ITSU-XX
NATIONAL REPORT submitted by CANADA

BASIC INFORMATION

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- **Primary Warning Recipient** (Person, Agency or Organization with primary responsibility receiving and acting upon messages issued by PTWC)
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- **Tsunami Advisor(s).** (Person, Committee or Agency managing Tsunami mitigation)
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- **Local Tsunami Procedures.** (If a local tsunami exists)
  Procedures for dealing with local and distant tsunami are provided in the *British Columbia Tsunami Warning and Alerting Plan* (2001 Edition), a copy of which is available on the web at:
  http://www.pep.bc.ca/hazard_plans/hazard_plans.html
  - Tsunamigenic events in the immediate source area are identified by the West Coast and Alaska Tsunami Warning Center (the regional warning center for the Pacific coast of Canada) and the Pacific Geoscience Centre (PGC) in Sidney, BC, Canada. The Pacific Geoscience Centre operates the seismograph network in Western Canada and advises PEP on earthquake events and seismic hazards.
    Web site: http://www.pgc.nrcan.gc.ca/seismo/table.htm
  - Earthquakes within the West Coast and Alaska Tsunami Warning Center (WC/ATWC) area of responsibility (AOR) over magnitude 7.0 trigger a warning covering the coastal regions within 2 hours tsunami travel time from the epicenter. When the magnitude is over 7.5, the warned area is increased to 3 hours tsunami travel time. This information is transmitted to PEP via the NOAA Weather Wire system and other means. The Pacific Geoscience Centre and the Canadian Hydrographic Service (CHS) provide observational data and advice to PEP to support their decision making.

- The Provincial Emergency Program is responsible for acting upon the above information in accordance with the *British Columbia Tsunami Warning and Alerting Plan*.
- A tsunami Cancellation Bulletin is issued to cancel all previously issued tsunami advisory bulletins when it has been determined that the threat has ended. The circumstances may be such that a wave exists but has been observed to be too small to be damaging, or that previous bulletins were based on erroneous information (i.e. no wave exists.)
- One local Tsunami Warning/Watch was issued by the WC/ATWC during the intersession period. Following a magnitude Mw 7.4 earthquake off the coast of northern California on June 14, 2005 the west coast of Vancouver Island was placed in Warning status and the areas further north were placed in Watch status. All essential PEP staff were activated within less than half an hour of the initial tsunami bulletin. PEP staff initiated the fan-out to all west coast communities within the Warning and Watch areas specified by the WC/ATWC. PEP contacted the Tsunami Duty Officer (CHS) and coastal tide stations were monitored for a possible tsunami wave. The PEP response was good, however, improvements are required in the areas of multiple and varied forms of emergency notification. Also, notifications need to go to both areas at risk and areas not at risk, and media contacts need to be improved. The Provincial Emergency Program (PEP) has reviewed the response to this event and is implementing additional methods of emergency communication.

- **Distant Tsunami Procedures.** (When a distant tsunami hazard exists)
  - Tsunamigenic events from a distant source area are identified by the WC/ATWC and this information is transmitted via the NOAA Weather Wire system to the Provincial Emergency Program. In addition, the Pacific Geoscience Centre, which operates the seismograph network in Western Canada, advises PEP on earthquake events and seismic hazards.
  - Formal warning and alerting for the province is the responsibility of PEP, which has undertaken the coordination procedures outlined in the *British Columbia Tsunami Warning and Alerting Plan*.
  - The Provincial Emergency Program is responsible for acting upon the above information in accordance with the *British Columbia Tsunami Warning and Alerting Plan*.
  - A Tsunami Cancellation Bulletin is issued to cancel all previously issued tsunami advisory bulletins when it has been determined that the threat has ended. The circumstances may be such that a wave exists but has been observed to be too small to be damaging, or that previous bulletins were based on erroneous information (i.e. no wave exists.)
  - The CHS looked for possible tsunamis in tide station records following major earthquakes on September 25, 2003 (Hokkaido), November 17, 2003 (Alaska), and December 26, 2004 (Indonesia). Smaller local earthquakes on November 2, 2004 (Vancouver Island) and June 15, 2005 (Northern California) were also investigated for possible tsunami. In addition, PEP contacted the Tsunami Duty Officer (CHS) whenever a WC/ATWC bulletin was received for an earthquake of magnitude greater than 6.5. This occurred about once a month and served to test communication procedures.

