data is collected, the Tsunami hazard zones could be revisited to assess the implications of the newer information.

5.9 Tides

High tides, that is those tides above 4.57 m, occur throughout the year, but predominate in November, December and January. Typically December has 23 days with high tides including nine days with tides approaching 5 m. January has seven days with high tides with typically four days of tides of 5 m. February, March, April and May each only have three days with high tides. June has one day, July 3 days, August 6 days, September 5 days, October 4 days and then an increase in November to 10 days. An additional wave height of 0.5 m or greater added on to these high tides would cause localized foreshore flooding. The extent to which this flooding would occur would depend on specific foreshore and beach elevations.

Meteorological conditions can cause differences between the predicted and the observed tides. On-shore winds are an additional flooding consideration when coupled with high tides. The effect of wind on sea levels also depends, in part, on the topography of the area as well as the strength, duration and fetch of the wind itself. A strong wind blowing onshore tends to raise the sea level. This is especially noticeable at the head of shallow bays. When coupled with low barometric pressure onshore winds can cause exceptionally high tides. On December 5, 1967 an anticipated high tide of 4.9 m was increased to 5.6 m by onshore winds. Similarly in December 16, 1982 and anticipated high tide of 4.7 meters increased to 5.6 m as measured at Point Atkinson respectively. These rare events, were they to be coupled with tsunami wave heights, would cause some localized flooding along the beaches and low-lying areas of the Regional District. The exact extent to which this would occur would require detailed survey of the beachfront and adjacent area elevations.

Low tides provide exceptional recreational opportunities particularly in. On warm summer days, particularly in July and August when low tides occur in early or mid afternoon, the recreational use of beaches and tidal flats can attract adults, youngsters and pets out into shallow waters and sandbars in excess of 500m from shore. July 2006, for example, has eight weekend days of significantly low tides occurring during times of high beach use and August has four similar days. For those that have ventured out onto the sand bars or into shallow water some considerable distance from shore a sudden 0.5 m wave would have significant impact. The most vulnerable could well be those most attracted to the low tide areas including young children and those with poor swimming skills. The seismic shaking and delay time before arrival of any tsunami waves should however allow those at risk to be made aware of the danger.

5.10 Significant erosion of the foreshore or beach caused by tsunami wave action is unlikely given the existing day to day tidal influences on the beaches. Much of foreshore is narrow beach and high bank upland. In exposed locations these are already subjected to localized flooding during winter storms with little damage. A retreating tsunami wave will cause some scouring but its major effect appears to be the accumulation of flotsam and debris. Unlike seaside locations exposed to significant tsunami impacts in other parts of the world, the Regional District has very little built on its low beachfront and where housing overlooks the beaches it is at elevations substantially above the high watermark.

5.11 The Regional District has a number of marinas. The locations are generally protected by relatively narrow entrances, protective rock fingers or favorable orientation. While some increase in sea level would occur as any tsunami wave dissipated the impact would be small compared with normal tidal fluctuations. Nevertheless, at high tides any poorly maintained dockage or utility connections could be subjected to additional forces and minor damage occur.

5.12 Summation

As discussed in Section 2.2, above, there are four mechanisms recognized as potential generators of tsunami wave action in proximity to the Regional District. The most detailed research has centered on the subduction potential of the Cascadia zone to generate a large earthquake and subsequent tsunami. The present research model suggests maximum wave heights for the upper reaches of the Georgia Strait in the range of less than 1.0 m. There would be over two hours of lead time before any wave reached any of the shorelines of the Regional District and warnings as to whether any tsunami had been created and its actual energy and size would have been posted and authorities notified.

It is generally agreed that the tsunami impact on the upper Georgia Strait from a large earthquake with an epicenter in the Alaska Aleutian chain is

negligible due to its protected nature afforded by the mass and orientation of Vancouver Island.
Less well understood are the tsunami impacts that a crustal earthquake with an epicenter in the Pacific Northwest could cause or be the triggering event for undersea or terrestrial landslides in or into the Strait of Georgia. The location of areas of settlement within the Regional District suggests that tsunami impacts from these sources do not constitute a significant risk. Wherever settlement, either on the islands or on the mainland, is predominantly on high bank locations, tsunami wave heights and run up do not constitute a hazard. In low bank and beach areas where any structures may be at risk detailed investigation of elevations, beach slope and orientation are required although the responsibility for this assessment may fall to private landowners and be beyond the scope and responsibility of the Regional District.

