

**CITY OF PORT ALBERNI  
TSUNAMI INUNDATION ZONE STUDY**

**FILE #: 6337-005-00-01**

**UMA ENGINEERING LTD.,  
MARCH 10, 1992**



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## 1.0 Introduction

UMA Engineering Ltd. has been contracted to complete a Tsunami Inundation Zone Study for the City of Port Alberni. The purpose of the study is to develop land use policies and provisions concerning development of the lands within the established Tsunami Inundation Zone (the Zone). The intent is to provide a rationale which enables policies to be developed which assist in reducing post-inundation recovery time in the affected area.

Tsunamis are created by subduction earthquakes. Subduction of the oceanic plates beneath the continental land masses is a continuing process. The strain which results from this action causes a build-up of stress along the planes of movement. Occasionally, the energy resulting from this stress is released in the form of an earthquake. If the earthquake results in vertical uplift movement of the oceanic crust, it causes a similar deformation of the water surface in the ocean. The subsequent propagation of the disturbance away from its source is a seismic sea-wave, or tsunami.

On the open ocean tsunamis travel at tremendous speeds and decelerate only when they reach shallow water. Typically tsunamis travelling on the open ocean have a low amplitude and a long period. Amplitudes are often less than a metre but the distance from crest to crest often measures 100 to 400 kilometres. Tsunamis are not subject to predictive analysis. Conventional hazard prediction methodologies do not apply; there are no predictable levels of tsunami wave heights or rates of recurrence as there are with periodic floods.<sup>1</sup>

The hazard resulting from tsunamis is the inundation of inhabited areas. To understand the nature of the hazard the following tsunami characteristics can be considered in the context of Port Alberni.

1. Not all earthquakes result in tsunamis. There is no "natural" warning mechanism as in the case of river flooding where the peak events will be preceded by heavy rains or unusually warm weather precipitating rapid snowmelt.
2. Tsunamis move at incredible speeds on the open ocean.
3. The amplitude of a tsunami is inversely proportional to the depth of the ocean while the speed of the wave is directly proportional to ocean depth.

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<sup>1</sup>. Seaconsult Marine Research Ltd. (1988). **Evaluations of Tsunami Levels Along the British Columbia Coast.** Report to the Institute of Ocean Sciences, Department of Fisheries and Oceans, Sidney, British Columbia.

4. The total depth of inundation from a tsunami and the speed with which it occurs are greater than for a river flood. The 10.3 metre depth of inundation at Port Alberni would occur over a period of 25 minutes; or at a rate of rise in water level of over 1 metre in three minutes.
5. The shape of Alberni Inlet causes magnification of the wave height by a factor of about three between Barkley Sound and the head of the Inlet at Port Alberni. Movement of the tsunami up Alberni Inlet is also quite rapid.
6. The overland flow velocity in the Zone will be in the range of three to six (3 to 6) metres per second. There is significant potential for scour around foundations.
7. The multiple wave aspect of the tsunami accentuates the inundation damage. The same is true of water borne objects from the lower part of the Zone (logs, boats, cars, etc.) which act as projectiles that impinge on structures.

Besides the 1964 event there have been a number of lesser tsunamis affecting Port Alberni since a tide gauge was installed in 1963. Murty and Henry (1972) report a sizeable tsunami occurred in 1960. Unfortunately only height estimates are available for this event. There are also accounts of a large tsunami in Alberni Inlet in 1896. The west coast of Vancouver Island has been subjected to 21 tsunamis since 1917 as measured at Tofino. These ranged from an amplitude of 0.6 metres (approximately 2 feet) in 1969 to 2.4 metres (7.9 feet) for the 1964 event.<sup>2</sup>

There is considerable seismic activity in the Pacific and earthquakes occur frequently in the area. As recent events have shown not all earthquakes result in tsunamis. Most people are not familiar with tsunamis as they are with floods, ocean storms or winter blizzards. Occasionally the lack of experience with tsunami events results in a lack of concern or complacency toward their destructive potential. Their unpredictability and lack of experience with tsunami events, can make it difficult to develop appropriate land use policies for land use management in an inundation zone.

Notwithstanding the above, there has been a considerable amount of research completed related to subduction earthquakes and tsunamis. At the Institute of Ocean Sciences in Sidney a number of seismologists and ocean physicists have focused their research on this subject. Scientists have been able to determine that seismic activity in the Pacific can

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<sup>2</sup>. Marshall Macklin Monaghan, (1986). **Development Management in Tsunami Hazard Areas of Port Alberni**. Report to the City of Port Alberni.

result in tsunamis of significant amplitude and have been able to mathematically model tsunami wave crest heights. There has also been specific analysis completed of the tsunami that struck Port Alberni on March 28, 1964.

Based on an earthquake similar to the March 27, 1964 earthquake in Alaska, it has been determined that a tsunami reaching Port Alberni could affect lands up to an elevation of 8.3 metres. The Zone in Port Alberni has been determined by combining high tide levels with a storm surge and this tsunami amplitude. The upper limit of the Zone is established at an elevation of 10.3 metres.

The Project Team has made use of existing studies and data as well as their technical capabilities and experience in engineering and land use planning, to complete this study. In addition, the firm and the City distributed a questionnaire to residents of Port Alberni in order to gauge the community's understanding of tsunami risk and associated issues. The results of the work carried out are provided below.

## 2.0 The Port Alberni Tsunami Inundation Zone

### 2.1 The City of Port Alberni

The City of Port Alberni is located at the end of Alberni Inlet approximately 55 kilometres from the head of Barkley Sound, see **Map 1 Regional Location** and **Map 2 City of Port Alberni**. It is the major forestry products centre on Vancouver Island. Recently, MacMillan Bloedel has closed two of its operations in the City but has maintained its large kraft pulp operation there. In 1990 the City's population was approximately 17,750 up slightly from 1989. In 1989 over \$32,289,000 of building permits were issued, approximately 77% more than the total value for permits issued in 1988. The number of dwelling starts was also up from the previous year by approximately 35%, although this is only an increase to 42 permits from 31.

### 2.2 The Tsunami of March 27, 1964

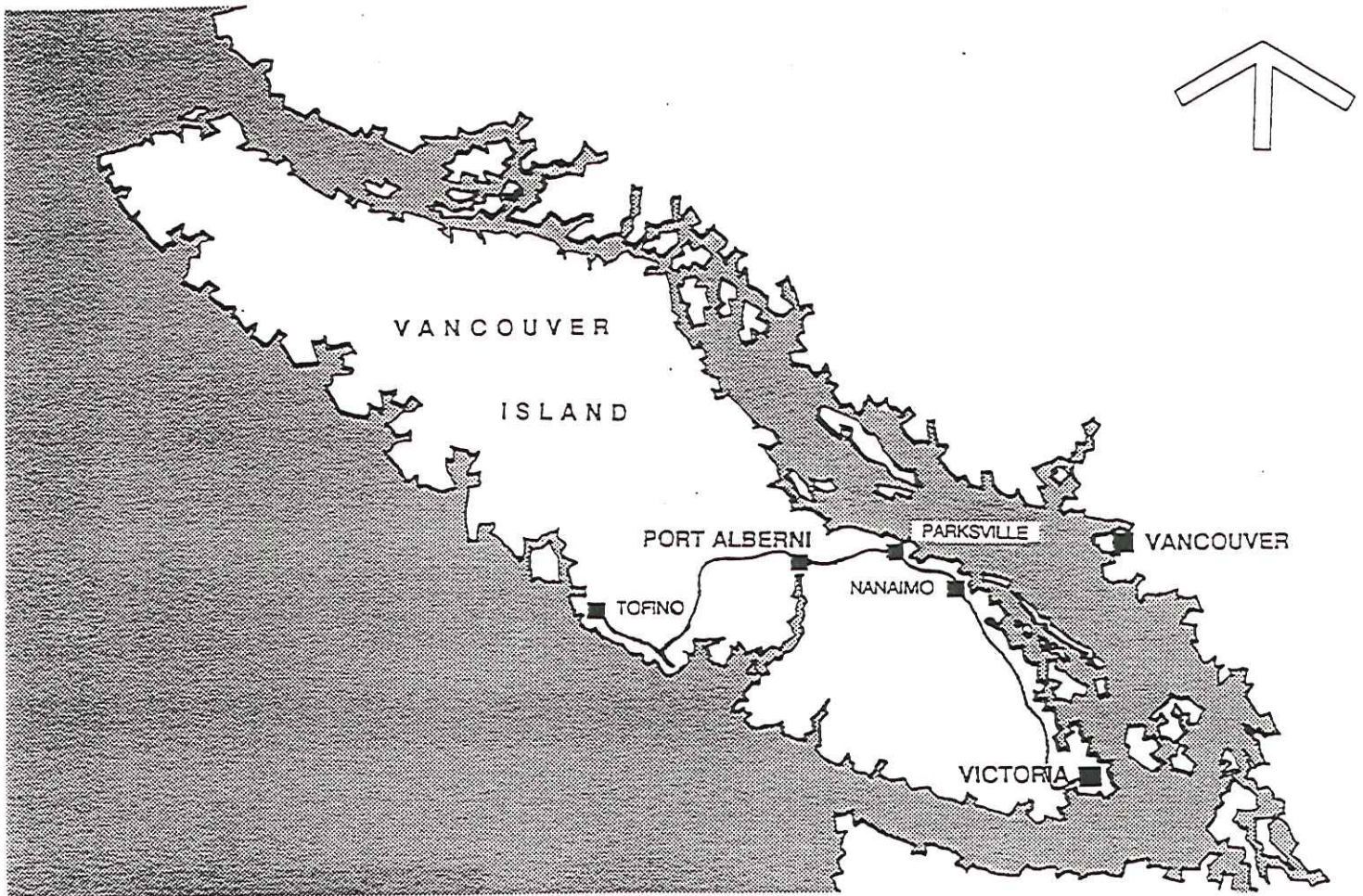
On March 27, 1964 an earthquake registering 8.4 on the Richter scale occurred in the Gulf of Alaska at 19:36 which caused a tsunami. Three waves which crested in Port Alberni were monitored from local observation, a tide gauge located in the Inlet was damaged by the first wave. The first wave reached Port Alberni 4.5 hours after the earthquake. Second and third waves came up the Inlet at 100 minute intervals. The oscillations continued for two days, but with decreasing amplitude after the third wave. The crest level of the third tsunami was 4.1 metres above normal tide level. Although resulting damage was assessed at \$5.0 million and many persons were temporarily displaced, no lives were lost in Port Alberni as a result of the event.<sup>3</sup>

Subsequent to the tsunami occurring several technical studies were carried out to determine the possibility of a similar event occurring. One of those studies, referred to as the Seaconsult Report, resulted in the creation of the Zone.

The Zone has been defined as that portion of the City below the 10.3 metre elevation. The extent of the Zone is illustrated on **Map 3 Tsunami Inundation Zone**. It is narrowest in the area from Polly Point to approximately Argyle Street. The limit of the Zone then proceeds east along Dry Creek to a point in line with the 9<sup>th</sup> Avenue right-of-way where it then proceeds west on the north side of the Creek to 4<sup>th</sup> Avenue. At this point it includes most of the area between 4<sup>th</sup> Avenue and Redford Street. The Zone then follows a line generally west to Stamp Avenue. From there it proceeds along an irregular line north, across the lower reaches of the Roger's Creek watershed to the south side of Kitsuksis Creek. From the north side of Kitsuksis Creek the Zone boundary follows an irregular line to the westerly corporate limit, located at approximately Falls Street. Lands within the City boundary on the west side of the Somass River are all within the Zone.

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<sup>3</sup>. Ibid.