- **National Sea Level Network.** (Please include a table with position and description of stations/sensors.)

ID	Name	Latitude (N)	Longitude (W)
7120	Victoria	48 25.5	123 22.3
7277	Patricia Bay	48 39.2	123 27.1
7654	New Westminster	49 12.0	122 54.6
7735	Vancouver	49 17.2	123 06.6
7795	Point Atkinson	49 20.3	123 15.2
8074	Campbell River	50 02.5	125 14.8
8408	Port Hardy	50 43.3	127 29.3
8545	Bamfield	48 50.2	125 08.2

8615	Tofino (+TWS)	49 09.2	125 54.8
8735	Winter Harbour (+TWS)	50 30.8	128 01.7
8976	Bella Bella	52 09.8	128 08.6
9354	Prince Rupert	54 19.0	130 19.4
9850	Queen Charlotte City	53 15.1	132 04.3
9964	Langara Point (TWS only)	54 15.3	133 02.7

Permanent Water Level Network (PWLN) configuration:
The PWLN was maintained at 13 tide stations. The network is jointly maintained by Water Survey of Canada (WSC) and CHS. Each station presently utilises a Sutron 8210 Data Logger coupled to a dual BEI encoder/ladder-chain float and counterweight system. One-second water levels are collected and averaged to provide 1-minute data. Each site is accessible via modem and all gauges and modems are backed up with dual batteries. Data acquisition is via PCBase2 software and is downloaded automatically once a day. Gauge clocks are checked weekly and downloads are checked daily from IOS. All acquired data are further processed to compensate for hardware and site specific limitations. CHS, WSC and local attendants acquire periodic 1-minute averaged tape readings, which are used to verify corrected water levels.

The stations at Tofino and Winter Harbour have both a telephone modem and a satellite link. In the event of a Tsunami Warning/Watch designated personnel will use telephone modem and/or MSAT software to establish a link with each station. Either method can be used. The MSAT link is costly and will only be used in the event of a test, an event alarm, or a Tsunami Warning/Watch. The telephone link can be accessed from any modem, but will be susceptible to phone line congestion or outage in the event of a major earthquake.

The station at Langara is a not a PWLN station (tsunami warning only) and due to its exposed location is equipped with a Paroscientific pressure sensor and bubbler system. In the event of a Tsunami Warning or Watch data can be transmitted to IOS using the MSAT communication system, but data is normally copied to memory chip once a month and mailed to IOS. The station at Tofino also has a bubbler system with external orifice to complement the standard PWLN configuration (as siltation in the horizontal intake pipes sometimes degrades system response to higher frequency signals.) The alarm feature for all three stations has been configured to forward ongoing data to the Tsunami Duty Officer following an alarm event.

- **Information on Tsunami occurrences.** (Please include records, pictures, etc.)

The December 26, 2004 earthquake off the coast of Sumatra (Mw = 9.3) generated a destructive tsunami that was recorded at many locations in the Atlantic and Pacific. The tsunami was recorded at 6 locations on the Pacific coast of Canada. Maximum trough-to-crest wave heights at these stations were: 9.0cm (Bella Bella), 4.5cm (Port Hardy), 21.0cm (Winter Harbour), 15.4cm (Tofino), 4.5cm (Bamfield) and 11.7cm (Victoria). The actual arrival times were much later than predicted (10-12 hours) and the duration of the oscillations at Winter Harbour, Tofino, Bella Bella and Victoria indicates that there were several sources of incoming waves (multiple reflections.) More information on this event is available at: http://www-sci.pac.dfo-mpo.gc.ca/osap/projects/tsunami/default_e.htm

Tide station records were checked following the September 25, 2003 Hokkaido earthquake (Mw = 8.3) and the November 17, 2003 Rat Island, Alaska earthquake (Mw = 7.7), however, no Canadian station recorded a tsunami from either of these earthquake events.