6.0 Experiences in Other Jurisdictions

6.1 Third world countries with no tsunami warning systems have experienced large tsunami waves and devastating damage in recent decades. Extensive low bank and foreshore settlement and development, poor building quality and inadequate public information has also contributed to extensive loss of life and property damage. While the underlying science associated with seismic and tsunami activity is significantly advanced by study of these phenomena, comparison to the threat situation in the upper Georgia Strait is not appropriate.

6.2 The States of Oregon and Washington on the West Coast of the United States have instituted extensive tsunami programs with their cities and counties along their coastlines which are exposed to a significantly greater threat than is the case for the Regional District and its island communities. However, a number of pointers can be drawn from their experience and activities. An extensive coastline signage, mapping and information system has been instituted including evacuation routes from low-lying areas. Some coastal locations have undertaken detailed survey of foreshore areas to determine the probable extent of any inland run up inundation for probable tsunami wave heights. Particular attention has also been given to alerting beach users to the risks associated with tsunami during low tides. Discussion with various county emergency managers in these States supports the benefit of exercising local emergency plans with an earthquake and tsunami threat scenario. These have brought to light the complexity of communications during an event of this type and the importance of on location signage to inform the general public beforehand as to the appropriate actions along exposed foreshore locations.

6.3 The Provincial Emergency Program has sponsored the investigation of tsunami threats along all coastal communities. The Regional District should participate with its adjacent community partners to understand the specific risks identified for them and examine any commonality of findings and recommendations that would benefit the District, in addition to any measures discussed here in Section 8. Recommendations

7.0 Conclusions

From the latest modeling research and geologic examination of estuarine deposits along the Strait of Georgia it can be concluded that none of the foreshore areas within the jurisdictional area of the Regional District are at risk of significant exposure to large destructive tsunami waves. Of the four mechanisms that could trigger tsunami in the upper Strait of Georgia none appears, at the present level of understanding, to contain the essential elements required to propagate a large wave but more probably a wave about 0.5 m in height by the time it reaches District beaches or foreshore. Both the various island communities and those on the mainland are protected by their location, high bank elevation, orientation or protective islands.
However, the combination of high tides, strong onshore winds and even a moderate tsunami wave may cause some localized flooding and beach or bank erosion in the most low-lying areas. In some areas of open beach the difference between high tide and surrounding foreshore is close to or less than 1.0 m so that, in the very unlikely event of a constellation of extreme metrological, tidal and seismic events, some inundation of adjacent upland would occur.

8.0 Recommendations

8.1 While the foreshores and settlement areas of the Regional District do not appear to have a significant tsunami risk, public perception has been heightened by previous worldwide events and will continue to be so as large tsunami strike other jurisdictions as was the 2004 case in Sumatra or in the latest March 2007 instance of the Solomon islands, and these receive worldwide, often graphic, media coverage.

The Regional District should develop a brief public messaging format or a web script to inform residents and visitors about the risk of tsunami, what to do if a tsunami Warning or Watch is issued, or a significant earthquake is felt when close to or on beaches, and where to find further information on the exposures both to the Regional District and in the general area of the Strait of Georgia.

8.2 A number of public information pieces such as " Prepare for Tsunamis in Coastal British Columbia" prepared by the Provincial Emergency Program and the" Earthquake and Tsunami Smart Manual" prepared jointly by the BC Ministry of Public Safety, Natural Resources Canada and by Fisheries and Oceans Canada provide general information on tsunami threats and risks. They are however, prepared to embrace locations that include significant tsunami risk and the Regional District may wish to consider preparing its own tsunami information piece. These pieces can be distributed through the normal emergency management information locations as well as at park and beach buildings close to low-lying areas on the foreshore.