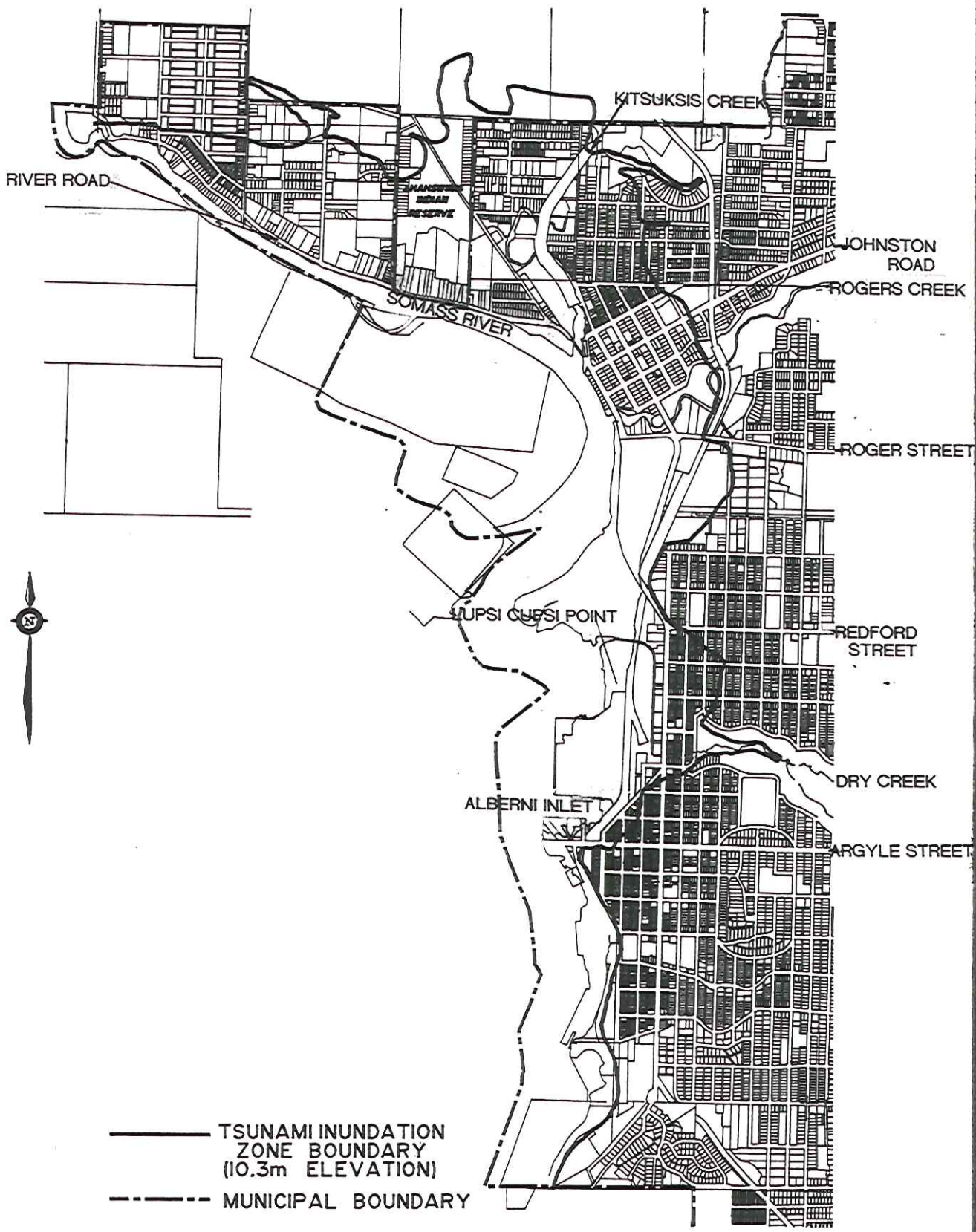
From Taylor Peach (1991)

## CITY OF PORT ALBERNI

TSUNAMI INUNDATION ZONE STUDY

MAP 1 REGIONAL LOCATION



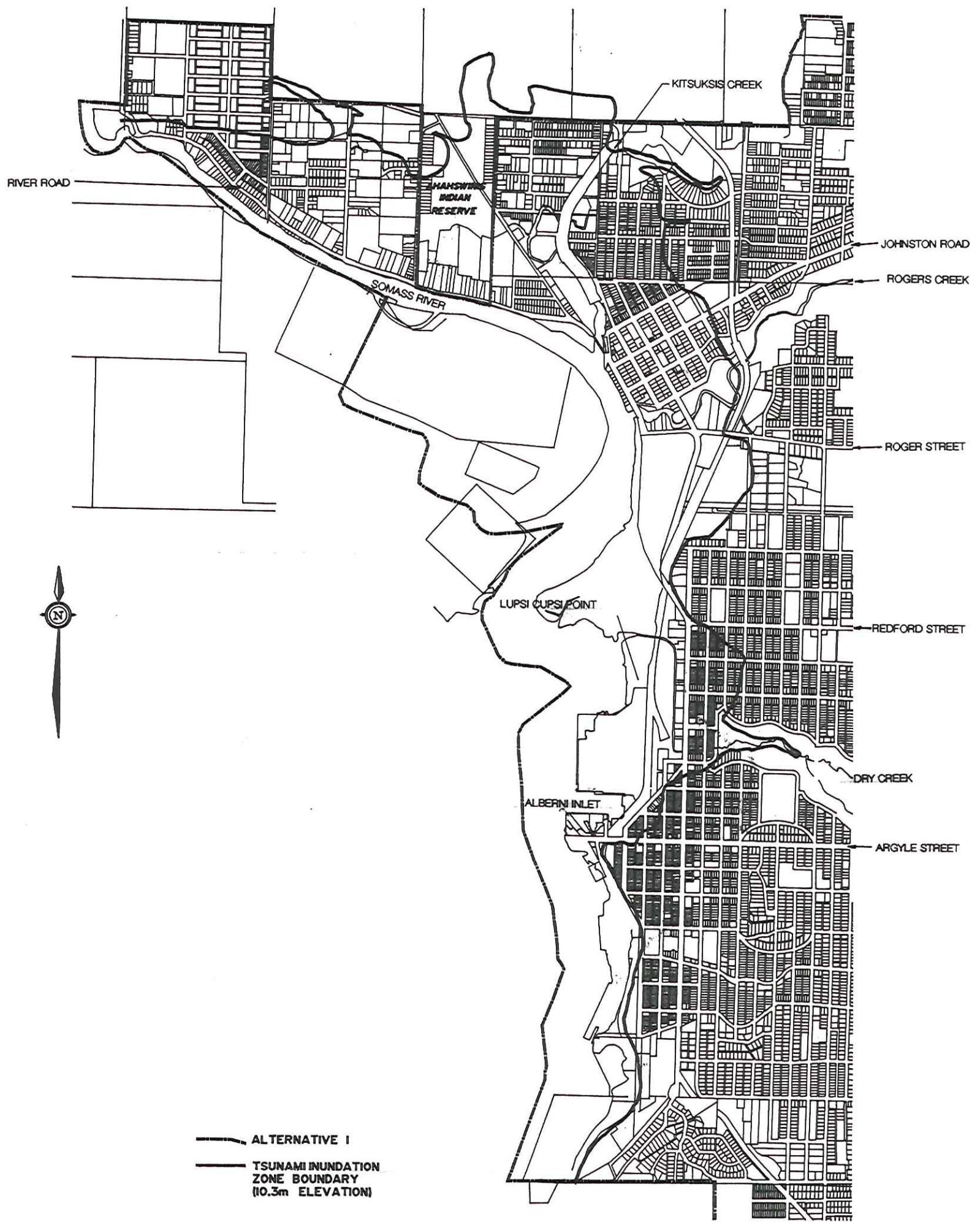


\_\_\_\_\_ TSUNAMI INUNDATION  
 ZONE BOUNDARY  
 (10.3m ELEVATION)  
 - - - - - MUNICIPAL BOUNDARY

**UMA Engineering Ltd.**  
 Engineers & Planners  
 1800 4th Street, North Vancouver, B.C. V7P 2C2  
 604-261-1111

**CITY OF PORT ALBERNI**  
**TSUNAMI INUNDATION ZONE STUDY**  
**MAP 2 CITY OF PORT ALBERNI**

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— ALTERNATIVE I  
 — TSUNAMI INUNDATION ZONE BOUNDARY (10.3m ELEVATION)

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**UMA Engineering Ltd.**  
Engineers & Planners

British Columbia    Alberta    Saskatchewan  
 Manitoba    Ontario    Yukon Territory  
 Northwest Territories  
 265-646, Yale Street, Victoria, B.C.  
 V8W 2R8    Telephone: 251-4004

**CITY OF PORT ALBERNI  
TSUNAMI INUNDATION ZONE STUDY  
MAP 3 TSUNAMI INUNDATION ZONE**

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The land area shown within the Zone on **Map 3** represents 35 to 40% of the land in Port Alberni. It includes a mix of typical urban uses although the waterfront area, along Alberni Inlet and the Canal, is heavily industrialized.

In certain areas, particularly in the southern portion of the City, the Zone consists of a narrow strip of land abutting the shore of Alberni Inlet. In other areas it reaches inland for considerable distances, notably so in the drainage areas of Dry, Roger's and Kitsuksis Creeks. Other areas within the Zone include the commercial area along Johnston Road and the adjacent residential and recreational uses to the east. The area north of the bridge over Kitsuksis Creek on the north side of the Somass River, including the Ahahswinis Indian Reserve also lie within the Zone. The area within the Zone narrows near the Falls Road area at the north end of the City.

The limits of the Zone were provided by the City and are based on data derived from previous studies. For the purpose of this study the Zone "stops" at the southerly and westerly City boundaries. The Zone actually extends beyond the limits established by this study and lands outside the City could be affected by a tsunami event, particularly if it surged up the Somass River as the 1964 tsunami did. The investigation of tsunami impacts on lands outside the limits of the City of Port Alberni however does not form part of this report.

### **3.0 Characteristics of Tsunamis**

#### **3.1 Introduction**

Tsunamis are complex seismically-related events. Their characteristics result in different impacts between communities. Further, different tsunamis affect the same community differently although they follow similar paths. Few studies have been completed related to tsunami damage and impact analysis. The work carried out by Preuss, Hebenstreit and others in impact analysis is discussed below. Tsunamis present multiple and variable risks. Multiple in that disruption to communities is extensive; variable in that not all communities affected by the same tsunami are affected in the same way. Similarly the risk from tsunamis is variable as it relates to their occurrence and time of impact. What is more readily predictable is the potential damage they may cause.

#### **3.2 Tsunami Risk and Damage**

The implications for damage within potentially affected communities from tsunamis can be significant. The interrelationships between wave resonance, run-up, amplitude and current, land use and types of structures, soils, moored boats and public uses and utilities is significant.

Tsunamis result in direct, secondary and indirect impacts. Direct impacts are caused by the tsunami colliding with a structure or land, the water pressure resulting from flooding and the force of the moving water. Secondary impacts are a result of the effect of the wave on the area where it reaches land. Examples of secondary effects include: erosion and loss of ground support for structures when the wave rises and falls, the wave surge lifting structures, trees and boats and carrying them from their foundation, base or moorage.

Indirect impacts are damages or problems which arise subsequent to a tsunami but which are a result of it occurring. Food in storage can become contaminated, as can be stored water; oil and gas spills can also occur creating different types of emergencies. These in turn can create health hazards. Economic dislocation can occur as a result of tsunamis. For example, large orders of goods needed in the community can be delayed causing local manufacturing to suffer. Also the impact on an industry such as tourism or manufacturing and processing operation can be significant.

Reducing damage from these events is based on understanding how the tsunami can affect the community. The potential damage should be assessed for various areas in relation to primary, secondary and indirect tsunami impacts. One of the readily available means of identifying potential damage is to complete an historical analysis of previous events. Using this information with the scientifically based research on potential tsunami amplitude, potential damage to the community can be predicted and planning for reducing post inundation recovery can proceed.