Small tsunamis were recorded following two regional earthquake events. A magnitude 6.6 earthquake on November 2, 2004 produced a 40km long rupture in the Explorer plate about 200km off the west coast of Canada. The motion of the earthquake was mainly strike-slip, but there was sufficient vertical motion to generate a small tsunami with maximum trough-to-crest wave heights of 11.0cm at Tofino and 6.5cm at

Bamfield. A magnitude 7.4 earthquake off the coast of northern California on June 15, 2005 produced a tsunami with maximum trough-to-crest wave heights of 4.5cm at Tofino and 2.0cm at Bamfield.

SUMMARY

There are three designated tsunami warning stations on the Pacific Coast of Canada, as well as eleven other Permanent Water Level Network stations. In the event of a Tsunami Watch or Warning the data from these stations is made available, through the Institute of Ocean Sciences, to assist the Provincial Emergency Program and the WC/ATWC and PTWC with their decision making. Through an MOU between CHS and the WC/ATWC GOES transmitters are being installed at the three Canadian TWS stations.

The tsunami produced by the December 26, 2004 earthquake off the coast of Sumatra (Mw = 9.3) was recorded at 6 locations on the Pacific coast of Canada. Small tsunamis were also recorded following regional earthquake events on November 2, 2004 (Vancouver Island, Mw = 6.6) and June 15, 2005 (northern California, Mw = 7.4).

The observations of the 1700 Cascadia tsunami in Japan were used to constrain models of tsunamigenic sea floor displacement, and these sea floor displacement models have been used for modeling of Cascadia tsunamis. Models were developed for four harbours on the south and west coasts of Vancouver Island – Ucluelet, Sooke, Esquimalt and Victoria. This modelling effort used bathymetric grids up to several orders of magnitude finer than previous studies. The 10 metre resolution grids give more accurate results and allow us to see variations within harbours not possible with previous models.

High-resolution topographic LIDAR data has also been obtained for one of these harbours. The 2m “bare earth” topographic grid produced using this data will be merged with the bathymetric grid to produce a seamless high-resolution grid so that the effects of inundation can be modelled.

The compilation and validation of historical data for a Canadian tsunami catalogue is continuing. This project is being carried out in partnership with the P.P. Shirshov Institute of Oceanography. The first phase of the project validated and expanded upon the pre-1981 work done by Wigen, Soloviev and Go. The second phase of the project has focused on identifying all tsunami events since that time.

The Geological Survey of Canada (GSC) operates the Canadian National Seismograph Network which includes 40 broadband seismographs in western Canada. The network transmits all data in real-time and produces automated preliminary locations and magnitudes. Seismologists at the Pacific Geoscience Centre in Sidney, BC (and at a centre in Ottawa) are on call 24/7. Since November, 2000, PGC has been exporting data from nine Canadian broadband seismograph stations in real-time via the Internet to the WC/ATWC. This data is routinely used by WC/ATWC for earthquake locations.

Since the discovery of Episodic Tremor and Slip (ETS) in the Cascadia subduction zone an intensive effort has been underway to record, model and understand this phenomena. This may lead to identifying windows of enhanced probability for occurrence of large subduction earthquakes. The GSC and CHS are establishing a prototype network of GPS receivers deployed at four geodetic quality installations to facilitate real-time positioning along the coast of the Canadian segment of the Cascadia subduction zone. The aim is to automatically determine, within minutes, major vertical and horizontal motion at coastal versus inland GPS stations that would unambiguously indicate tsunami generation. It is hoped that this relatively low cost technique can become a mainstream tool of tsunami warning systems worldwide.

In addition to the on-going operational responsibilities and development initiatives mentioned previously, the Sumatra earthquake and tsunami on December 26, 2004 had a major impact on earthquake and tsunami response personnel in Canada. In the days immediately following the event approximately 100 interviews were provided to newspapers, magazines, television networks, and radio stations. A focus of many interviews was the similarity between this destructive tsunami and the tsunami likely to result from

a Cascadia subduction zone earthquake. Since then presentations on earthquakes, tsunamis and emergency preparedness have been made to emergency managers, civic officials and the general public in many coastal communities. Interest in earthquake and tsunami preparedness remains high.

In January 2005 the provincial and federal governments made commitments of almost 2 million dollars in Tsunami Preparedness funding. The money is being used to identify risks, develop enhanced response plans, upgrade communications and warning systems, and support public education programs. As part of this funding the Institute of Ocean Sciences received $200K for the purchase of a new tsunami modelling computer.

NARRATIVE

In addition to regular servicing and maintenance of the Tsunami Warning System (TWS) the CHS carried out or initiated a number of system upgrades during the inter-session period:

- An MOU between the CHS, Pacific Region and the WC/ATWC. NOAA purchased GOES transmitters for each of the Canadian TWS stations and CHS agreed to install and maintain the transmitters so that WC/ATWC will have timely access to water level data from these stations. It was originally intended to integrate the GOES into the existing data acquisition systems, but Sutron 9210 (XPert) data acquisition hardware has now been purchased for this purpose. Installation was delayed awaiting Department of Communication licences for use of the transmitters, but these have now been received and testing (prior to installation) is proceeding.
- A temporary station was installed at Henslung Cove on Langara Island. The data from this station was compared with the data from the Langara Island TWS station. The data analysis indicated that Henslung Cove is better suited as a tsunami warning station site. A permanent station will be installed at Henslung Cove in the coming months and when it's operational it will become the new TWS station.
- Sutron XConnect software was purchased (March 2005) to provide automatic posting of incoming water level data to the web. This software has been installed, but is not yet operational.

A three year modelling study, funded by the National Search and Rescue Secretariat, was completed in 2004. The observations of the 1700 Cascadia tsunami in Japan were used to constrain models of tsunamigenic sea floor displacement, and these sea floor displacement models were used for modeling of Cascadia tsunamis. Models were developed for four harbours on the south and west coasts of Vancouver Island – Ucluelet, Sooke, Esquimalt and Victoria. These models predict both water levels and currents in the harbours. In the future, other scenarios for locations in the Gulf of Alaska and along the Aleutian Trench will also be modelled. The model used for this study is MOST3 (Titov and Synolakus, 1998), a shallow-water wave model used by NOAA to study tsunami effects along the west coast of Washington, Oregon and California, and in the inland waters contiguous to Canada and the U.S.

This modelling effort used bathymetric grids up to several orders of magnitude finer than previous studies. The fine resolution (10m grid) gives more accurate results and allows us to see variations within harbours not possible with previous models. This will assist Coast Guard SAR in preparing emergency response plans for their facilities and for the local marine communities they serve.

In March 2004, high-resolution topographic data was collected at Ucluelet using topographic LIDAR. The 2m "bare earth" topographic grid produced using this data will be merged with the bathymetric grid to produce a seamless high-resolution grid so that the effects of inundation can be modelled. The resulting model results will hopefully provide motivation for additional funding for tsunami modeling and for the collection and integration of more topographic LIDAR data.

The compilation and validation of historical data for a Canadian tsunami catalogue is continuing. This project is being carried out in partnership with the P.P. Shirshov Institute of Oceanography. The first phase of the project validated and expanded upon the pre-1981 work done by Wigen, Soloviev and Go.

The second phase of the project has focused on identifying all tsunami events since that time. In addition to three known tsunami events, work has identified at least three previously undocumented events.

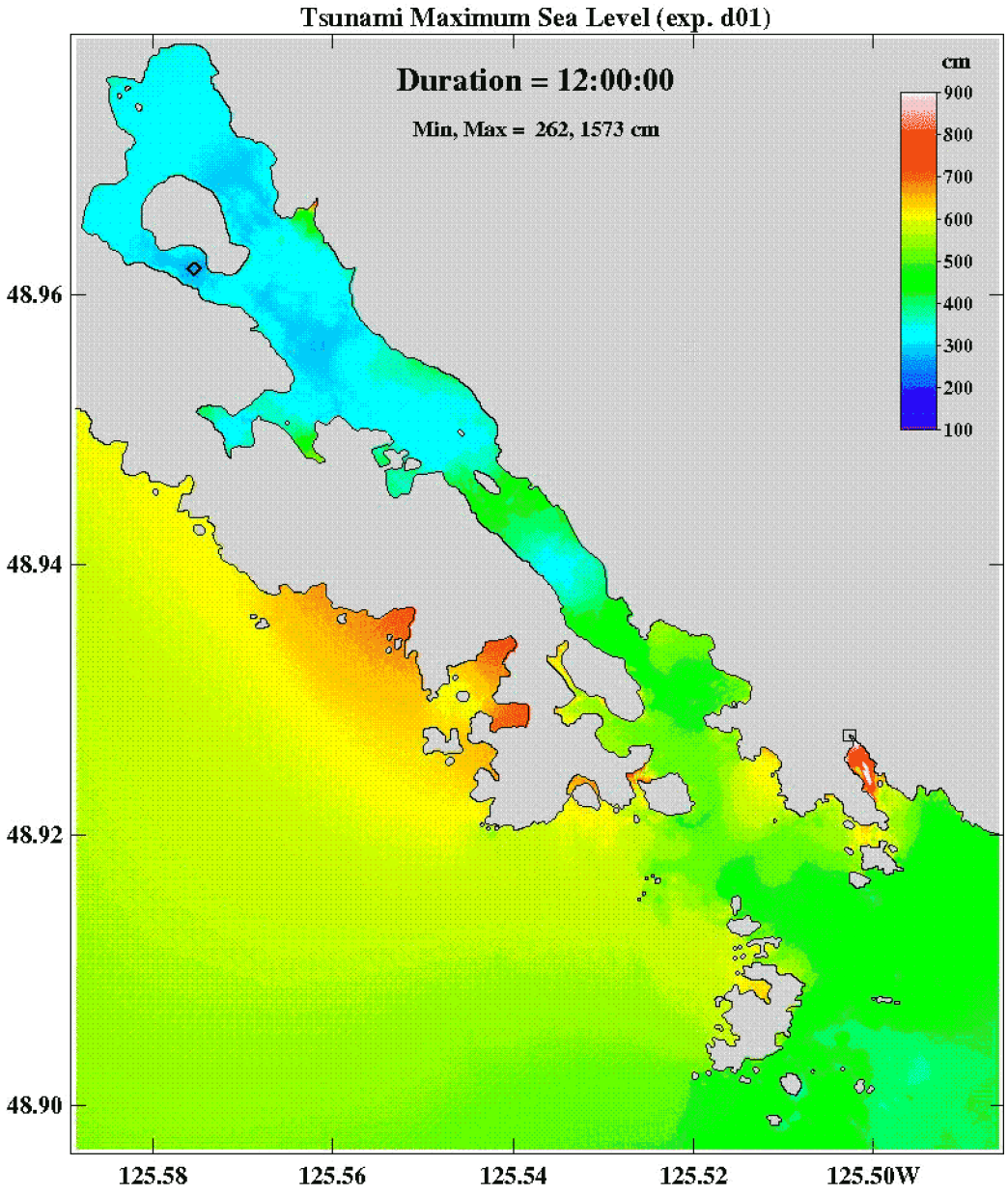

Figure 1 - Maximum modeled tsunami heights at Ucluelet, B.C.

With regard to previously undocumented events, geologists, tsunami researchers and archaeologists are investigating a landslide-generated tsunami that occurred in Knight Inlet (central B.C. coast) in the late 1500's. Part of a rock slope 640m high collapsed into a fiord with water depths up to 540m. A large First Nations village on the opposite side of the inlet was completed destroyed with loss of life estimated to be

more than 150 persons. Wave modelling is proceeding, although it is certain from available topographic information that the wave was at least 10m high when it impacted the village.

The Geological Survey of Canada (GSC) of Natural Resources Canada (NRCan) operates the Canadian National Seismograph Network which includes 40 broadband seismographs in western Canada. The network transmits all data in real time and records and archives the data at analysis centres in Sidney, BC and Ottawa, Ontario. The network produces automated preliminary locations and magnitudes, and seismologists are on call 24/7 at each analysis centre. Since November, 2000, GSC's Pacific Geoscience Centre (PGC) in Sidney, BC has been exporting data from requested Canadian broadband seismograph stations in real-time via the Internet to the West Coast and Alaska Tsunami Warning Center in Palmer, Alaska. Currently 9 stations are exported to WC/ATWC which are routinely used by WC/ATWC for earthquake locations. The GSC contact at PGC is Dr. Garry Rogers (grogers@nrcan.gc.ca)

The broadband stations of the Canadian National Seismograph Network are being used to routinely determine seismic moment tensor solutions in the coastal and offshore regions of western Canada and nearby southeast Alaska. Over 450 regional moment tensor solutions have been calculated. Steps are now being taken to move to automated moment tensor calculations for larger earthquakes.

Geological Survey of Canada has deployed 80 newly developed low-cost Internet communicating strong motion accelerographs in the Cascadia subduction region of western Canada. The instrument network extends from the outer coast to 150km inland. Automated algorithms are being explored to make this an effective part of a tsunami alerting system.

The Geological Survey of Canada is currently setting up a prototype network to facilitate real-time positioning along the coast of the Canadian segment of the Cascadia subduction zone. The aim is to evaluate the realizability and effectiveness of automatically determining, within minutes, major vertical and horizontal motion at coastal versus inland GPS stations that would unambiguously indicate tsunami generation. Four GPS receivers purchased by the Canadian Hydrographic Service are currently being deployed at geodetic quality installations with continuous on-line communications. The target date to have a prototype system operating is December 2005. It is hoped that this relatively low cost technique can become a mainstream tool of tsunami warning systems worldwide.

Since the discovery of Episodic Tremor and Slip (ETS) in the Cascadia subduction zone an intensive effort has been underway to record, model and understand this phenomena. This may lead to identifying windows of enhanced probability for occurrence of large subduction earthquakes. The region of ETS also appears to define the downward extent of rupture during subduction earthquakes; thus mapping it helps to define the magnitude of future subduction earthquakes and the proximity of shaking to inland population centres.

In addition to the on-going operational responsibilities and development initiatives mentioned previously, the Sumatra earthquake and tsunami on December 26, 2004 had a major impact on earthquake and tsunami response personnel in Canada. In the days immediately following the event approximately 100 interviews were provided to newspapers, magazines, television networks, and radio stations. A focus of many interviews was the similarity between this destructive tsunami and the tsunami likely to result from a Cascadia subduction zone earthquake. In mid January the Provincial Emergency Program coordinated presentations on earthquakes, tsunamis and emergency preparedness to over 300 emergency managers and civic officials in 77 communities in British Columbia. These presentations were done by ‘conference call’ using pre-distributed PowerPoint presentations. Since that time a number of other live presentations have been made to audiences at the Royal B.C. Museum’s IMAX theatre, the University of Victoria, the Institute of Ocean Sciences, and in communities on Vancouver Island. Community interest in earthquake and tsunami preparedness remains high and the province of British Columbia has an *Earthquake and Tsunami Smart Manual* to assist in this regard. This 17 page manual, which was produced prior to December 2004, is also available on the PEP web site.

The Geological Survey of Canada, in cooperation with IOC and the Republic of Seychelles, sent four GSC scientists to document and map tsunami run-up and tsunami effects of the December 26, 2004 tsunami in the Republic of Seychelles. Their report can be found at http://ioc.unesco.org/iosurveys/seychelles/sey1.htm

Comparison of the 2004 Sumatra earthquake and tsunami and the 1700 Cascadia event are underway. The length of rupture and the vertical displacement along the shoreline are very similar. Far-field observations of the two tsunamis and near-field tsunami deposits are also very similar.

The Canada National Contact to ICG/ITSU attended the IOC "International Coordination Meeting for the Development of a Tsunami Warning and Mitigation System for the Indian Ocean within a Global Framework" in Paris (March 2005.) This important meeting was the first in a series to develop the technical and 'legal' framework for the establishment of the Indian Ocean System. He also attended a June 2005 workshop in Halifax, Nova Scotia to define an interim warning system for the Atlantic coast of Canada. Because of the low frequency of tsunami in the region, and because of the similarity in public risk from tsunami and from high water levels resulting from storm surges, it was agreed to use a common procedure and warning system for both types of hazard. The interim warning system will make use of existing infrastructure (e.g. seismic stations, water level gauges, WC/ATWC, dissemination networks, etc.). A plan for augmentation of this infrastructure, to establish a more comprehensive and sustainable warning system, will be developed over the next year.

The BC Earthquake and Tsunami Working Group (PEP, NRCan, DFO and PSEPC) meets approximately once per year. This Working Group last met on May 31, 2005.

In January 2005 the provincial and federal governments announced a total of $1.85M in Tsunami Preparedness funding. The money is being used to identify risks, develop enhanced response plans, upgrade communication and warning systems, and support public education programs. Higher-risk communities on the west coast of Vancouver Island and along the central and north coast are each receiving $20,000. Communities in the Georgia Basin and south coast, which are more protected, are each receiving $10,000. As part of this funding envelope Public Safety and Emergency Preparedness Canada (PSEPC) provided $200K in funding to the Institute of Ocean Sciences to purchase a new tsunami modelling computer.

As part of the on-going public education program, all telephone directories for communities in BC coastal areas contain information on earthquake and tsunami response. The recently produced *Earthquake and Tsunami Smart Manual* is also readily available. In addition, PEP, NRCan and DFO all provide tsunami and earthquake information on their web sites. The present DFO modelling studies and tsunami catalogue provide valuable information for public education and mitigation planning.

Publications of Interest

Fine, I.V., A.B. Rabinovich, B.D. Bornhold, R.E. Thomson, E.A. Kulikov, 2005: The Grand Banks landslide-generated tsunami of November 18, 1929. Marine Geology, 215:45-57.

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Kulikov, E. A., Rabinovich, A. B. and R. E. Thomson. 2005. Estimation of Tsunami Risk for the Coasts of Peru and Northern Chile. Natural Hazards 35:185–209.

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Rabinovich, A.B. and F. E. Stephenson. 2004. Longwave Measurements for the Coast of British Columbia and Improvements to the Warning Capability. Natural Hazards 32:313–343.

Rogers, G. and Dragert, H. 2003. Episodic tremor and slip on the Cascadia subduction zone: the chatter of seismic slip, Science, 300, 1942-1943.

Satake, K., Wang, K. and Atwater, B. 2003. Fault slip and seismic moment of the 1700 Cascadia earthquake inferred from Japanese tsunami descriptions. Journal of Geophysical Research, 108, B11, doi:10.1029/2003JB002521

Titov, V., Rabinovich, A. B., Mofjeld, H.O., R.E. Thomson and Frank I. González. 2004. The Global Reach of the 26 December 2004 Sumatra Tsunami. 2004. Science. 25 August 2004. (10.1126/science.1114576)