8.3 the Regional District and its associated islands benefit from a healthy and active tourism trade with visitors coming from many parts of the world some of which experience destructive earthquake and tsunami activity. Tourism information centers may also be an appropriate location for public information provided in a number of languages describing the comparatively limited exposure that the Regional District has to tsunami due to its location and protected harbors as well as sensible precautions to take while in the area.

8.4 Despite the fairly limited exposure that the Regional District will have to major tsunami, either triggered as a subduction event on the West Coast of Vancouver Island or in the Alaska Aleutian chain, Warnings or Watches issued by the Provincial Emergency Program, in its role of disseminator of this information, will include mass media and press outlets. It is commonplace for such information to be exaggerated or misinterpreted yielding extensive public concern and inevitable phone calls to emergency organizations. The Regional District should examine effective ways to diminish unnecessary calls to emergency organizations, 911 and responders where the triggering event is most unlikely to cause damage in the community.

8.5 The Regional District needs to ensure that if it receives tsunami Warning or Watch information at any time 24/7 that has relevance to the citizens of the Regional District that there is a fully effective protocol for receipt of the information from the Provincial Emergency Program and an efficient distribution of that information within the administrative structures to ensure that staff that require notification receive it on a timely basis. Equally important is for the Regional District to have an equally efficient system for the distribution of tsunami "all clear" announcements.

8.6 Tsunami wave action caused by distant earthquake is, in most instances, delayed in its arrival time from the point at which the earthquake occurs until it reaches adjacent shorelines. This would be the case for District and island beaches. A near shore earthquake would be felt by beach and foreshore users and would provide an evident warning. The Regional District may wish to consider limited beachside signage indicating that, following an experience of significant earthquake shaking, recreational users should leave the water, flats and beachfront areas as a precaution and that they should move well inland if there is any indication of withdrawal of the sea or sudden rise in sea level.

8.7 During periods of high recreational use, vehicle parking often overflows from designated parking places. This can severely limit access and egress from some locations. Were large numbers of people to decide to leave beachside locations at one time, significant traffic congestion would very likely result. A plan for this eventuality, following an indication that a potential tsunami could occur and that might induce people to leave beachfront areas, may be worthy of consideration .

8.8 If signage is eventually decided as appropriate, particularly for areas of sandbars and very shallow waters during low tides, the Regional District should adopt the tsunami hazard logo approved for British Columbia which utilizes a blue background the small white figure escaping from a large white wave.

8.8 In some instances during the field inspection very shallow unprotected foreshore erosion points were seen. Tidal erosion during high tides and winter storms is evident. In some locations elevations of less than 0.75 m from the upper bank occur. These locations may require to be more fully identified and surveyed .

8.9 The field work and photographic review for this report identified a number of private Marina locations. Most of these marinas rely upon quayside, walkway and floating dock connections for utilities. A small tsunami wave coupled with strong onshore winds may well cause some damage or detachment of utilities in Marina settings. Of particular concern would be failed sewage connections. The Regional District may wish to consider advocating inspection of these facilities for compliance with existing legislation and provision of a small information piece reminding Marina operators and users on their responsibilities for maintenance of utilities under adverse marine conditions.

8.10 The Regional District should maintain in the Emergency Plan a procedure for post-tsunami wave impact assessments in order to quickly identify or catalogue any unsafe conditions or erosional activity that would require prompt remediation or safety warnings.

8.11 Tsunami wave action can bring in, uplift or float considerable quantities of debris. Beaches, while cleaned regularly by tidal activity, often end up with large waterlogged logs as beach 'furniture' above the tide line particularly during the summer months. This material and loose debris could be picked up and dispersed along the foreshore or at the extremity of any upland flooding. We're such debris impacts public safety the Regional District should make provision for debris handling and removal in their Emergency Plan.

8.12 In those areas which are particularly low-lying and may be at risk of erosion or inundation more detailed elevation mapping would be required to confirm this.