In the case of Port Alberni the type of information required would include the land use inventory detailed below, as well as the historical accounts of tsunami damage within the City. The effects of stored materials such as logs, lumber and boats removed from their area by the wave can be significant. These can become projectiles causing extensive damage to weight-bearing walls, columns or piles. Similarly, improperly anchored structures which can be lifted off their foundations and rendered useless, can be carried considerable distances by tsunamis. Even well anchored and constructed structures can suffer significant negative impacts, such as requiring considerable cleaning or renovation as a result of water damage.

Preuss, et. al., (1988) and Preuss and Hebenstreit (1990) note that although damage patterns will vary between and within affected communities, historical analysis of impacts indicates certain trends are evident with tsunami damage. In summary they state:

- the location of the community relative to the source of the earthquake does not correlate with the severity of damage;
- well built structures tend to withstand wave forces even in high impact areas;
- poorly constructed or poorly anchored structures do not withstand moderate events;
- damage occurs as a result of the interaction of several forces;
- causes of damage reflect both the characteristics of the tsunami and the susceptibility of different uses to the hazards;
- communities with industrial ports are susceptible to greater risk than those without, particularly where secondary impacts are concerned;
- marine uses located on ports tend to break loose in a tsunami becoming debris and thus part of the secondary hazard;
- roads, airports and railways are considered to be vulnerable uses; and,
- damage to infrastructure, including damage to sewer and water systems delays post-inundation recovery.

As noted in Section 2.0 the Zone has been established at an elevation of 10.3 metres. It is the sum of the amplitude of a mathematically modelled tsunami and a high tide with a storm surge. As the Zone is a "best estimate", it is possible that the maximum amplitude of a tsunami could exceed the 10.3 metre elevation used by the City. There is also the possibility that the maximum amplitude may not be reached.

## 4.0 Existing Land Uses

### 4.1 Introduction

Land uses within the Zone comprise the full range of urban uses, see **Map 4 Existing Land Uses**. They include high, medium and low density residential uses, highway, service and local commercial development and a variety of industrial uses, as well as parks and open space, institutional uses and transportation corridors. The harbour and adjacent waters are heavily used for industrial, commercial, recreational and transportation related uses.

The Project Team completed an existing land use survey of the Zone. The upland area of the City was inventoried beyond the 10.3 metre mark in order to include uses which abut the Zone boundary. In addition to conducting a survey from the upland area of the City, planners also had the opportunity to view harbour uses from Alberni Inlet, from Polly Point in the south to the Clutesi Haven Marina in the north.

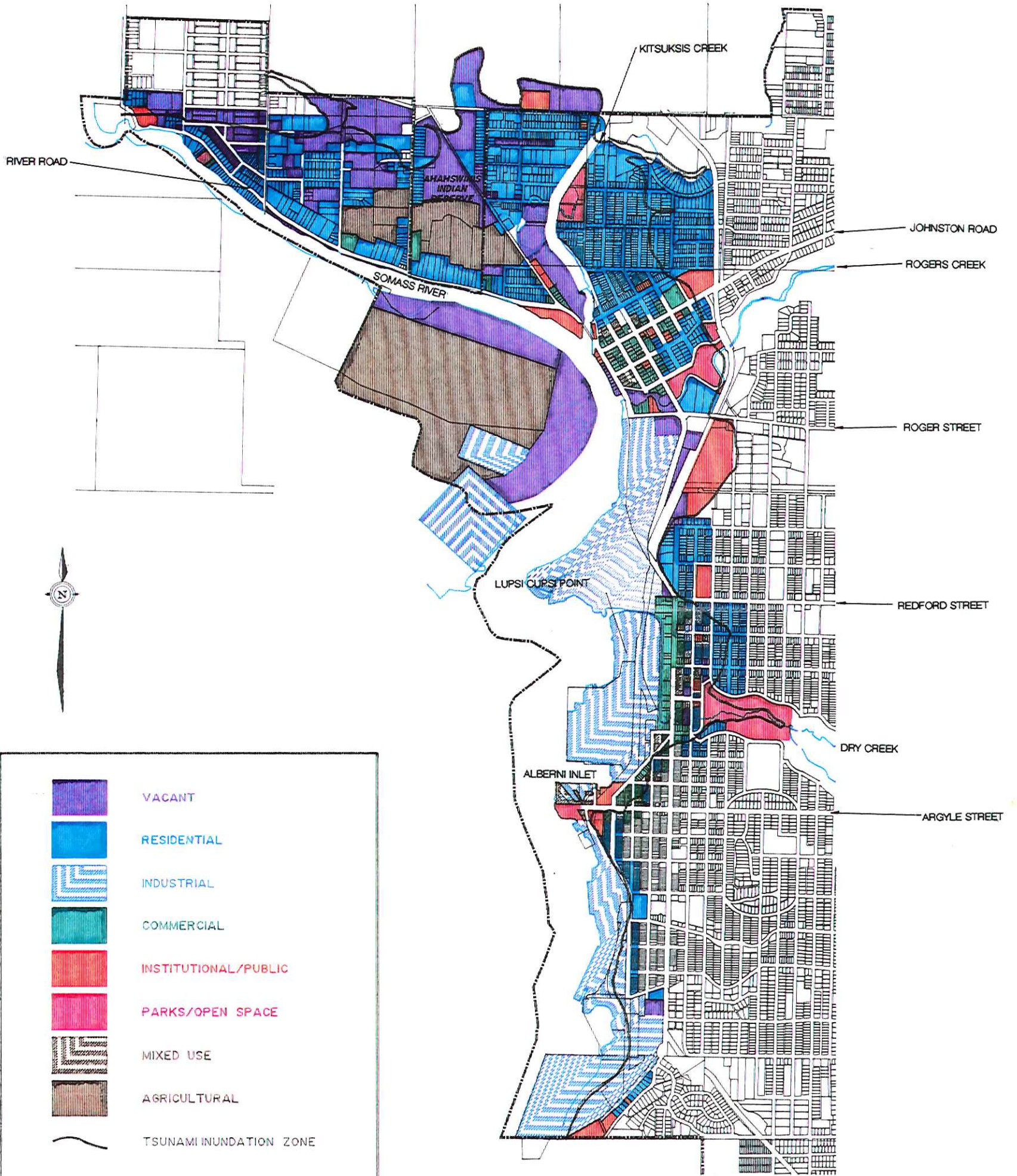
### 4.2 Land Use Inventory Summary

The waterfront includes a mix of forestry-based industries. A variety of mills, storage areas and shipping facilities related to or forming part of the MacMillan Bloedel Ltd. industrial complex span the entire length of the harbour from Polly Point in the south to Roger's Creek in the north. Industrial service uses on the waterfront include docking facilities, fuel depots, active and abandoned piers, barge operations and skids and marine engineering works, among others. The Port Alberni Harbour Commission, a major shipping facility and administrative centre, and the Fisherman's Harbour are also located within this general area.

Harbour Quay is a commercial/recreational/industrial area located at the foot of Argyle Street, in the heart of the industrialized port. It consists of a variety of shops, boutiques restaurants and tourist facilities serving the City. The MV Lady Rose also berths at Harbour Quay. The Quay has become an important tourist attraction and provides significant public access to the waterfront. It provides an opportunity to "experience" the harbour from the safety of a central, land-based node. A portion of the Quay is also a major waterfront park.

The Port Alberni waterfront is dominated by the operations of MacMillan Bloedel. These are industrial uses which, through direct employment and need for ancillary services, provide economic vitality to the community. It is without question that much of the activity on the Inlet, in the harbour and within the City generally, is a direct result of this industrial development.

The area north of Argyle Street and west of 3<sup>rd</sup> Avenue includes a mix of industrial, commercial, highway commercial, institutional, and residential uses, as well as a limited



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**UMA Engineering Ltd.**  
 Engineers & Planners  
 British Columbia Alberta Saskatchewan  
 Manitoba Ontario Yukon Territory  
 Northwest Territories  
 301-546 Yates Street, Victoria, B.C.  
 V8W 1K6 Telephone: 361-1504

**CITY OF PORT ALBERNI**  
**TSUNAMI INUNDATION ZONE STUDY**  
**MAP 4 EXISTING LAND USES**

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amount of vacant land. The areas in the vicinity of Kingsway to 2<sup>nd</sup> Avenue and from Dunbar Street to Redford Street along 3<sup>rd</sup> Avenue also have the mix of uses noted above. The lower reaches of the Dry Creek watershed are located between Dunbar and North Park Drive in this area.

The area east of 3<sup>rd</sup> Avenue to 6<sup>th</sup> Avenue is primarily residential in nature, interspersed with local commercial and some industrial uses. Commercial uses and a park are located along Napier Street at 5<sup>th</sup> Avenue, while industrial and highway commercial uses are located along Bute Street. A gravel road is located on the west side of 3<sup>rd</sup> Avenue north of Dunbar Street providing access to an industrial area. Uses along this road include log and lumber storage, a foundry, outside storage of machinery and natural gas/propane storage. Residential uses make up the primary use of land outside the Zone boundary, to the east of 6<sup>th</sup> Avenue north of Dry Creek.

From the intersection of Stamp Avenue and Redford Street, the Zone boundary generally follows the CNR right-of-way to the laneway north of and parallel to Maitland Street. This area consists primarily of vacant lands. From the laneway the boundary extends in an easterly direction to a point across 6<sup>th</sup> Avenue. It then follows a generally northwesterly direction across the lower reaches of the Roger's Creek and Kitsuksis Creek watersheds to the northerly City limit at Compton Road.

The area west of Stamp Avenue, from Maitland Street to Roger Street, is the site for the MacMillan Bloedel pulpmill. Other uses in the area include a large hydroelectric transformer station, a natural gas metering and distribution station, the B.C. Hydro office and yard, the R.C.M.P. detachment, the City's Public Works yard and recycling depot, a helipad, a large hotel and a variety of commercial, open space, institutional and residential uses.

The area bounded by Helen Street on the east, Pemberton on the south, Victoria Quay on the west, and Burke Road on the north includes a broad mix of uses. A park is located on the south side of Pemberton Street within the Roger's Creek drainage area. In addition to the general commercial nature of the area, particularly along Johnson Road and along Victoria Quay and Margaret and Gertrude Streets, there are a number of industrial uses close to Johnson Road. Churches, schools and other institutional uses also fall within the Zone in this area. It is important to note that the westerly portion of the playground of the school located at the intersection of Helen Street and Johnson Road is within the Zone.

Most of the residential uses in the area are single-detached units, although there are some multiple-residential uses located here. In addition, there are residential uses located above the commercial and industrial uses in the area. The Clutesi Haven Marina and the terminus of a pedestrian walkway along Kitsuksis Creek, linking this area of the City with Blair Park, are also found here.



The area within the Zone north of Burke Road to the northern City limit consists primarily of single-detached residential uses. Some multiple residential uses are located east of Gertrude Street, north of Glenside Road. Blair Park and the northern terminus of the Kitsuksis Creek Walkway are located between Margaret Street and the Creek.

From Compton Road the Zone boundary follows an irregular line to the western City limit at Falls Street. The area west of the Kitsuksis Creek channel to the westerly City limit includes as diverse a mix of uses as the other areas of the City with the notable absence of heavy industrial uses. The single-detached houseform dominates the uses in the area. The Ahahswinis Indian Reserve is located here. Although it does not form part of the City, land uses within the Reserve were inventoried and recorded. Uses in this area include residential, commercial and agricultural uses, as well as tracts of vacant land.

Land use densities in the area adjacent to the Reserve are not as intensive as in other areas of the City. The residential densities appear to be relatively low given the large areas of vacant lands and lands in agricultural production in the area. The area which appears to be most intensively developed is that portion of the area along River Road between Golden and Falls Streets although lots in this area appear to be large.

The area west of the Somass River includes lands within the City boundary which fall within the Zone. The City's and MacMillan Bloedel's sewage treatment lagoons are located here. There are also agricultural and vacant lands, as well as an airfield, located in the general area however the airfield is not within the City boundary.

### 4.3 Overview of Land Uses

The most striking element of the land use inventory is the extent and intensity of the industrial uses along the waterfront. Although it is recognized that the MacMillan Bloedel complex will not be included in the area affected by the recommendations of any subsequent report, its significance in terms of location, intensity and extent must be addressed. From observations carried out it appears considerable damage could result from logs or lumber being swept up and back through the Zone by a tsunami.

The City of Port Alberni has an area of approximately 1915 hectares, or approximately 4730 acres. It is estimated that between 35 and 40% of this area, or roughly 670 to 770 ha (1655 to 1900 acres) fall within the Zone.

There are a number of uses which, by their nature, may be difficult to deal with by the municipality when attempting to regulate development within the Zone. The BC Hydro transformer station located along Stamp Avenue and a number of lots with natural gas/propane storage tanks located on them may present problems. Although the location of fuel storage tanks may be changed, it may be more difficult to relocate the transformer station. However there have been discussions concerning the station's relocation.

There are a number of matters which have to be accepted when reviewing the land uses in the Zone with the intent of developing policies for the area. Foremost is that intensive urban development has occurred in the Zone. How it is to be managed in the future is one of the objectives of this study.

Second, the potential to predict an earthquake is remote if not impossible. Tsunamis, and subsequent impacts on the City, can be more readily identified subsequent to a subduction earthquake. It remains to be recognized that the potential for a tsunami exists; that a tsunami event similar in intensity to the 1964 event could occur. The municipality and area residents already live with that risk. It is the degree to which the risk is recognized which requires consideration.

Third, there has to be a willingness on behalf of the public to recognize the risk and to choose the type of action they wish to take. Unfamiliarity with an event the magnitude of which struck the City in 1964 may result in complacency on the part of residents and landowners and tenants who may be affected. Internationally acknowledged scientific research recognizes the risk of a tsunami-generated subduction earthquake occurring in the Pacific Ocean. Such an event could be as close as within 160 kilometres (100 miles) off the west coast of Vancouver Island. It is possible a tsunami can occur which will affect the City at some point in the future. Neither the amplitude nor the time of occurrence can be accurately predicted. The potential damage which could result from a tsunami can only be predicted once a subduction earthquake has occurred and a tsunami has been generated.

Fourth, although the City is using the established 10.3 m elevation as the maximum amplitude for a tsunami, that elevation may not be completely accurate depending on tidal conditions, the level of the Somass River, or offshore weather conditions. It is however based on scientific research and is the most accurate information available. The potential tsunami may have a greater or lesser elevation than that being used.

In the development of new OCP policies it will be necessary to recognize that development has occurred on most lands, and is on-going on other lands, within the Zone. It will remain to be determined if development, or redevelopment, of those lands should be permitted in the future. A qualitative judgement; based on a number of factors such as assuming risk, municipal liability, valuation of property, etc.; will have to be made when developing policies for the Zone.

There is a certain responsibility which comes with recognizing the risk of a natural hazard. For example, when a floodplain is defined through analysis a precise line can be drawn which separates developable from undevelopable areas. Difficulty exists in predicting an earthquake, let alone its magnitude; some scientists in the field admit it is next to impossible. A tsunami can only be predicted and monitored once an earthquake has occurred. Some form of relief is offered as time frames for the evacuation of inundation-prone areas can be established once the location of the earthquake and the, magnitude, speed and direction of the tsunami are known.

## **5.0 Overview of Official Community Plan (OCP) Policies**

### **5.1 Introduction**

The Port Alberni OCP was adopted by Council in 1973 and was subsequently amended in 1975 and 1979. The purpose of the OCP is to guide growth of the City. It establishes municipal intent insofar as land use and development is concerned. The existing OCP has no specific policies providing for the use of land in the Zone. Nor are there policies specifically referring to floodplain or floodprone areas. As a result the OCP is weak and does not relate to tsunamis. The following review is intended to provide an overview of the existing policies of the Plan and provide a basis for discussion of the implications which exist for areas of the City within the Zone.

This portion of the report discuss the policies of the Plan in the sequence in which they appear in the actual document. They will be discussed from a descriptive point of view bearing in mind the purpose of the study. The community objectives will be examined from the perspective of how these might apply to the Zone. In addition, the general policies of the OCP will be examined in order to determine what implications might arise for areas within the Zone. Finally, the physical development proposed in the Plan, will be reviewed from the perspective of how the location of land uses within the Zone might affect and be affected by the policies of the Plan.

The overview is being completed to achieve two objectives. First, it will serve to familiarize all those involved in the study with the status of the OCP policies viz à viz the Zone. Second, it will shed light on how the City can deal with the potential tsunami in the context of the OCP. This will be done from an objective a perspective as possible so as not to prejudice the outcome of this study or the policy recommendations to the City which might emanate from it.

### **5.2 Community Objectives**

This part of the Plan establishes the philosophy and framework for the development of the Plan. The community objectives for Port Alberni are to preserve and create a pattern of development which provides for the general well-being of residents and visitors to the City and the general region. The OCP calls for the provision of a proper sequence of development which is in the public interest by organizing development within this framework. Related to this is the provision of an efficient transportation network within and around the City.

Development which is in the public interest cannot assume that a tsunami will not occur in Port Alberni. The possibility that it may occur requires providing for "...a proper sequence of development which is in the public interest ...", include policies which recognise the potential for such an event. The risk and potential damages associated with a tsunami have been discussed; it follows that it is in the public interest to recognize the risk and plan appropriately.

The OCP policies for the Zone could define a Special Policy Area where specific types of uses, may be permitted in the Zone under certain conditions. It would be necessary to include the area as a "hazard" development permit area. Policies would be oriented to managing redevelopment in the area. It would seem appropriate to permit development in the area with the possible exception of residential uses.

These broad policy statements would require the consideration of the Zone in the context of providing for the general well being of the City, a proper sequence of development and sensitive physical design. The Zone elevations would figure significantly in developing community objectives based on preserving the overall pattern of development in the remainder of the City while simultaneously creating suitable a pattern of development within the Zone.

### **5.3 Pattern of Development**

According to the OCP the transportation network has primacy insofar as the pattern of development is concerned as opposed to sequence, types and location of development, floodplains or the Zone. All land uses are to be located with reference to the existing and proposed regional transportation network and are to be compatible with surrounding uses. The City is divided by physical barriers into four residential districts providing services and amenities to residents. Districts are defined by arterial roads and natural features. The watercourses and ravines separating districts are to be preserved. Neighbourhoods form the basis for the development of residential districts and are to be defined by the system of collector roads within districts.

The road network within the City will play a significant role in post-inundation recovery. It will be essential to have an efficient road system to provide for the effective delivery of goods and services and the relocation of residents, if necessary. The road system appears to be fairly well developed with wide arterial and collector streets with limited on-street parking. The level of local and other traffic accommodated by the existing street system is generally heavy. The uses located along major routes are either local and service commercial, tourist/highway commercial or industrial. The appropriateness of development would have to be determined through the level of risk traditionally associated with the use.

Existing uses cannot be removed unless the City, or another level of government or corporate entity, determines it is cost effective to purchase the affected properties and remove or relocate them. The recognition of expendable and non-expendable uses then becomes critical. Preuss, et.al.,(1988) discuss this under the concept of risk management. Risk management can be said to balance land use needs while minimizing property damage and other effects by combining physical and regulatory alternatives.

Risk management considers the traditional risk associated with a specific uses. It is traditionally accepted that marine uses face higher hazard risks as a result of their location

and function. If the economic cost or opportunity cost of replacing the use is low compared to mitigation costs, then it could be advantageous to permit the development of certain uses to continue on the harbour. There would likely be a low tolerance of risk for hazardous materials or fire whereas water intrusion/flooding might be given a high level of tolerance. A commercial operation such as a hotel located on a harbour would have a low tolerance to risk due to the potential number of persons which could be affected. Where docks, fishing harbours and marine oriented industries might be justified in the Zone it may be more difficult to justify the location of a new hotel or similar intensive use on the harbour.

It is important to determine whether there is an inherent risk and whether it would exist without the tsunami potential. The existing uses on the waterfront in Port Alberni already exhibit a high tolerance for risk. Introducing intensive commercial uses in this area would not appear to be justified given the low tolerance of risk of such a use when compared to traditional harbour-oriented activities. This would be compounded by the tsunami risk which although it already exists, has not been taken into consideration in the OCP.

#### **5.4 Sequence of Development**

General policies relating to the sequence of development encourage the orderly extension of services. The OCP discourages the location of new districts within floodplains or other low-lying areas. Whenever new districts are to be created they are to be a logical extension of the pattern and sequence of development already established in the City. The random development of land uses is to be discouraged.

The existence of the Zone, and eventual development of policies applicable to it, will impact on the sequence and pattern of redevelopment in the City. Redevelopment of existing districts will be affected as a good portion of the developed areas of the City lie within the Zone. Policies for the Zone will have to consider existing development in these areas and, make provision for the location of new uses. Given the existing development and amenities, economies of scale require consideration in determining if existing land uses are inappropriate. Juxtaposed against this is the liability which may have to be assumed by the City, developers, land-owners and others in affected areas.

#### **5.5 Types of Development**

The OCP allows for the development of a range of uses varying from heavy industrial activity to three types of commercial uses, residential, and park and institutional uses. The policies are broad and relate to the established pattern of development and its logical extension in the future. Proper buffering between incompatible uses, mitigation of the negative impacts of noxious omissions, noise, traffic and the like are to be achieved by having regard for the orderly extension of existing development. Policies to be developed for the Zone would have to be more explicit and restrictive than existing policies.

Policies relating to Light Industrial uses require specific attention. The OCP notes Light Industrial areas:

"are located outside the residential districts which meet such site requirements as comparatively flat ground, ready access, adequate services and suitable fire protection. Frequently such sites will also be unsuitable for residential development, by reason of a floodplain location, by reason of isolation, ..."

By inference, Light Industrial uses would be permitted in a floodplain. The location of any type of use within floodplain areas, other than perhaps passive recreational and non-structural uses, is not considered good planning. It follows that the policies relating to the location of Light Industrial uses should be re-evaluated in the development of policies for the Zone.

Particular attention should also be given to existing Parks policies. In certain instances it is appropriate to have passive recreational uses, eg. green spaces for informal recreation, trails, natural areas, etc., located in floodprone areas. It may be logical to permit similar uses in the Zone. The nature and intensity of proposed recreational uses on lands subject to flooding, including tsunami inundation should be carefully regulated.

## **5.6 Transportation**

The City is an important transportation terminus for the west coast of the Island. Although the role of the harbour has perhaps diminished given the increased importance of roads in the transportation of goods, particularly wood products, there is still an important role to be assumed by the harbour. This is particularly true given uses on Alberni Inlet, at Bamfield and for industrial uses on the Inlet and along the west coast of the Island. The development of policies for the Zone will have to take this into consideration.

More importantly however is the role to be assumed by the road network. Many existing collector and arterial roads, are located within the Zone. Highway 4, the only provincial highway to the interior and the west coast of Vancouver Island, is located within the Zone. It will be necessary to specifically consider the location, design and function of municipal roads and the provincial highway given their location in areas subject to tsunami inundation, as well as crossings over Roger's and Kitsuksis Creeks.

## **5.7 Physical Design**

The implementation of the Community Objectives and General Policies is provided for in Section 7 - Physical Design, of the OCP. These include policies on transportation and the establishment of residential districts in the City. Specific attention will have to be given to transportation policies outlined in the Plan. Their locational and functional attributes will also require attention relative to their impact on the Zone.

There are four residential districts established by the OCP. Three will be affected by policies for the Zone. The only District not extensively affected will be the South District, all others have extensive areas within the Zone. All districts will be affected to some degree by a tsunami. Close consideration of the objectives of the OCP district policies will be required in developing policies for the Zone. Matters requiring specific attention from a locational perspective include the impact of a potential tsunami on the functional aspects of the community, parks and recreation, neighbourhood development, commercial facilities, and educational policies. Other matters to be considered include liability to be assumed and the general impact of a potential tsunami on the established form of a district.

## **5.8 Conclusions Regarding OCP Policies**

The OCP is not specific insofar as the location of flood-prone areas. Reference is made to the location of light industrial uses in low-lying areas. The OCP notes that these sites will be unsuitable for residential development because of their location in the floodplain and thereby infers that they are suitable for light industrial uses.

The policies of the OCP have inherent weaknesses which preclude their effective use for controlling land uses within the Zone. There has to be formal recognition of tsunami risks on certain lands, i.e. the Zone, and appropriate policies must be developed. The implementation of revised OCP policies and the new provisions of the Zoning By-law, will determine the effectiveness of the controls. Equally important is for the public to recognize there is a risk of a tsunami affecting Port Alberni to occur at any time in the future. It may be necessary to have a public education process to ensure the public is aware of the dangers associated with tsunamis.

## **6.0 Tsunami Inundation Zone Questionnaire Analysis**

### **6.1 Introduction**

The questionnaire portion of the Port Alberni Tsunami Inundation Zone Study was devised to gather information and elicit comments regarding citizen's views and concerns over land use in the Zone. The design of the questionnaire was such that it was possible to determine the awareness of residents to tsunami risk and associated matters. Question 6 regarding the location of property in relation to the Zone was poorly worded although a number of respondents, over 10%, were able to state whether or not their property was inside or outside the Zone.

Approximately 5,000 questionnaires were mailed with the May 1991 municipal water bills, roughly one for each Port Alberni household. Residents were requested to return surveys to City Hall with their payment. There were 1280 questionnaires returned, approximately 25% of the total mailed out. As most "return required" surveys generally obtain only a 5% return, the data gather from this questionnaire can be considered of good representational quality.

The following is a question by question analysis of the questionnaire. Brief comments are offered following each question and conclusions follow at the end of the section.

### **6.2 Analysis**

#### **Question 1. Was your property affected by the 1964 tsunami?**

Only 14% of the respondents to this question did not know whether their property was affected by the 1964 tsunami. Of the remainder, 73 (5%) respondents said they knew their property was affected, while the balance, 958, approximately 75%, said their's was not affected. It has been assumed that the no answers were from citizens who lived above the affected area in 1964, and the don't know answers were from people who did not live in Port Alberni at the time.

In analyzing the survey results, it was discovered that the respondent's answer to question one outlined a natural split for questions two, seven, eight and twelve which cover extent of damage, precautions, permitted land uses and assumption of risk. This most likely is the result of different experiences between those people who were located within the Zone in 1964 and those who were not or did not live in Port Alberni at the time.

#### **Question 2. If you are aware property was affected by the 1964 tsunami, can you briefly describe the extent of the damage?**

Question two was textual in response, requiring a description of property damage as a result of the Tsunami in 1964. Those who responded yes to question one, described



personal loss and damage. Those who answered no or don't know to question one, described general damage. Only a few respondents placed a dollar value on the damage, and figures given were between one and two million dollars.

Questions 1 and 2 were asked to determine if residents were aware of the tsunami hazard and the level of damage which could occur as a result of a tsunami. There is a good knowledge of the damage caused by the 1964 earthquake by the 1991 residents of the City. Many remember the extensive damage that was caused and the effort that was required to clean up subsequent to the event. It can be inferred that residents are somewhat aware of the potential damage should a future event occur. Whether or not a link was made between the event in 1964 and a future tsunami in terms of risk and damage could not be determined.

**Question 3. In your opinion could an off shore earthquake cause a tsunami more devastating than the 1964 event?**

Of the 1044, responses received for this question 80% of the respondents felt that an off-shore earthquake could cause a tsunami more devastating than the one of 1964. Three response groups were created and their responses to this question was cross-referenced to Question 1, i.e. Was your property affected in 1964? Roughly 66% of those who responded yes to this question also answered yes to Question 1. More than 70% of the respondents who answered no or don't know to Question 1 answered yes to this question. The reason for these results could be because of the devastation witnessed by those whose property was affected who would find it difficult to understand how a more devastating event could occur. Another reason might be because of flood control structure built adjacent to the Somass River and the level of confidence felt by residents as a result of it being there. The comment was made that because of the raising of River Road the devastation from a tsunami would not be as extreme. The nature of these comments makes it evident there is a need for appropriate regulatory policies for the Zone in the new OCP.

**Question 4. What do you believe the odds are that such an earthquake could occur in your lifetime?**

Approximately 38% of the respondents to the questionnaire felt that the chance of an earthquake similar to that of 1964 occurring was less than 25%. Of the remainder roughly 20% believed odds were between 25% and 40%, approximately 17.5% believed the odds were between 41% and 60% and while the remaining 14.4% believed the odds were better than 60%. On the latter question, unsolicited written response highlighted a small number of people who viewed the 1964 tsunami as a freak of nature. As noted elsewhere in this report, unfamiliarity with the risks associated with tsunamis may result in complacency toward the risk thereby explaining that assumption.

**Question 5. Other than for the description provided above are you aware of the area defined as the Port Alberni Tsunami Inundation Zone?**

Approximately 57.5% of the respondents to the questionnaire are aware of the existence of the Zone. The remainder stated they were not familiar with the extent of the Zone. Some respondents mistakenly identified the Somass River, Lugin Creek or Kitsukis Creek floodplains as the Tsunami Inundation Zone.

The responses to this question indicate to the study team that there may be a requirement to make residents aware of the existence of the Zone. This could be done through a series of articles in newspapers, the design of a pamphlet to inform people of the general location of the Zone or mailing information with municipal water bills to City residents or a combination of any of these.

**Question 6. Do you know if your property lies within the existing Tsunami Inundation Zone?**

Unfortunately question six was not clearly worded and was read by almost all respondents as unclear and ambiguous. However, it appears from the written responses accompanying this question that most residents know the location of their house in relation to the Zone. It should be noted that some confusion exists between the definitions and boundaries of the Zone and the floodplains within the City, again an indication of the lack of knowledge of how tsunami may affect the City.

Although Question six was not as clear as it could have been in eliciting responses, respondents to the question added comments to clarify whether or not their property was within or outside the Zone. Approximately 12% of the respondents indicated they knew their property was either within or outside the Zone. Of the 147 questionnaires with comments added to question six, 141 respondents indicated they knew their property was outside the Zone, while only six respondents knew their property was within it.

**Question 7. What precautions have you taken to reduce damage on your property in the event of a tsunami?**

Of the 73 respondents who were directly affected in 1964, 23 (31%) have taken some form of action in preparing for the possible event of a second tsunami. For example, they have done one, some, or all of the following: moved out of the Zone, put together an earthquake kit, discussed evacuation procedures with the family, altered contents of the house (ie. secured the water heater), altered the house or lot (ie. raised elevation of dwelling, bermed lot), or purchased earthquake insurance. Those 958 respondents who were not directly affected in 1964, for the most part have only purchased insurance. Only twenty of this respondent group have done any form of personal or property preparation/alteration.

**Question 8. Because a Tsunami Inundation Zone has been established by the City based on technical studies, should active land uses be permitted within the Zone?**

The majority of respondents to the questionnaire were of the opinion that active land uses should be permitted in the Zone. Unsolicited written responses were few, but those received qualified the response with the need for restrictions on certain activities and land uses. Many of the comments regarding permitted land uses noted the type and intensity of uses permitted should be restricted. In addition respondents noted those responsible for assuming the risk on lands in the Zone should be the owners of the property.

Question eight was also analyzed in the context of the respondents answer to the first question. Oddly enough the proportion of respondents who answered yes to question one, i.e. Was your property affected by the 1964 tsunami?, and to permitting active land uses in the Zone, was greater than those who were not affected by the 1964 tsunami. This may be a result of the precautions taken by residents affected by the 1964 event and better preparation to deal with any future event.

**Question 9. In your opinion should land owners/tenants in the Tsunami Inundation Zone be made aware of its existence and the consequences of a potential tsunami?**

A total of 1165 responses were received to this question. Of these 1148 or 98.5% stated owners and tenants should be notified of the Zone and of the potential risk. The remaining 17, or 1.5%, did not feel it was necessary to issue a notification. The overwhelming positive response to notification is indicative of the need to respond to the public good generally as opposed to the interests of the individual.

The responses received to this question provide a strong indication for the need to have specific policies for the Zone. When coupled with the responses to Question 8 it demonstrates that a comprehensive approach to risk and land use activity within the Zone is appropriate.

**Question 10. Should information concerning a tsunami for properties within the Tsunami Inundation Zone be:**

1. posted on the affected sites;
2. noted on leases;
3. the owners notified by registered letter;
4. notification on the municipal tax bills;
5. registered on title;
6. other means (specify)?

The responses for question ten are shown on the following page. Although registration on title and notification on the municipal tax bill were by far the preferred methods, the

written comments are quite telling. They can be summarized by stating that respondents felt that any means that can be taken should be acted upon.

Response	No.	%
1. posted on the affected sites:	178	14
2. noted on leases	380	30
3. the owners notified by registered letter	363	28
4. notification on the municipal tax bills	513	40
5. registered on title	591	46
6. other means (specify)	25	2

Some of the written comments included: painting lines on poles or signs to note the extent of the Zone, individual notification of tenants with literature on what action to take, making maps available at City Hall and at the Regional District Office. Other comments included no notification was necessary as the threat was not that serious and why frighten people, if a tsunami comes it may damage a lot of the Island.

The responses to this question provide an indication of the willingness of residents of Port Alberni to minimize risk through public notification. The means of notification may be varied thereby avoiding dependency on one particular method of notification. Varying the form of notice to include more than one method will better enable persons to decide whether or not to locate in the Zone. If a person is notified of the risk and chooses to locate in the Zone it is a conscious choice based on the most accurate information available.

**Question 11. In your opinion, would registering information on title on properties within the Tsunami Inundation Zone affect their value?**

Two-thirds of the respondents felt that registering information on title of properties lying inside the Zone would affect their value. However the written comments provided indicate that it is felt the impact would likely be slight. Some residents equate the Zone with the floodplain and are of the opinion that land is thereby reduced in value. Others note that other forms of natural hazards may occur, eg. landslides, but that until they occur value is not affected. Comments on impacts on value were also made with the qualification that "people should be made aware" of the risk.

**Question 12. Given a risk of a Tsunami event and that government authorities are aware of that risk, should the liability concerning a potential Tsunami lie with the governments or with private land-owners?**

The majority of those surveyed, 705 of 1280, or 55%, felt that the government should generally be held responsible for liability from tsunamis. This included 71% of the respondents who lived in the Zone in 1964 and 58% of those who lived outside the zone

or the city during the event. The remaining respondents, 566 or 44% felt the responsibility should rest with the land owner.

It should be noted that a small group of respondents believe that liability should be shared on a percentage base. Others are of the opinion that government should be responsible for liability on lands where structures were built prior to and until 1964 with land owners would be liable if the lands were built upon subsequent to 1964.

In relating responses to this question to the manner in which the same respondents answered Question 1, it was found that respondent support for government assuming liability was generally strong when averaged over the three types of answers given to Question 1, i.e. 64.6%. All of the respondent groups to Question 1 expressed majority support toward government assuming liability.

Given the response to this question it is difficult, to understand how the same group could support the development of active land uses in the Zone. If government is to permit active land uses in the Zone under certain restrictions, one of those being notification of the location of the Zone and of the property within it, then it follows that liability should be assumed by those locating in the Zone, if theirs is a permitted use. It is illogical to ask a government to approve active land uses on lands subject to hazard, i.e a tsunami, then require that same level of government to assume the liability for permitting the use.

Although their responses were in the minority, 44% responded that owners should be liable for uses in the Zone. If a use is to be permitted and proper notification provided as to the hazards which exist and the prohibitions which are in effect, and the choice is made to locate within the Zone then it appears logical that the land owner/developer choosing to locate there should assume liability. Asking government to assume liability subsequent to authorizing development does not complement the principle of risk management discussed in Section 7.

**Question 13. What controls should be placed over land uses in the Tsunami Inundation Zone:**

1. permit existing uses;
2. introduce new uses as well as permitting existing ones;
3. only permit passive recreational uses;
4. no uses at all;
5. other (specify)?

Approximately 60% of the respondents believe some type of land use controls should be implemented in the Zone. The percentage breakdown on land use control options was as follows:

Option	No.	%
1. permit existing uses	455	36
2. introduce new uses/permit existing ones	423	33
3. only permit passive recreational uses	260	20
4. no uses at all	34	3
5. other (specify)?	96	8

Concern was voiced that developments that could result in hazardous uses being introduced to the Zone should not be permitted. Residents noted certain uses should be removed from the Zone, i.e. the B.C. Hydro Sub-Station and the chlorine tanks at the MacMillian Bloedel Mill. However no reference was made to the propane storage tanks or tank farms found throughout the Zone nor the several service stations located there as well.

**Question 14. What measures could be used to minimize damage caused by a series of backwash waves on the existing or new development:**

1. use of breakaway doors on buildings;
2. steel re-enforced concrete structure;
3. road design to provide drainage;
4. minimum building elevation;
5. structural raising of buildings;
6. use of building tie-downs;
7. use of deflector dykes;
8. other (specify)?

In eliciting what respondents felt to be appropriate methods for minimizing damage by a tsunami responses varied as follows:

Responses	No.	%
1. use of breakaway doors on buildings	74	6
2. steel re-enforced concrete structure	171	13
3. road design to provide drainage	385	30
4. minimum building elevation	255	20
5. structural raising of buildings	14	1
6. use of building tie-downs	103	8
7. use of deflector dykes	481	38
8. other (specify)	173	13

The methods suggested in the questionnaire were based on the premise that certain mitigating measures may be appropriate for uses permitted in the Zone. Given the potential amplitude and velocity of a tsunami moving through Port Alberni it may be that some of the suggested methods may not be applicable. The methods presented are based on the fact that certain structures withstood the 1964 event. Using the measures noted

here would likely improve the chances of a structure withstanding such an event with reduced damage.

Some of the remedial measures are more readily implemented than others and some could be quite costly. Others, such as road design and the use of deflector dykes have to be examined on a municipally wide scale in order for them to be effective. It was obvious from the responses provided that certain methods were preferred over others.

Some of the comments received indicated that the methods identified in the questionnaire were too technical for laypersons to be able to comment upon. This is a fair criticism, however, the total number of selections obtained in the responses to the question, approximately 1660, is also an indication that there is some understanding of the principles suggested and that these should be pursued as alternatives.

Finally the responses which could be provided to this question were multiple choice. This explains the variation in the number of responses to specific alternatives

**Question 15. OPTIONAL - If you are interested in participating in the development of policies and provisions for use in the Port Alberni Tsunami Inundation Zone please leave your name address and telephone number in the space provided below.**

As indicated above, Question 15 was the only optional answer question provided on the questionnaire. Approximately 125 respondents provided the information requested on the questionnaire. In order to respect the confidentiality of the respondents the list of individuals who provided their names is being withheld for the time being.

### 6.3 Conclusions

Given the number of respondents to the questionnaire it is obvious that there is a strong interest in the future use of land in the Zone. A great number of people and uses will be affected by the action which is eventually taken by the City in controlling development in the area. Similarly, there appears to be some polarization as to permitted uses in the Zone as well as to who should assume responsibility for them locating there.

The responses elicited have proven to be informative and will be useful in the eventual development of policies for the Zone. In addition they have provided an excellent basis for approaching the community in a public forum which enables residents to provide, and for the study team to obtain, additional comments and input on the management of the Zone.

The following section discusses risk and its implications for land use management in areas subject to tsunamis. Where solutions have been engineering dependent in the past, a process is discussed which is a combination of engineering and planning principles which enables the risk to be better understood and the issue of land use management in the Zone to be effectively addressed.

## **7.0 Analysis of Risk**

### **7.1 Introduction**

When discussing tsunami risk, the focus is on determining how land uses relate to the characteristics of tsunamis. It is important to understand what the impact of a tsunami may be in Port Alberni and be able to project land use patterns against this scenario to determine potential impacts. In order to identify potential impacts the inundation area, wave height and its sequence have to be determined. Damage from tsunamis is a function of amplitude, period of the waves, topography, land uses, friction and the velocity of the moving water. The uses causing impacts as well as the location of the impacts can then be determined. Once identified an attempt at mitigating the potential level of impact can be achieved through the development of appropriate land use policies.

Four underlying objectives are the focus of determining risk and developing appropriate land use policies:

1. The definition of characteristics and dimensions of the potential tsunami threat to Port Alberni;
2. The identification of land use and population distribution patterns;
3. The establishment and location of secondary hazards resulting from the earthquake; and
4. Potential direct, secondary and indirect hazards resulting from the tsunami should be identified.

### **7.2 Damage Analysis in Port Alberni**

As noted earlier there is considerable seismic activity in the Pacific Ocean. Subduction earthquakes can occur and cause tsunamis which can threaten communities along the west coast of British Columbia. The potential risk in Port Alberni for a tsunami to reach the community is high as is the potential for damage to buildings and infrastructure is high.

There is little information available on past or potential damage patterns in Port Alberni should a tsunami affect the City. Historical data consists of photographs and journalistic accounts of the 1964 event. No numerical simulation of the potential tsunami has been completed, although one is currently being conducted by ocean physicists at the Institute of Ocean Sciences in Sidney. Calculations based on scientific study completed to date indicate that the amplitude of the wave when combined with currents created by land friction could damage structures to within a metre, more or less, of the uppermost limit of the Zone. It is therefore necessary to examine historical information and relate its significance in terms of existing land use patterns to develop policies for Port Alberni.



Specific data on the damage which occurred in the 1964 tsunami is limited. However, it is known that:

" Damage in the Alberni area was centred on the low-lying areas along the north bank of the Somass River from Rogers Creek to Russell Road in the west, on the north of Watson Road, the southern third of the Indian Reserve, Forest Road, and on the east, Elizabeth Street, Swansome Street and Gertrude Street."<sup>4</sup>

The same article goes on to note that damage to structures ranged from total destruction to minor water damage. The risk of fire was reduced by the quick response of BC Hydro crews who dealt with downed wires. Buildings not bolted to their foundations were swept inland for up to 300 metres (1000 feet) and that some boats were moved over 2 kilometres. Buildings with concrete block foundations or whose frames were fixed to the foundations moved only short distances. Log booms from the Inlet were carried high on shore and caused heavy damage and obstructed rescue operations. All objects submerged by the tsunami required considerable, time-consuming clean-up due to heavy deposits of silt. In addition, there was risk of fire due to ruptured and leaking propane tanks. Although the sewage system was not damaged the sewage lagoon was filled with logs and the walls of the lagoon were weakened as material washed away. Heavy industry was halted until the clean-up was carried out to those operations. Finally, many small businesses suffered damage to stock and equipment.

The damage reports provided by the local Civil Defence indicate 55 houses were a total loss while another 14 were moved off their foundations. Over 300 houses were flooded with damage ranging from minor to severe. A total of 375 dwellings were directly damaged by the tsunamis. These damages resulted in costs approaching 5 million dollars (1964 dollars) when combined with the losses to commercial establishments and businesses. This represents between 15 and 17 million in 1991 dollars.

The following is a summary of a damage report for the area adjacent Alberni Inlet and the Somass River. A social worker in Port Alberni received a call from residents on Victoria Quay just after 12:30 a.m. of 28 March 1964 stating their house had been flooded by approximately a foot of water. A trip to Victoria Quay by the same social worker at 7:00 a.m. the same day resulted in the following report:

"Took quick trip through area where most damage done on junction of Somass and Kitsucsis (sic) Creek - noted that home from which first call had come was completely washed away."<sup>5</sup>

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4. Civil Defence Publication, Edition No.64, Summer 1964, p. 9.

5. Ibid. p. 35.

Direct, indirect and secondary impacts were experienced throughout the affected area. From structures being washed away, to logs filling the sewage lagoon to the risk of fire from leaking propane tanks. The total damage to the communities of Alberni and Port Alberni was estimated at \$5 million in 1964. Written and photographic evidence demonstrates physical damage to structures was substantial and that employment was affected. Many enterprises could not start-up immediately after the tsunami due to the extensive clean-up that was required. Those who were not included in the clean-up were without work until operations started again.

### 7.3 Definition of Risk in Port Alberni

Maps on the damage experienced as a result of the 1964 tsunami were unavailable for review however, a photographic record of the event was obtained. It would have been useful to be able to compare the damage reports with the Existing Land Use Map completed for this study. An attempt could then have been made to predict the level of damage which might occur in each area of the City, given a similar event. Any damage analysis will have to be based on the mathematical modelling of an event and on the contour mapping available at the time, using the existing land use map prepared for this study.

No accurate mathematical model incorporating shoreline and bottom friction exists at this time for Alberni Inlet. Scientists at the Institute for Ocean Sciences expect to have a computer-based mathematical model of the Inlet completed and operational by the end of 1991.<sup>6</sup> It will be possible to model tsunamis of different amplitudes and determine their effect on land uses in a specific area once the modelling process is refined. The model being developed will consider shoreline and bottom friction and, as a result, will provide more accurate representation of potential impact than existing models.

It is not possible to state conclusively what the policy implications for the City once this model is completed. Because the ocean floor and the shoreline will be included, a more accurate prediction of the impact of a tsunami will be possible. With the new model it may be determined that the maximum elevation of the Zone is reduced. On the other hand shoreline and bottom friction may increase the speed of the wave to the extent that run-up and hydrostatic pressure could cause more damage to uses than that which is currently anticipated at the existing maximum level of the Zone.

The policies which will be developed should therefore be as applicable to any elevation as they are to a 10.3 metre elevation. The purpose of having the policies in the OCP is to assist in post-inundation recovery time as well as provide for proper land use management. Policies will be based on the existing maximum Tsunami Inundation Zone elevation however their intent would be to address the management of risk within the

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<sup>6</sup>. Personal communication with Dr. Tad Murty, Department of Ocean Sciences, Institute of Ocean Sciences.

Zone from the Inlets waters to the 10.3 metre elevation. If, subsequent to the refinement of the model being developed, it is determined that the maximum elevation of the Zone should be changed, then an amendment to the OCP may be required. It is anticipated that notwithstanding the elevation of the Zone, the intent of the policies will remain the same and only minor amendments to the text and Schedule of the OCP would be required. If the City is completing a review of the OCP at the time the model is refined, then the required modification to the maximum elevation could be accommodated by the Review process.

Based on the work completed by Preuss, et. al., (1988) and Preuss and Hebenstreit (1990), addressing tsunami damage trends it is possible to establish criteria to identify uses, and subsequently areas, which would be damaged in a tsunami. It is known that Port Alberni's location relative to the source of the earthquake does not correlate with the severity of damage which might occur. It is also known that tsunami damage in Port Alberni can be significant. On this basis, it is possible to relate what these experts state in relation to types of uses which have the potential to suffer most from tsunamis and identify areas of the City where damage is likely to be the most extensive given the age of buildings, any retrofitting done to them and the technical matters discussed below.

If the economic cost or opportunity cost of replacing a use is low compared to mitigation costs, i.e if the structure is considered to be more or less expendable, then it could be a permitted use within the Zone. Similarly, uses which are subject to a traditionally high level of risk may be appropriate in the Zone. Such uses could include the Fisherman's Harbour, the Harbour Commission's Assembly Wharf, Clutesi Haven Marina and the Harbour Quay Wharf with some commercial uses, among others. These uses risk flooding from high tides, damage from wind storms, potential industrial accidents, etc.

Damage occurs as a result of the interaction of several forces. Causes of damage reflect both the characteristics of the tsunami and the susceptibility of different uses to the hazard. The hydrostatic pressure of a tsunami is without question a significant force on structures. This coupled with poorly constructed buildings and secondary and indirect tsunami risks could result in significant damage to structures and uses within the Zone.

It is known that well built structures tend to withstand wave forces even in high impact areas while poorly constructed or poorly anchored structures do not withstand moderate events.<sup>7</sup> In terms of Port Alberni older buildings in the Zone may or may not have the structural integrity to withstand the hydrostatic pressure of a tsunami. The same may be true of newer structures which are not designed to withstand the maximum credible earthquake.

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<sup>7</sup>. Preuss, et. al. (1988) and Preuss and Hebenstreit, (1990).  
op. cit.

It is relatively certain that damage would occur along the length of the harbour and up the Somass River should a tsunami affect Port Alberni. The extent of the damage cannot be predicted as it is dependent upon the amplitude of the tsunami. Because accurate contour elevations of the Zone are not available for review it is not possible to specifically determine where impacts would be greatest. Without this information it can only be concluded that the level of risk within the entire Zone is high.

#### 7.4 Development of Policies for the Zone

Because Port Alberni is an industrial port it will likely be prone to greater risk of damage than a non-industrial port. There is a significant vulnerability to indirect and secondary risks in the City. The chemical-using, heavy industrial uses located on the Harbour as well as the tank farms, propane and natural gas storage and the movement of freight (chemicals and other materials) via rail also poses a problem. Log storage in booms, boats moored in the harbour, abandoned structures on the harbour, the location of the large, BC Hydro transformer station within the Zone, and the MacMillan Bloedel pulp mill, can cause significant damage within the Zone. The combined effects of primary, indirect and secondary impacts could be significant, despite the fact that the level of log storage and sorting in the Inlet has been reduced since 1964. Marine uses located on ports are also more prone to potentially extensive damage. These tend to break loose from their moorings in a tsunami becoming debris and thus part of the secondary hazard.

Transportation infrastructure such as roads, airports and railways are considered to be vulnerable uses as they can be the lifeline of the community immediately, and subsequent to an event. In addition, damage to infrastructure including damage to sewer and water systems delays post-inundation recovery. These uses and services should therefore be designed and installed in such a manner to withstand considerable impacts.

A number of studies to quantify the possible tsunami wave have been carried out in the past. These reviewed have defined the wave height as the distance above the normal tide level. To delineate the Zone, these values have to be increased to account for wave uprush over land and for the fact that higher waves could coincide with high tide. As noted earlier this is, in part, how the 10.3 metre elevation for the City was determined.

A probabilistic method of analysis to define the maximum wave height and the extent of the inundation zone based on a seismic event having a medium or high probability of occurrence is not considered realistic in view of the potential loss of life. The deterministic approach to define the seabed uplift associated with the "maximum credible earthquake", and the resultant wave height is considered to be more valid. Thus the importance of the modelling of Port Alberni by the Institute of Ocean Sciences.

There are a number of approaches that can be taken to land use management within the Zone. All must be based on the fact that it is unacceptable for a regulatory body to assume high levels of risk when there is the possibility for loss of life. The question of

property damage is somewhat more ambiguous; even public property such as a park will suffer some damage when a tsunami event occurs.

Structures such as barriers and dykes have been suggested in the past and subsequently rejected due to their cost, mass and lack of aesthetic character. In the absence of protective structures, restrictions on future use and development of lands in the Zone should be applied.

When developing policies wave height and velocity must also be borne in mind. The velocity of incoming and outgoing wave motion in the Inlet has been calculated in the order of 3.5 to 4.5 metres/second (7 to 10 miles/hour). These figures do not include the increases in velocity and the creation of eddies through bottom and shoreline friction.<sup>8</sup> The net effect of friction is that the velocity of the wave can be increase by 0.30 times. This results in wave velocities approaching 4.6 to 5.9 metres/second (10 to 13 miles/hour). Building tie-downs are not expected to be viable safety measures as mitigation measures with this level of wave velocity particularly when the resonance of Alberni Inlet is considered. This is particularly true if "projectiles" are considered, eg. logs and other debris. Further, with this wave velocity, physical barriers such as dykes may only work in the upper part of the Zone.

Wave velocity will have an impact on the physical solutions which are considered for permitted uses. The construction of a tsunami barrier in the Inlet to protect upstream uses has already been suggested. A significant amount of attenuation would likely be achieved with Inlet barriers, however their cost would likely be prohibitive. Dykes are an alternative protection measure. However, a 10-metre high embankment with riprap slope protection near the shoreline has drawbacks in terms of aesthetics, waterfront access, etc. In addition prudent floodplain design and management measures would require floor levels to be at the top of the dyke elevation. Dykes and raised building levels at the upper limit of the Zone are probably more practical.

As the solutions proposed above, with the exception of the last suggestion, are generally considered unacceptable, restrictions on future land use and improvements should apply in the Zone.

Tsunamis of varying amplitudes will undoubtedly affect Port Alberni in the future. Because such events cannot be predicted with reasonable accuracy, it is considered more appropriate to recognize the risk and attempt to mitigate damages through a more deterministic approach. Uses locating in areas susceptible to tsunami inundation should only be permitted based on specific criteria while others would be prohibited. Risk to property may be acceptable, however risk to life is unacceptable.

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<sup>8</sup>. Personal communication with Dr. Tad Murty, Institute of Ocean Sciences, Sidney, B.C.

Notice regarding tsunami risk would have to be given to individuals with interests in land when policies are established for the Zone. This could be achieved through registration on title, site posting, notification on municipal tax bills and notification on leases, among others, for uses within the Zone. In addition, the City might consider having developers waive holding the City liable for damages should they build within the Zone and a tsunami occur. By notifying those with interest in land of the potential risk, and by establishing appropriate policies for the Zone based on its understanding of the potential risk, the municipality would likely only be responsible for public services and roads within the Zone. The risk of locating uses within the Zone would have to be borne by those choosing to develop land there. Similarly the cost of repairing damaged uses would likely have to be assumed by the interested party.

As a result of having the tsunami warning system, the existing transportation network and an established Tsunami Inundation Zone, it may be appropriate to consider the location of a mix of uses within the Zone. It seems reasonable to locate public uses such as theatres, churches and schools within the Zone, as well as certain commercial and industrial uses, due to their controlled hours of operation and the reasons noted above. Permitting new commercial and industrial uses in the zone should be based on the intensity and nature of the use, among other criteria. Regard should be had for possible loss of life and property damage as well. Uses which could generate secondary impacts such as fuel storage depots, large transformer stations, service stations, intensive chemical using industries etc., should be discouraged from locating in the area due to the increase in risk they introduce through indirect impact. The municipality may wish to consider permitting residential uses based on the density, nature and type of development assuming of course the risk of possible loss of life is minimized.

Permitting new residential uses in the Zone has to be oriented to the appropriateness of the use in the location, the density of development, and risk among others. New apartment buildings, housing for special groups eg., the elderly, the handicapped, etc., are not considered appropriate uses for the zone. This is due to the high potential for loss of life associated with having large numbers of persons located in comparatively small areas. In addition, groups requiring special types of housing would also demand special attention. It is likely the cost of constructing large structures to withstand the force of a tsunami would also be prohibitive.

Permitting new single detached or multiple residential uses, duplexes and semi-detached units, at low densities may be appropriate if the possibility of loss of life can be rendered minimal or equivalent to that associated with commercial or industrial uses. Residential uses where notification at night will be difficult should not be permitted in the zone. Having lower densities, ie. single detached or small multiple residential developments on large lots, may not result in as much difficulty in warning or evacuating residents as with dense, large-scale multiple residential uses and would likely reduce post-inundation recovery time. Similarly permitting large-lot development would allow for flood-waters to disperse more quickly than with denser development and would not create friction

causing marginal increases in the speed of the wave. Finally, constructing smaller buildings to withstand tsunami forces may be more feasible than constructing larger buildings.

It should be borne in mind that risk to life will be a major concern. While permitting residential uses in the Zone may appear to be in conflict with assuming responsibility for risk to life, the risk may not be as high as if other types of uses such as denser commercial or more intensive industrial development were to be permitted. This is based on the fact that residential development would have to be dispersed and would have to occur at low densities.

Caution will have to be exercised in locating residential uses, particularly in the lower reaches of the Zone. More intensive residential development, higher density single detached and multiple residential uses would likely be appropriate only in the upper reaches of the Zone, particularly if deflector dykes can be constructed and buildings raised above flood elevations. Wherever residential uses are permitted, appropriate provisions similar to flood protection provisions would have to be included in the Zoning By-law and would have to be in compliance with the policies of the OCP.

A pattern of permitted uses within the Zone can be established based on risk. Design standards for these uses as well as transportation networks can also be established. Permitted uses would include those where investment costs are low and where impacts on other uses in the community are minimized. It does not appear to be appropriate that the land in the Zone be sterilized, nor that unnecessary risks be assumed. If a building or structure is expendable, i.e. the risk tolerated is considered to be high, then the use may be permitted to locate in the area. On the other hand if the risk tolerated is low or if the risk to life is unacceptable, then the use should be prohibited.

The transportation network in the City should support the location of uses within the zone. The location of large parking lots and on-street parking should be minimized in order to reduce the incidence of debris subsequent to a tsunami and to keep the transportation network functional.

One of the elements to be considered in managing land uses in the Zone should be the recognition of existing uses. These may be permitted uses in the Zone because of their tolerated high levels of risk in terms of water damage, flooding and to some degree, hazardous materials, or they may be uses deemed to be unacceptable for the Zone. Certain existing uses will have to be recognized as legal non-conforming uses. Where the use will be one deemed to be legal non-conforming then the use should be encouraged to relocate in an area of the City where it would be permitted. The provisions of the Municipal Act regarding the continuation of non-conforming uses would also apply.

The presence of hazardous materials will likely have to be tolerated on the harbour and elsewhere in the Zone given existing uses may be recognized. Specific policies

encouraging their relocation should also be included in the policies for the Zone. Similarly, uses with extensive outside storage for raw or processed materials may pose a threat because of secondary impacts and therefore require control and regulation.

The risk of a tsunami and the potential for damage exists as much now as it will subsequent to the adoption of land use policies for the Zone. The recognition of existing uses will not necessarily guarantee their automatic continuation nor that these or similar uses will be permitted in the future should they for any reason cease to exist. In addition, their recognition will only be one aspect of the policies applicable to the Zone. The policies will consider, more specifically, uses which will be permitted when the redevelopment of existing uses within the Zone is proposed. This would be where the risk management policy development methodology as developed by Preuss, et. al. (1988) and Preuss and Hebenstreit (1990) could be considered. Redevelopment of existing uses should only be considered based on the tolerance level toward risk, the indirect and secondary impacts on its immediate location and on surrounding uses in the event of a tsunami and the risk to property and to life.

It is also necessary to consider additional regulations in effect at present. There are floodplain elevations established for Lugin Creek, Kitsuksis Creek and Rogers Creek which should continue to be in effect. Although these low-lying areas will be subject to inundation during a tsunami, the occurrence of a tsunami cannot be predicted. Controls over lands and uses in the floodplain will be required in order to protect existing uses from the predictable flood levels, the 1:200-year flood, despite the potential for a tsunami. It remains to be noted that no accurate flood-plain mapping exists for Port Alberni. The mapping completed by the province for the area was withdrawn by the Ministry of the Environment some time ago. Although the municipality has taken initiatives to regulate development on flood-prone lands, there has been an absence of direction from provincial agencies. The City will also look to taking initiative with the Tsunami Inundation Zone.

The appropriate location of the Tsunami Inundation Zone policy boundary must be determined. Four alternatives for the location of a boundary are presented here.

The location of the Zone line at 10.3 m is considered to be excessive by some due to the manner in which it was derived. On the other hand the Provincial Emergency Program has used a 16 m (50-foot) elevation as an evacuation line. Thus the first alternative to consider is the 10.3 m elevation. The City has accepted the 10.3 m elevation as the maximum tsunami level. Despite potential difficulties in administering the policy based on this line, where portions of lots would lie both within and outside the Zone, this elevation is established and known, and requires consideration as an alternative.

The City may consider locating the line conservatively as demonstrated by Alternative 1. An additional buffer zone between the Zone elevation line and the policy boundary might be considered as included with this alternative. This would create an area in addition to



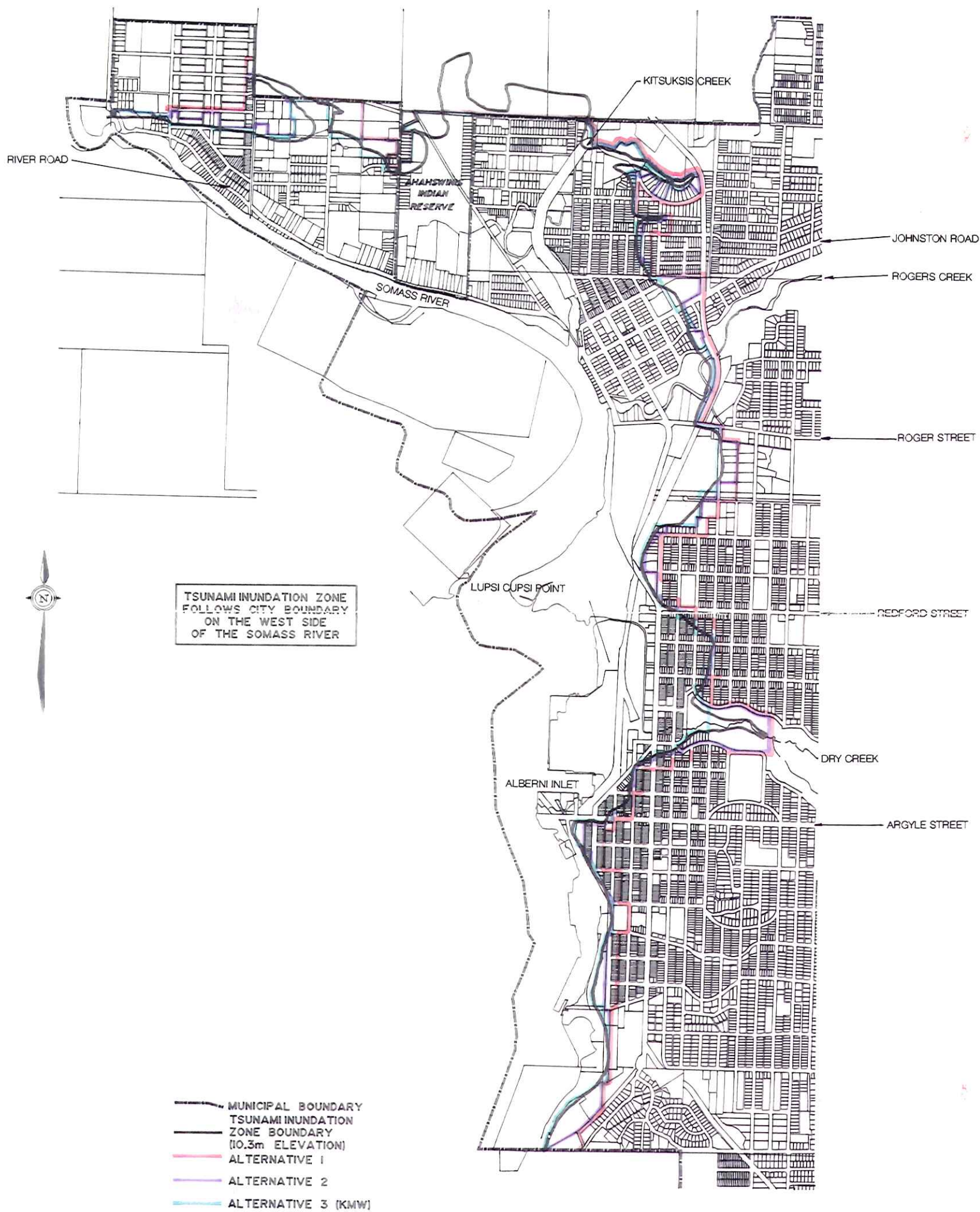
the Tsunami Inundation Zone where development would be controlled. This would enable Council to be more secure in the knowledge that maximum protection is being provided given existing knowledge. However, this alternative would likely have a serious negative impact on properties within the policy boundary in terms of affecting their potential for redevelopment, of sterilizing certain properties from development, of property values being negatively affected and of involving the City in litigation. Although this alternative is shown on **Map 5, Alternative Policy Boundaries**, it is considered the least desirable due to its potential negative impacts.

Another alternative, Alternative 2 on **Map 5**, more conservative than the Tsunami Inundation Zone line already established and the previous alternative suggested, would be establishing a policy boundary on the lot-line nearest the 10.3 m elevation outside the Tsunami Inundation Zone. This would result in the City exercising control over lands outside the Zone for tsunami protection purposes and could potentially sterilize them from development. As with the third alternative described below, Alternative 2 is not considered to be as effective as Alternative 3 from an administrative perspective. It does however offer the security of a more conservative approach.

Finally Alternative 3 on **Map 5** has been suggested by City staff. It would establish the policy boundary based on the elevations of the lot(s) in question rather than strict adherence to the 10.3 m elevation. It is likely that the construction of deflector dikes on these properties in the upper limits of the Zone would also assist in permitting development in these locations. It may be of interest to the City, particularly from an administrative perspective, to have these properties identified, and having justification for their exclusion from the Zone provided by those developing the lots. The City may wish to proceed with the establishment of this boundary as it would permit development on lots where minimum by-law provisions can be satisfied.

Either Alternative 2 or 3 shown on **Map 5** would likely be workable solutions the City. Although land use controls would be exercised over a larger area with Alternative 2, demonstrating a portion of the lands in question are developable in accordance with the OCP and the Zoning By-law by the developer would permit the development of that portion of the property. If insufficient land is available then the lot could not be developed.

Alternative 3 takes the most license by excluding areas of the Zone from the proposed policy boundary. The policy boundary has been drawn based on property lines within the Zone which abut or nearly abut the Zone elevation and which have a known elevation or which are known to be developable to City staff. This alternative would likely be the least onerous to administer as it would permit development to occur on lots within the Zone without justification for their development being provided. As the upper limits of the Zone will likely suffer the least from a tsunami, the development of lots in this location, with appropriate structural mitigation such as deflector dikes and raised buildings elevations, the location of the boundary as proposed in Alternative 3 would be appropriate.



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**UMA Engineering Ltd.**

Engineers & Planners  
 British Columbia Alberta Saskatchewan  
 Manitoba Ontario Yukon Territory  
 Northwest Territories

301-344 Yates Street, Victoria, B.C.  
 V8W 3K6 Telephone 361-1004

**CITY OF PORT ALBERNI  
 TSUNAMI INUNDATION ZONE STUDY  
 MAP 5 ALTERNATE POLICY BOUNDARIES**

UMA SCALE: 1:25000 DATE: 08/01/01  
 6337-005-00-01 DEL: REV: 0

The last two alternatives presented require serious consideration with Alternative 2, the more conservative of the two, being preferred by the Project Team. Both alternatives are situated close to the upper limit of the Zone. They would allow for the exclusion of certain lands based on information being provided by the developer, to be checked and verified by City staff, on the suitability of the lands for development. As the lands are located in the upper limit of the Zone the impact of a tsunami would likely be minimal; the water level of a tsunami at this elevation would be reduced and it is likely the speed and the hydrostatic pressure of the wave would have been significantly dissipated by the time it reached these lands. The construction of deflector dikes and adherence to provincial building standards for earthquake resistance would have to be respected in permitting development to occur in the upper reaches of the policy area. It is to be borne in mind that the City will have little control in restricting the continuing operation of existing uses other than regular through existing zoning, property standards and other similar by-laws.

As the policy area will be a well defined area with unique limitations, it appears logical to have the lands within the Tsunami Inundation Zone considered a Special Policy Area in the OCP. It would be appropriate to designate the lands within the proposed Special Policy Area subject to Development Permit policies due to the environmental hazard presented by a tsunami. The Permits in this instance could vary use and density in the Special Policy Area as they relate to health, safety and protection of property from damage.

Appropriate policies will be developed for the area based on the work completed to date by the Project Team, the work completed by other experts in the field, eg., Preuss, Hebenstreit and others and referenced here, input from the public gathered through the questionnaires administered and the public information meeting, and input from City staff and Council. Policies will be reviewed with staff prior to a subsequent information meeting being held to inform the public of policies being considered and to obtain feedback on their applicability.

## **7.5 Recommendation**

The Project Team recommends the selection of Alternative 2 as the upper limit of the Tsunami Inundation Zone policy area. Members of the Team should meet with City Staff to discuss the development of appropriate policies for the Zone. It may also be necessary to consult with staff from the B.C. ministries of Municipal Affairs and Environment prior to finalizing any policy alternatives for the Zone. A schedule for presenting draft policies to Council for review and for a Public Meeting where the draft policies would be presented, should be established.

## BIBLIOGRAPHY

- Anderson, W.A. (1967) Seismic Sea-Wave Warning in Crescent City, California, and Hilo, Hawaii. Research Report #13, The Disaster Research Centre, The Ohio State University, Columbus, Ohio.
- British Columbia Ministry of Environment (1985) Memorandum Re: Lugin Creek Flooding. Victoria, B.C.
- British Columbia Ministry of Environment and Parks (1988) Policy Manual. Victoria, B.C.
- Cave, Dr. Peter W., (1991) Hazard Acceptability Thresholds for Development Approvals by Local Governments. A paper presented to the British Columbia Geologic Hazards Workshop, February 20 & 21, 1991.
- City of Port Alberni (1989) By-law No. 3911 Port Alberni Land Fill Prohibition By-law. Port Alberni, B.C.
- \_\_\_\_\_ (1990) By-law No. 3947 Soil Removal and Deposit Regulation By-law. Port Alberni, B.C.
- \_\_\_\_\_ (1973) By-law 3104 Official Community Plan By-law 1972. Port Alberni, B.C.
- \_\_\_\_\_ (1989 Consolidation) Port Alberni Zoning By-law 1972. Port Alberni, B.C.
- Hebenstreit, G.T., and T.S. Murty (1990) "Tsunami Amplitudes from Local Earthquakes in the Pacific Northwest Region of North America Part 1: The Outer Coast". Marine Geodesy Volume 13, pp. 101-146.
- Marshall Macklin Monahan, McCrae McGill, T.W. Loney and Associates, and Northwest Hydraulic Consultants (1986) Development Management in Tsunami Hazard Areas of Port Alberni. Port Alberni, B.C.
- Murty, T.S. and G.T. Hebenstreit (1990) "Tsunami Amplitudes from Local Earthquakes in the Pacific Northwest Region of North America Part 2:; Strait of Georgia, Juan de Fuca Strait and Puget Sound" Marine Geodesy Volume 13(2) pp. 101-146.
- McCrae McGill Ltd. (1984) Lugin Creek Drainage Design Memorandum. Prepared for the City of Port Alberni and the British Columbia Ministry of Environment.
- Preuss, J. and Gerald T. Hebenstreit (1990) Integrated Hazard Assessment for a Coastal Community: Grays Harbour, Washington. Seattle, Washington.

Provincial Civil Defence (1964) Edition No. 64 Port Alberni Tsunami (?). Victoria, B.C.

Selkregg, L.L., Jane Preuss, et. al. (1984) Earthquake Hazard Mitigation Planning and Policy Implementation, The Alaska Case. Anchorage, Alaska.

Seaconsult Marine Research ltd. (1988) Evaluation of Tsunami Levels Along the British Columbia Coast. Vancouver, B.C. Prepared for the Institute of Ocean Sciences, 9860 West Saanich Road, Sidney, British Columbia.

Taylor Peach & Associates (1991) Port Alberni Shoreline Master Plan. Vancouver, B.C. Prepared for the port Alberni harbour Commission and the City of Port Alberni.

Urban Regional Research (1988) Planning for Risk; Comprehensive Planning for Tsunami Hazard Areas. Seattle, Washington.