8.13 The understanding of likely tsunami activity in the upper Strait of Georgia is based on extrapolated modeling which is currently and constantly being refined. The Regional District should ensure that it keeps abreast of new scientific findings, postulated wave heights and the current state of understanding as to near source seismic and tsunami behavior in the Strait of Georgia as it might impact the foreshore and beaches of the Regional District. Much of the west coast research is centered at the Pacific Geosciences Center at Sydney on Vancouver Island. Staff is particularly helpful in providing interpretation of current earthquake and tsunami investigations. The specific orientation of the island communities in the regional district component of the mainland in particular, the bathymetry, tidal influences, foreshore configuration, specific beach types and elevations require more detailed study beyond the scope of this overview in order to identify locations of specific risk for probable or worst case tsunami threats.

8.14 The Provincial Emergency Program is currently reviewing and revising the British Columbia's Tsunami Warning and Alerting Plan. The Powell

River Regional District should ensure that it maintains liaison with the Provincial Emergency Program staff in order to remain conversant with any changes and adaptations to the existing plan that may impact the Regional District

8.15 Experience in all jurisdictions is that exercising of emergency plans provides insight into their effectiveness and constraints. The Regional District should consider a tabletop exercise of its Emergency Plan with a scenario that incorporates a seismic event that also triggers a tsunami with an order of magnitude similar to that discussed in this assessment, as a way to examine and identify operational and communication issues.

8.16 A number of jurisdictions with a high threat exposure to tsunami have, or are, examining audible methods to inform residents and businesses at risk. The known threat from tsunami to the Regional District does not appear to warrant the further investigation of audible alarms for the jurisdiction at this time.

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Links to Other References and Sources
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http://www-sci.pac.dfo.gc.ca/osap/projects/tsunami/tsunamimodel
BC Provincial Emergency Program
http://www.pep.bc.ca
US National Oceanic and Atmospheric Administration
http://www.tsunami.noaa.gov/tsunami

Appendix I

WAVE RUN-UP CALCULATIONS

Beach slope (degrees)	Tsunami Wave Height (m)	Tan Beach slope	Tsunami Wave Run-up Distance (m)
1	1	0.0174	57
1	2	0.0174	115
1	4	0.0174	229
1	5	0.0174	286
1	6	0.0174	343
1	8	0.0174	458
1	10	0.0174	572
1	20	0.0174	1145
1.5	1	0.0261	38
1.5	2	0.0261	76
1.5	4	0.0261	152
1.5	5	0.0261	190
1.5	6	0.0261	229
1.5	8	0.0261	305
1.5	10	0.0261	381
1.5	20	0.0261	763
2	1	0.0349	28
2	2	0.0349	57
2	4	0.0349	114
2	5	0.0349	143
2	6	0.0349	171
2	8	0.0349	229
2	10	0.0349	286
2	20	0.0349	572
3.5	1	0.0611	16
3.5	2	0.0611	32
3.5	4	0.0611	65
3.5	5	0.0611	81
3.5	6	0.0611	98
3.5	8	0.0611	130
3.5	10	0.0611	163
3.5	20	0.0611	326
5	1	0.0874	11
5	2	0.0874	22
5	4	0.0874	45
5	5	0.0874	57

Beach slope (degrees)	Tsunami Wave Height (m)	Tan Beach slope	Tsunami Wave Run-up Distance (m)
5	6	0.0874	68
5	8	0.0874	91
5	10	0.0874	114
5	20	0.0874	228
7.5	1	0.1316	7
7.5	2	0.1316	15
7.5	4	0.1316	30
7.5	5	0.1316	37
7.5	6	0.1316	45
7.5	8	0.1316	60
7.5	10	0.1316	75
7.5	20	0.1316	151
10	1	0.1763	5
10	2	0.1763	11
10	4	0.1763	22
10	5	0.1763	28
10	6	0.1763	34
10	8	0.1763	45
10	10	0.1763	56
10	20	0.1763	113
15	1	0.2679	3
15	2	0.2679	7
15	4	0.2679	14
15	5	0.2679	18
15	6	0.2679	22
15	8	0.2679	29
15	10	0.2679	37
15	20	0.2679	74
20	1	0.3639	2
20	2	0.3639	5
20	4	0.3639	10
20	5	0.3639	13
20	6	0.3639	16
20	8	0.3639	21
20	10	0.3639	27
20	20	0.3639	54

Hazard Maps

Notes: