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Ministry of Forests, Lands and Natural Resource Operations

With federal funding support through Natural Resources Canada's Regional Adaptation Collaborative Program

Coastal Floodplain Mapping – Guidelines and Specifications

Final Report
June 2011

KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

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KWL File No. 2785.001

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REVISION HISTORY

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1	Feb. 25, 2011	Draft	Draft report issued for MFLNRO review.	EE/DS/JR
2	Mar. 31, 2011	Final Draft	Final Draft issued for MFLNRO review.	EE/DS/JR
3	April 29, 2011	Final	Final report.	EE/DS/JR
4	June 27, 2011	Final	Final report incorporating MFLNRO comments.	EE/DS/JR

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EXECUTIVE SUMMARY

The purpose of coastal floodplain maps is to identify the coastal flood hazard(s) and to provide the technical basis for land use planning and developing floodplain bylaws. Floodplain mapping is an important first step in developing a flood hazard management plan, as floodplain maps identify the flood hazard(s) and provide information on the spatial distribution of Flood Construction Levels (FCLs).

Historically, the main causes of coastal flooding have been due to astronomical (tides) and meteorological factors (storms). Tsunamis also pose a flood hazard to coastal communities in BC. Estimation of the associated flood hazard from tides and storms typically has been predicated on the assumption of a stationary mean sea level. However, information from the global community of scientists and scientific agencies indicates sea level rise (SLR) is already occurring, and is expected to continue for some time. Furthermore, it is anticipated that the rate of sea level rise will increase in the future. As the sea level rises, it poses an increased risk of flooding to coastal communities, and also poses a challenge for local governments in terms of land development planning.

Based on recent work by Ausenco Sandwell (2011b), the coastal Flood Construction Level can be estimated as the sum of the following components:

- the higher high water level tide (HHWLT) elevation;
- an allowance for future sea level rise (SLR), tied to a particular time horizon, such as 2100;
- the estimated storm surge associated with the selected design storm;
- the estimated wave effect associated with the design storm; and
- freeboard.

This report contains guidance on estimation of some of the FCL components identified above (Section 2), as well as a scope of work for more detailed site-specific engineering studies that also must be undertaken in order to derive the FCL (Appendix A). In addition, the report summarizes recommended standards for topographic mapping that also will be required in the production of coastal floodplain maps (Section 3 and Appendix D). As an illustration of the coastal floodplain mapping process, a sample coastal floodplain map and Design Brief have been prepared for the City of Campbell River (Appendix E). In conjunction with this project, a coastal flood hazard web application has been developed that illustrates potential year 2100 floodplain areas in coastal BC based on approximate FCLs (Section 2.6).

Separately, an estimate has been prepared for the cost of preparing coastal floodplain mapping for communities throughout BC.

This report is intended to provide a technically-sound basis for local governments to develop coastal floodplain maps, including an estimation of Flood Construction Levels based upon best mapping and engineering practices. In light of rising sea levels, coastal floodplain maps will also allow local governments to define sea level rise planning zones, which will facilitate land use planning and development decisions.

Section 1

Introduction

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1. INTRODUCTION

1.1 BACKGROUND

The purpose of coastal floodplain maps is to identify coastal flood hazard(s) and to provide the technical basis for land use planning and developing floodplain bylaws. Floodplain mapping is an important first step in developing a flood hazard management plan, as floodplain maps identify flood hazard(s) and can provide information on the spatial distribution of Flood Construction Levels (FCLs).

In 2004, the Province of British Columbia transferred responsibility for all aspects of floodplain management to local governments, and the Provincial Government no longer funded the preparation and maintenance of floodplain maps.

Local governments are responsible for making decisions about local floodplain development practices, including decisions about floodplain bylaws within their communities. The guidelines included within this document are intended to provide a technically-sound basis for local governments to develop coastal floodplain maps, including an estimation of Flood Construction Levels, based upon best mapping and engineering practices. In light of rising sea levels, coastal floodplain maps will also allow local governments to define sea level rise planning zones, which will facilitate land use planning and development decisions.

Floodplain maps are used by local governments to regulate construction by requiring flood-proofing practices and designs to achieve the FCL. Floodplain maps are also invaluable for emergency preparedness, planning and response. In addition to the technical procedures outlined within this document, readers are referred to the BC Flood Hazard Area Land Use Management Guidelines (BCWLAP, 2004).

It is anticipated that local governments will use the guidelines, standards and specifications provided in this report to produce coastal floodplain maps.

1.2 COASTAL FLOOD HAZARDS

The current project specifically addresses floodplain mapping for coastal communities, with a view to updating and formalizing the methods used to produce coastal floodplain maps. Coastal flooding may arise from a number of causes, including:

- severe storm surges (in combination with other factors such as high tide);
- on-going sea level rise; and
- tsunamis.

Historically, the main causes of coastal flooding have been due to astronomical (tides) and meteorological factors (storms). Estimation of the associated flood hazard from tides and storms was predicated on the assumption of a stationary mean sea level. However, information from the global community of scientists and scientific agencies indicates sea level rise (SLR) is already occurring, and is expected to continue for some time. Furthermore, it is anticipated that the rate of sea level rise will increase in the future. As the sea level rises, it poses an increased risk of flooding to coastal communities, and also poses a challenge for local governments in terms of land development planning.

Tsunamis also pose a flood hazard to coastal communities in BC. Tsunamis may be generated by a number of causes, including earthquakes (both distant and nearby) and large landslides (above or below-water). Tsunami wave heights are extremely sensitive to site-specific conditions and therefore detailed modelling is required to determine the potential run-up at a given location.

OTHER HAZARDS

Sea level rise planning will entail the consideration of a number of factors, including establishing setbacks from the estimated future floodplain limit. Although setback distances will typically consider effects such as wave and related splash impacts, consideration also will have to be given to potential coastal erosion. Rising sea levels will both encroach on existing coastal bluffs, potentially resulting in increased erosion rates, and may also expose new steep, erodible terrain to ocean processes.

The intent of the floodplain maps is to locate the position of the future floodplain limits; potential coastal erosion resulting from the position of the floodplain with respect to the surrounding terrain should be considered as part of the planning process to establish setbacks.

1.3 SCOPE OF WORK

Kerr Wood Leidal Associates Limited (KWL) was retained by the Ministry of Forests, Lands and Natural Resource Operations (MFLNRO) to provide a methodology to develop floodplain maps for coastal communities for coastal flood hazards, including sea level rise. This report summarizes guidelines and specifications for coastal floodplain mapping, as per the MFLNRO RFP. The report also includes a sample coastal floodplain map prepared for the City of Campbell River, as well as an associated design brief.

A separate technical memorandum has been prepared to estimate the cost of producing coastal floodplain mapping for communities in BC.

In conjunction with this project, a coastal flood hazard web application has been developed that illustrates potential year 2100 floodplain areas in coastal BC based on approximate FCLs.

1.4 PROJECT TEAM

The project team includes:

- David Sellars, P.Eng., KWL (Project Manager);
- Erica Ellis, M.Sc., P.Geo., KWL (Project Geoscientist);
- John Readshaw, P.Eng., SNC Lavalin (Coastal Engineer); and
- Dave Neufeldt, P.Eng., Terra Remote Sensing Inc. (Mapping Specialist).

Nina Baksh at the City of Campbell River provided spatial data for the sample floodplain mapping.

Dr. Thomas James at NRCAN provided assistance regarding regional uplift and subsidence data.

Finally, Kutalmis Saylam at GeoBC provided background information regarding Provincial LiDAR resources.

Preparation of this document was made possible through funding by Natural Resources Canada's Regional Adaptation Collaborative program and administration by the Fraser Basin Council.

Section 2

Preparation of Floodplain Mapping

2. PREPARATION OF FLOODPLAIN MAPPING

2.1 BASIC STEPS

There are four basic steps that are required to develop coastal floodplain maps:

1. Acquisition of detailed floodplain topography.
2. Coastal engineering analysis to estimate the water level components associated with the design condition, and the associated Flood Construction Levels.
3. Preparation of floodplain maps indicating areas subject to flood hazard(s) and the magnitude of the hazard(s)
4. Preparation of Design Brief to document the analysis.

For communities that are subject to flood hazards due both to coastal processes and riverine processes, floodplain maps will also have to include the river-related flood hazard; guidance for floodplain map production for rivers is provided in the 2004 "*Floodplain Mapping Guidelines and Specifications*" report (Water Management Consultants, 2004).

2.2 DERIVATION OF FLOOD CONSTRUCTION LEVEL (FCL)

BACKGROUND

Historically, in the absence of a detailed coastal engineering analysis, the derivation of a coastal flood construction level (FCL) has been based on the concept of the "natural boundary", which refers to the effect that the ocean has on the land in terms of making a change in the soil and the vegetation. The coastal flood construction level has often been defined simply as the elevation of the natural boundary + 1.5 m. This definition becomes problematic when considering processes such as sea level rise, because the position of a future natural boundary cannot be theoretically determined nor established in the field through observations. In order to deal with this challenge, a new approach has been developed to approximate the position of the natural boundary under a rising sea.

CURRENT APPROACH

The MFLNRO has recently commissioned a study to address the issue of sea level rise and flood hazards, which provides a standard approach to the derivation of the coastal flood construction level that incorporates sea level rise (Ausenco Sandwell, 2011b). The approach sums up a number of contributing factors to yield a total flood construction level.

Based on Ausenco Sandwell (2011b), the coastal FCL is the sum of:

- the higher high water level tide (HHWLT) elevation;
- an allowance for future sea level rise (SLR), tied to a particular time horizon, such as 2100;
- the estimated storm surge associated with the selected design storm;
- the estimated wave effect associated with the design storm; and
- freeboard.

Stated formally:

FCL = HHWLT + SLR + Storm Surge + Wave Effect + Freeboard

Essentially, this approach systematizes the informal, historical approach to derivation of the coastal FCL and allows the coastal FCL to be predicted for future time horizons incorporating estimated sea level rise.

It should be noted that the FCL is both *year* and *design-storm* specific under this formulation, since an explicit planning time-horizon is required to estimate an allowance for sea level rise, and both storm surge and wave effect estimates require a design storm to be specified.

If applied today to derive the current coastal FCL (i.e. by not including an allowance for SLR), the results have been shown, in an example location, to be very similar to the "natural boundary" + 1.5 m (Ausenco Sandwell, 2011b).

Tsunamis have the potential to affect all coastal areas of BC. In some locations, the tsunami run-up may exceed the hazard level calculated from high tide, storm surge and wave effect. In these cases the tsunami elevation would govern the FCL. However design criteria and design parameters for tsunamis for floodplain mapping have not yet been developed.

2.3 DESIGN CRITERIA FOR FCL COMPONENTS

Appendix A presents a detailed summary of the coastal engineering studies that are required to produce coastal floodplain mapping. The design criteria for coastal floodplain mapping have been developed based on consultation of a number of sources, including:

- "*Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use – Draft Policy Discussion Paper*" (Ausenco Sandwell, 2011a).
- "*Guidelines for Management of Coastal Flood Hazard Land Use*" (Ausenco Sandwell,2011b);
- "*Sea Dike Guidelines*" (Ausenco Sandwell, 2011c);

- "*Dike Design and Construction Guide*" (Golder, 2003);
- "*Floodplain Mapping Guidelines and Specifications*" (Water Management Consultants, 2004);
- BC Floodplain Mapping Program (maps and design briefs); and
- Federal Emergency Management Agency reports (FEMA, 2004, 2008)[1].

The following is a listing and explanation of the design criteria associated with the derivation of the FCL presented in Section 2.2. Note that additional information on some of the FCL components is provided in Appendix A.

HIGHER HIGH WATER LARGE TIDE (HHWLT)

In general, high tide is the highest level reached at a place by the water surface in one tidal cycle. Higher high water large tide is a specific parameter, which is the average of the highest high water levels from 18.6 years of data.

The HHWLT data are collected and published by the Canadian Hydrographic Service (CHS) for a number of Reference Stations, and can be determined for a network of Secondary Ports. Figure 2-1 (located at the end of this Section) shows the location of the Reference Stations and Secondary Ports along the BC coast.

The tidal water level data reported by CHS are published relative to the local tide datum, which nominally corresponds to a normal low tide. The "Mean Water Level" published by CHS can be taken to be equal to the 0 m elevation for the Canadian Geodetic Vertical Datum 1928 (CGVD28).

GLOBAL SEA LEVEL RISE

Estimated rates of sea level rise have recently been assessed for British Columbia based on the latest research (Ausenco Sandwell, 2011a). Figure 2-2 below shows the recommended curve for sea level rise policy in BC, which is superimposed on the range of sea level rise projections.

[1] Note: the FEMA documents do not have official citations and are described within the documents as "living" documents that will be updated whenever FEMA determines that changes are appropriate. The documents, which exist as DRAFT documents are presently under review. FEMA will post a new version on the website: http:/www.fema.gov/fhm/gs_main.shtm, as a collection of pdf files.

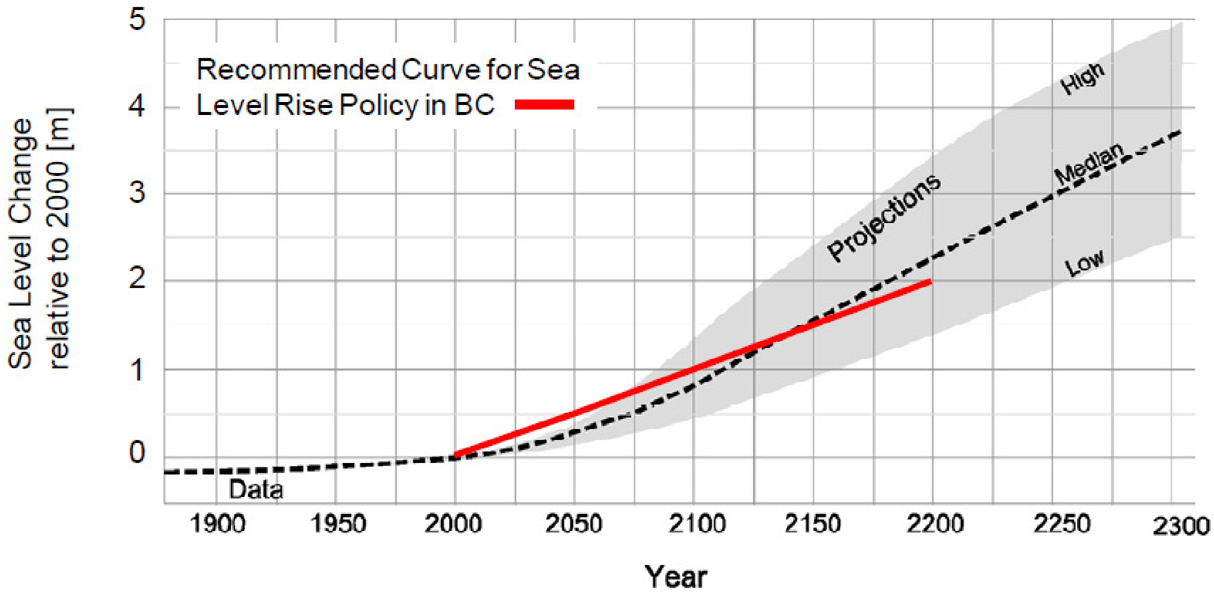


Figure 2-2: Recommended Global Sea Level Rise Curve for Planning and Design in BC (Ausenco Sandwell, 2011a)

Based on this work, the following allowances for sea level rise are suggested:

- 2100 time horizon: 1 m; and
- 2200 time horizon: 2 m.

These values represent an initial precautionary approach and will require regular updates as new data become available, and sea level rise projections are updated. The provincial Inspector of Dikes Office should be consulted for the latest SLR allowances at the time floodplain mapping is undertaken.

REGIONAL ADJUSTMENTS TO GLOBAL SEA LEVEL RISE

Sea level is defined relative to the land surface; therefore, vertical land movements also affect the sea level. The global sea level rise allowance should be adjusted to reflect site-specific conditions such as regional uplift or subsidence of the land surface. Areas where the ground is rising should lower the allowance for sea level rise based on the estimated rate of uplift, and vice versa for areas where the ground surface is falling.

Rates of ground movement are presented for coastal BC in Figure 2-3 (end of Section) based on information presented in Ausenco Sandwell (2011a). As shown in this figure, the land surface along the coast appears to be slowly rising, but there are also areas of local subsidence.

The scientific literature on projected changes to global sea level, and the implications for projections of regional or local sea level, is evolving rapidly. Therefore, similarly to the global sea level rise estimates, the regional adjustment numbers require periodic updates.

Natural Resources Canada[2] should be consulted for the latest uplift/subsidence rates at the time floodplain mapping is undertaken.

STORM SURGE

In addition to the astronomical tidal cycle, sea levels along the BC coast are also affected by storms. Storms affect water levels through many mechanisms, including:

- changes in atmospheric pressures;
- effect of strong winds blowing over the water surface;
- waves; and
- changes in ocean currents or temperature.

The combined effect of all these factors is often called "storm surge". Storm surge effects on water level can be substantial and may last for a period of days. The more severe the storm, the greater the magnitude of the associated surge.

Based on work by Ausenco Sandwell (2011a, c) suggested deep water storm surge magnitudes are summarized in Table 2-1 below for coastal floodplain mapping in British Columbia. Near-shore bathymetry and/or wind may also have an effect on storm surge: "deep water" storm surge refers to storm surge not including local effects (see below for additional discussion of local effects).

Note that in Table 2-1 a more severe condition is suggested for heavily developed areas, such as the Fraser River delta. A given community has the discretion to decide whether the level of development warrants the use of a more severe condition for either planning or design purposes.

Table 2-1: Suggested Deep Water Storm Surge for Coastal Floodplain Mapping

Area	Designated Storm	Design Storm Surge (m)
Metro Vancouver (including Lower Fraser River Dikes, Vancouver Harbour)	1:500 year	1.3
Other highly developed areas such as: Squamish, Victoria, etc.	1:500 year	1.3
West Coast Vancouver Island	1:200 year	1.25
Juan de Fuca Strait	1:200 year	1.25
Georgia Strait	1:200 year	1.25
Central Coast	1:200 year	1.05
North Coast	1:200 year	1.05
Note: Storm surge magnitudes from Ausenco Sandwell (2011c).		

[2] In general, requests for vertical velocities of GPS sites can be made to: Director, Geodetic Survey Division, Natural Resources Canada, 615 Booth St., Ottawa, ON, K1A 0E9 (Phone: 1-613-995-4410, e-mail: information@geod.nrcan.gc.ca).

The results in Table 2-1 are based on preliminary analysis of the available long-term water level records and may be revised in the future. The provincial Inspector of Dikes Office should be consulted for the latest expected deepwater storm surge amplitudes along the BC coast at the time floodplain mapping is undertaken.

Local Effects on Storm Surge

As mentioned above, depending on the location of the floodplain mapping and the details of the bathymetry offshore of the area of concern, the storm surge may be augmented due to local effects. Examples of local effects on storm surge include:

- shoaling of the deepwater storm surge over shallow water; or
- the effect of storm winds blowing over shallow water.

Local coastal engineering studies will be required to adjust the estimated deep-water surge for site-specific conditions.

Procedures for estimating the local storm surge effects are outlined in Section 2.5 and Appendix A.

WAVE EFFECT

Flooding

The presence of breaking waves, during design conditions, along the shoreline of an area being mapped must also be considered. Breaking waves will further increase the depth of water near the shoreline and will result in wave runup and possibly wave overtopping that may result in flooding. The extent of flooding will depend on the terrain located landward of the shoreline.

Procedures for estimating an allowance for wave effect are outlined in Section 2.5 and Appendix A.

Erosion

In addition, over time sea level rise will expose existing shorelines to a persistent wave effect that can result in coastal erosion, which may expose new lands to the risk of flooding.

Anticipated erosion from waves can be addressed by specifying setbacks, which are intended to provide a provision for coastal erosion. In some cases such as coastal bluffs and shorelines protected by non-standard dikes or shoreline defences, special measures may be appropriate.

FREEBOARD

A nominal freeboard is typically added to a Flood Construction Level, which accounts for uncertainties associated with the estimation of the design water level. A nominal freeboard amount of 0.6 m will be included in the coastal FCL.

TSUNAMIS

The Institute of Ocean Sciences (IOS) in Sidney, BC has carried out detailed modelling of large tsunamis generated by Cascadia subduction zone earthquakes west of Vancouver Island. The results of this modelling need to be interpreted for use in coastal floodplain mapping. In addition, research is required to determine the magnitude of potential tsunamis resulting from submarine landslides in the Strait of Georgia. It is recommended that a comprehensive tsunami study be carried out that:

- builds on existing research efforts;
- develops tsunami design criteria and design parameters for floodplain mapping; and
- provides specific numerical values for tsunami elevations for floodplain mapping in communities in coastal British Columbia.

Tsunami design elevations for emergency planning have been established by EMBC throughout coastal BC (Appendix B), which, when combined with topographic mapping, indicate areas for evacuation planning. These tsunami evacuation planning areas will be shown on the floodplain maps.

SUMMARY

A summary of the components of the FCL is provided in Table 2-2 below, along with the appropriate source for the required data.

Table 2-2: Summary of FCL Components

FCL Component	Data Source
Higher High Water Large Tide (HHWLT)	▪ CHS Reference Stations and Secondary Ports. ▪ See Figure 2-1 for locations.
Sea Level Rise (SLR)	▪ Global SLR allowance: 1 m (2100), 2 m (2200). ▪ Adjust for regional ground movement. ▪ Contact Inspector of Dikes for latest SLR allowances. ▪ Contact Natural Resources Canada for rates of ground movement.
Storm Surge	▪ See Table 2-1 for deep water surge estimates based on designated storm/location. ▪ Coastal engineering study required to estimate site-specific "local" effects.

FCL Component	Data Source
Wave Effect	▪ Coastal engineering study required to estimate wave effect ▪ Wind/wave analysis must be consistent with the designated storm adopted for storm surge.
Freeboard	▪ Nominal freeboard = 0.6 m.
Tsunami	▪ Evacuation planning areas based on PEP (Appendix B). ▪ A comprehensive study is required to establish tsunami elevations for floodplain mapping.

2.4 MAPPING COMPONENTS

The purpose of the coastal floodplain maps is to display the extent of current and future floodplain limits, as well as to provide Flood Construction Levels. By incorporating future sea level rise, planning areas can be defined based on the estimated position of the future floodplain.

The coastal floodplain maps will contain the following components:

- FCLs for 2010, 2100 and 2200;
- Floodplain limits for 2010, 2100 and 2200;
- Sea Level Rise (SLR) planning areas for 2100 and 2200; and
- Tsunami evacuation planning area.

FCLs will be estimated based on the design criteria discussed in Section 2.3. The 2010 floodplain limit will be estimated to show the current position of the floodplain following the same procedure as outlined in Section 2.3 but without including an allowance for sea level rise.

SLR planning zones extend to cover the area between the three floodplain limits: the 2100 SLR planning zone extends from mean sea level to the 2100 floodplain limit, and the 2200 SLR planning zone extends from the 2100 floodplain limit to the 2200 floodplain limit.

Figure 2-4 shows a sketch of the expected mapping components. Appendix E contains sample coastal floodplain mapping prepared for the town of Campbell River.

MAP NOTATIONS

Coastal floodplain maps must include the notations listed in Table 2-3 below.

Table 2-3: Coastal Floodplain Map Notations

No.	Map Notation
1.	Under the provisions of the Flood Hazard Statutes Amendment Act, 2003 (Bill 56), local governments have the role and responsibility for making decisions about local floodplain development practices, including decisions about floodplain bylaws within their communities. Information on floodplain management guidelines can be found in the BC Flood Hazard Area Land Use Management Guidelines.
2.	Users must note the dates of base mapping, aerial photography, ground or bathymetric surveys and issue of mapping relevant to dates of development in the map area. Subsequent developments or changes within the floodplain or channel will affect flood levels and render site-specific map information obsolete.
3.	The accuracy of the location of a floodplain boundary as shown on this map is limited by the base topography. It is generally assumed to be plus or minus one-half the increment of the ground contours.
4.	The floodplain limits are not established on the ground by legal survey. A site survey is required to reconcile property location, ground elevations and designated flood level information. Building and floodproofing elevations should be based on field survey and established benchmarks.
5.	Flooding may still occur outside the defined floodplain boundary and the local government does not assume any liability by reason of the failure to delineate flood areas on this map.
6.	The required or recommended setback of buildings from the natural boundaries of watercourses to allow for the passage of floodwaters and possible bank erosion is not shown. This information is available from the local government. In addition, site-specific setbacks from the floodplain limit must be considered.
7.	Flood construction level is based on a global sea level rise of [*insert number*] m by [*insert year*]. May need to be revised after [*insert year*].

2.5 SCOPE OF WORK FOR COASTAL ENGINEERING STUDIES

Appendix A contains a detailed summary of the coastal engineering studies that are required to produce coastal floodplain mapping. The following is a summary of the general scope of work for coastal engineering studies to produce coastal floodplain mapping.

Coastal engineering studies are required to estimate some of the FCL components. As presented in Section 2.2, the FCL is the sum of the following:

- the higher high water level tide (HHWLT) elevation;
- an allowance for future sea level rise (SLR), tied to a particular time horizon, such as 2100;
- the estimated storm surge associated with the selected design storm;
- the estimated wave effect associated with the design storm; and
- freeboard.

Some of these components are specified, such as the global allowance for future sea level rise, and freeboard. Other components may be estimated in a straightforward manner, such as the HHWLT. However, estimation of storm surge and an allowance for wave effect requires a site-specific coastal engineering study.

The coastal engineering study to estimate storm surge and the wave effect will have to consider the general character of the area (i.e. open and exposed to waves, or more sheltered and protected).

In addition, the geometry and substrate of the nearshore area is also important, as this affects how storms and waves propagate onto the adjacent shore. Different nearshore areas such as steep rocky shorelines, estuaries, and shoreline protected by man-made structures (e.g. seawalls, spits or groynes), may have very different interactions with storms and associated waves. If the nearshore area is not homogeneous, it may be important to differentiate between different zones, such as estuaries vs. steep rocky shorelines, as the predicted wave effect can vary greatly between nearshore types.

The coastal engineering study also must define the “Designated Storm” that will be used for the estimation of wave effect. The Designated Storm is associated with specific wind speeds and a sea state, which must be consistent with the estimated deep water storm surge.

The combination of the above factors will yield an estimated FCL that may vary depending on the character of the nearshore zone(s) to be mapped.

As an example, preliminary 2100 FCL values for various locations in coastal BC are summarized in Table 2-4 below. Note that these values have been derived assuming a natural gravel-pebble nearshore area. The wave effect will increase on steeper shorelines.

Further details on the scope of work of the coastal engineering studies are provided in Appendix A.

Table 2-4: Preliminary 2100 FCL Estimates for Various Locations (Ausenco Sandwell, 2011b)

FCL Component	Fraser River Delta	Vancouver Harbour	Squamish River Delta	East Vancouver Island	West Vancouver Island	Central and North Coast
Global SLR (2100)	1 m					
Regional Adjustment	+0.21 m	0 m	0 m	-0.17 m	-0.27 m	-0.22 m
HHWLT	2.0 m	1.9 m	2.05 m	1.6 m	2.0 m	3.8 m
Storm Surge	1.7 m	1.4 m	1.3 m	1.3 m	1.3 m	1.7 m
Wave Effect	0.65 m	0.65 m	0.65 m	0.65 m	0.65 m	0.65 m
Freeboard	0.6 m	0.6 m	0.6 m	0.6 m	0.6 m	0.6 m
FCL	**6.2 m**	**5.6 m**	**5.6 m**	**5.0 m**	**5.3 m**	**7.5 m**

Notes:
1. Reproduced from Ausenco Sandwell (2011b), Table 3-2.
2. Regional adjustment based on current values. Vancouver and Squamish assumed to be neutral.
3. HHWLT = Higher High Water Large Tide. Varies by site and location in BC.
4. Storm surge allowance includes allowances for local wind setup.
5. Wave effect allowance assumes runup on natural gravel-pebble shoreline.
6. FCLs are elevations relative to Canadian Vertical Geodetic Datum.

2.6 COASTAL FLOOD HAZARD WEB APPLICATION

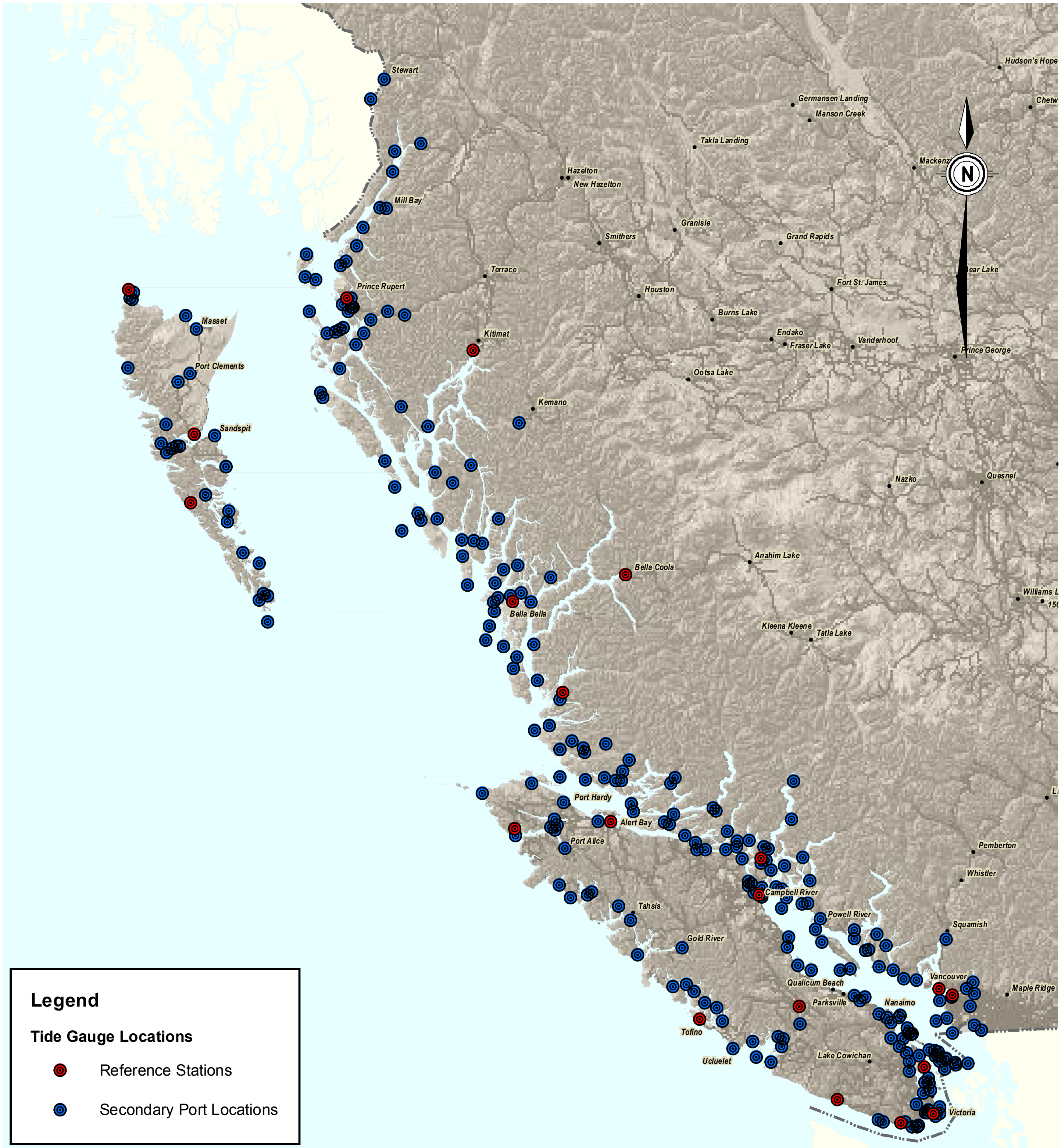
A web-based coastal flood hazard screening tool has been developed for coastal areas in BC (http://68.179.65.105/coastalfloodmapping/)[3] as an additional task associated with this project. The website displays potential year 2100 floodplain areas based on approximate FCLs (incorporating sea level rise). Note that floodplain areas have not been ground proofed, verified or studied to confirm their exact location.

The year 2100 FCLs used in the hazard screening website are approximate and intended only to provide general guidance. The intent of the coastal flood hazard screening website is to only highlight areas that may benefit from development of coastal floodplain maps.

FCLs for the web application were developed through a high-level analysis, considering coastal region and type. A nominal allowance has been made for wave effect; the actual wave effect may differ greatly from the allowance depending on the location. In addition, the presence (or absence) of dikes or other flood protection works has not been factored into the analysis.

[3] As of the writing of this report, the website will be maintained at this URL until April 2012.

As discussed in this report, additional comprehensive site investigations, data collection and coastal engineering analysis is required to establish the actual year 2100 FCL at any given location.



Note:
Higher High Water Large Tide and Mean Water Levels for each Reference Station and Secondary Port Locations are available in "*Canadian Tide and Current Tables – Volumes 5, 6 and 7*", published annually by Fisheries and Oceans Canada, Catalogue No. FS 74. The most current issue should be consulted.

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Coastal Floodplain Mapping Guidelines and Specifications

Project No.	Date
2785-001	April, 2011

100 0 100
Scale in Kilometers

Reference Station and Secondary Port Locations

Figure 2-1

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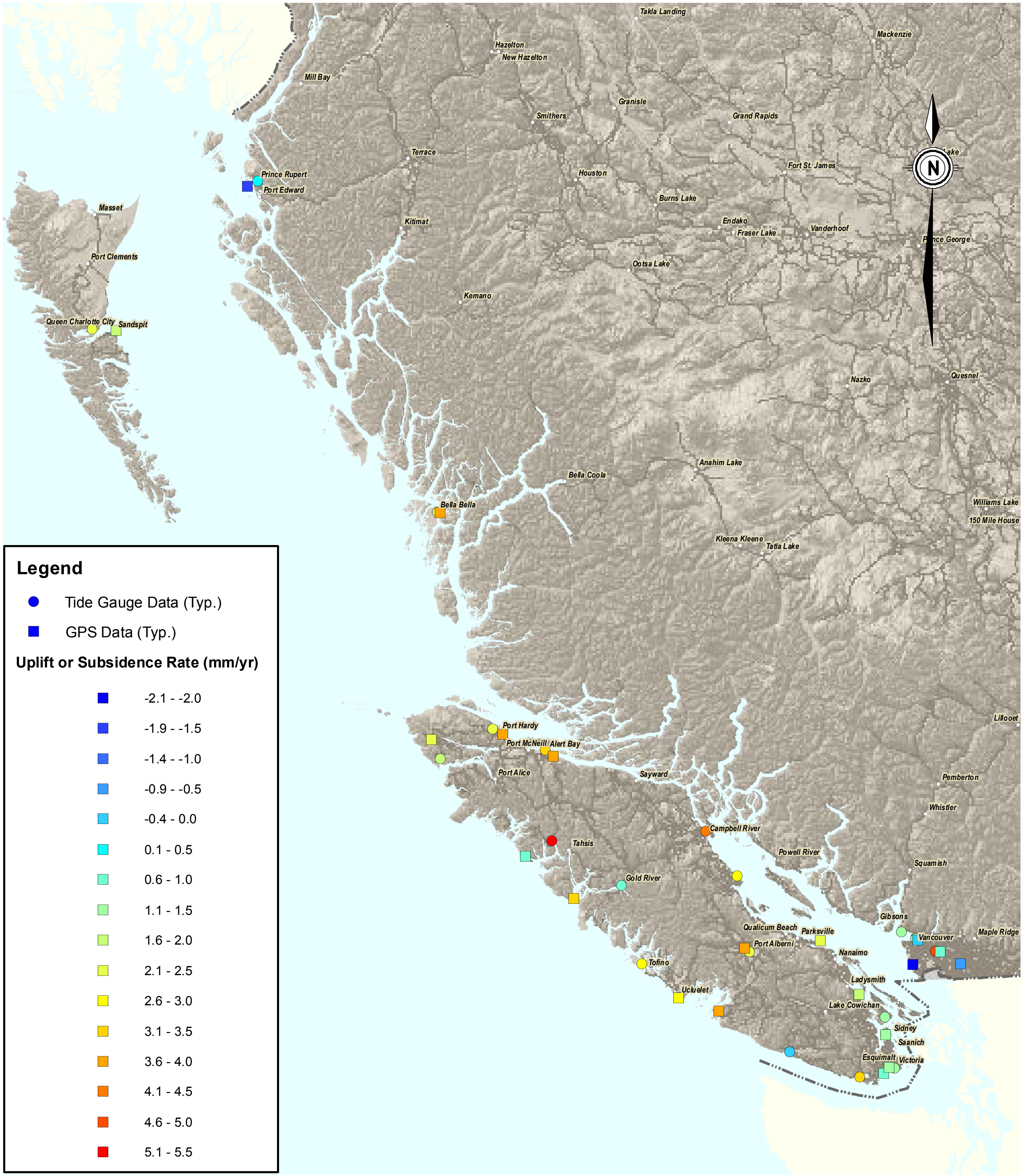
Author: EEllis



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Author: EEllis

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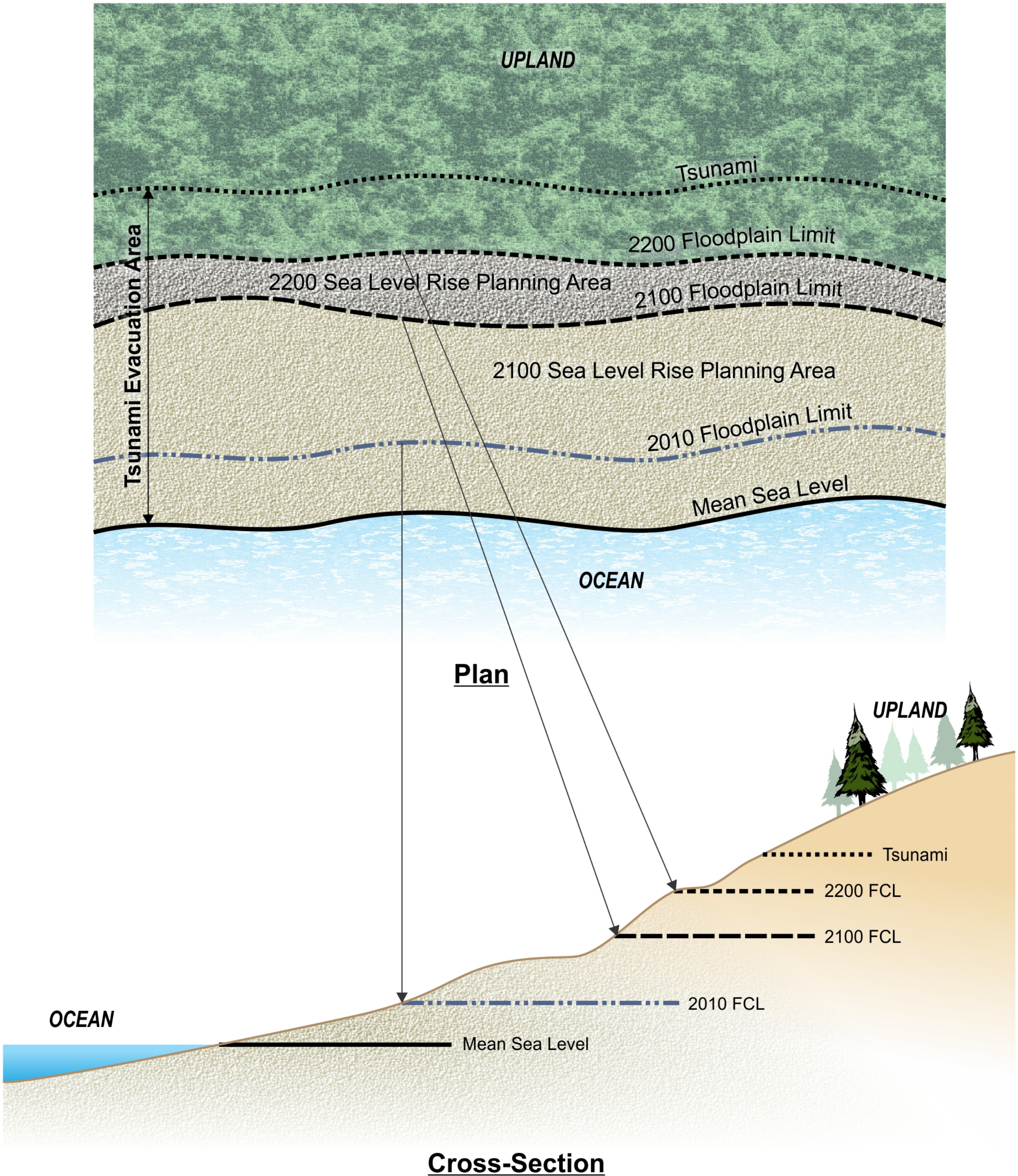
Coastal Floodplain Mapping Guidelines and Specifications

Project No.	Date
2785-001	April, 2011

100 0 100
Scale in Kilometers

Uplift and Subsidence Rates for Coastal BC

Figure 2-3



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Project No.	Date
2785-001	April 2011

Not to Scale

Sketch of Mapping Components

Figure 2-4

Section 3

Topographic Mapping

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3. TOPOGRAPHIC MAPPING

3.1 STANDARDS

There are no published standards specifically for floodplain mapping. Existing floodplain mapping in BC prepared under the Canada/BC Floodplain Mapping Agreement (1987) is typically at a scale of 1:5,000 with 1 m contours. Some interim floodplain designations were made using 2 m contours.

Federal guidelines, Environment Canada (1976) imply an optimum mapping scale of 1:2,000 with 0.5 m contours. Federal Emergency Management Agency criteria (FEMA, 2003) are 2 ft (0.6 m) contours for floodplains. The required digital elevation model (DEM) point spacing to achieve this would be about 2 m. A 2007 report by the National Research Council's Committee on Floodplain Mapping Technologies identified the capability of LiDAR to achieve 1 ft equivalent contour accuracy in very flat coastal or inland floodplains (National Research Council, 2007).

The following criteria are proposed for floodplain mapping based on these considerations. The accuracy standards to achieve these criteria are described in Section 3.3.

STANDARDS FOR NEW TOPOGRAPHIC MAPPING

Criteria for new mapping are summarized in the following table.

Table 3-1: Standards for New Topographic Mapping

Map Property	Criterion
Scale	1:10,000 minimum (1:5,000 preferred)
Contour interval	0.5 m minimum (0.3 m preferred)
DEM point spacing	10 m minimum (1.5 m preferred) Alternatively, use a breakline to enhance terrain features in TIN.
Accuracy	Sufficient to define the floodplain boundary and consistent with the standard accuracy implied by 0.5 m contours
Horizontal Datum	North American Datum 1983 (NAD83)
Vertical Datum	Canadian Geodetic Vertical Datum 1928, mean sea level (CGVD28)
Supplementary	GPS surveys of road centrelines if DEM does not adequately define

MINIMUM STANDARDS FOR USE OF EXISTING TOPOGRAPHIC MAPPING

For municipalities that have existing mapping and may wish to use it for floodplain mapping, proposed criteria are summarized in Table 3-2 below.

Table 3-2: Standards for Use of Existing Topographic Mapping

Map Property	Criterion
Scale	1:10,000 minimum
Contour interval	1.0 m
DEM point spacing	10 m minimum
Accuracy	Consistent with the standard accuracy implied by 1.0 m contours
Supplementary	Centreline surveys of roads and other embankments.

3.2 MAP DATA COMPONENTS

Floodplain map data shall be comprised of two basic data components:

1. **Planimetric data**: showing features such as buildings, roads, bridges and any major structures that will impact the flood analysis including related elevation data. This data may be provided through standard base maps or through digital orthomosaics.

2. **Topographic data**: comprising DEM, contours, and breaklines. Where the DEM data meets the preferred 1.5 m point spacing as set forth in Table 3-1, breaklines shall not be required as they will be adequately defined by the DEM points.

For certain project areas, new data may only be required for either the topographic or elevation components if existing data is available that meets the standards in Section 3.1. For example, topographic mapping may exist that sufficiently defines the location of features affecting the flood analysis but the mapping was only compiled as a 2D dataset. If there has not been significant development in the area only the elevation data is required for new mapping.

RECONCILING DIFFERENT DATA SOURCES

In cases where only elevation or topographic data are being acquired, precautions must be taken through appropriate checks to ensure there are no systematic biases between the two map datasets. Coordinates of a minimum of 10 identifiable points distributed throughout the project area shall be compared and the results should be normally distributed about a zero mean value with 95% of the points being within the accuracy specifications set forth below.

3.3 MAP ACCURACY

DERIVATION

Map accuracy is determined by calculation of an RMSE (root-mean-square-error) and then converting the RMSE into an accuracy at a specified confidence level. A confidence level of 95% shall be the standard used for floodplain mapping. Further details on calculation of the RMSE are provided in Appendix D.

Note that a TIN dataset, derived from the mass points and breaklines used to create the DEM, preserves more detail with respect to slope and aspect than the regular gridded DEM and therefore provides a better method of assessing the accuracy of the elevation data.

Elevation data such as DEM and contours do not typically contain well-defined points. The accuracy for these datasets is established based only on the vertical component.

STANDARD

Horizontal and vertical standards for the required accuracy of new mapping are summarized in the following table.

Table 3-3: Horizontal and Vertical Accuracy Standard for New Mapping

Dimension	Standard
Vertical (95%)	50% of Contour Interval (see Table 3-1)
Horizontal (95%)	Class 1: ▪ 1:10,000 scale: 6.1 m at 95% ▪ 1:5,000 scale: 3.05 m at 95% ▪ 1:2,000 scale: 1.25 m at 95%
Note: 1. Source for accuracy standard: ASPRS LIDAR Guidelines: Horizontal Accuracy Reporting (ASPRS).	

A minimum of 20 check points must be used to establish the accuracy of a dataset and evaluate whether it complies with the standard. In general the points should be well distributed throughout the map area.

3.4 DATUM AND MAP PROJECTION

VERTICAL DATUM

Unless otherwise specified the vertical datum will be mean sea level as established by the Geodetic Survey of Canada[4].

Since the objective of the mapping is flood analysis, deriving the correct orthometric height of the map data is critical. Elevation data derived from GPS, however, is based on a reference ellipsoid. It is, therefore, essential for map data acquisition programs that are

[4] Note that a new vertical datum is being developed for Canada with an anticipated implementation date of 2013. Further details may be obtained from Natural Resources Canada (http://www.geod.nrcan.gc.ca/hm/index_e.php).

GPS-based to also include a plan for recovering the vertical datum and modelling the geoidal corrections to obtain orthometric heights of the map data within project area(s).

HORIZONTAL DATUM AND PROJECTION

Floodplain map data shall be delivered on the Universal Transverse Mercator (UTM) Projection based on the 1983 North American Datum, unless the location is near a UTM Zone Boundary.

An Albers projection is recommended over a UTM projection in situations where a floodplain mapping project would cover a large area that is known to be near a UTM zone boundary (e.g. If a region to be mapped was in or near both zones 8 and 9, or 9 and 10). In this case, there are distortions at the UTM zone boundaries that could cause problems. These distortions would be avoided by using an Albers projection.

3.5 MAPPING TECHNOLOGIES

There are a number of technologies that provide the capability to acquire the DEM data necessary for floodplain mapping. The usefulness of the data from these technologies with respect to floodplain mapping applications varies significantly as do the costs and accuracies. Appendix C provides a description of the technologies discussed below (ground survey, photogrammetry, and LIDAR).

COMPARISON OF TECHNOLOGIES

Mapping technologies suited to floodplain mapping include:

- ground survey;
- photogrammetry; and
- LIDAR.

For most areas, photogrammetry and LIDAR or LIDAR/digital imagery provide the best alternatives for floodplain mapping. The main disadvantage of photogrammetry compared to LIDAR is that there is no ability to determine ground elevations beneath thick vegetation cover. However, photogrammetry offers the ability to concentrate data collection in areas of rapidly varying terrain, so as to better define breaklines.

In general, it is unlikely that a community would opt for photogrammetry over LIDAR except in cases where the air photographs (at a suitable scale) have already been collected, in which case there may be a cost savings.

Ground surveys provide an important auxiliary role. Since they provide the highest accuracy, they should be used as means of monitoring the accuracy of the results received from the use of other technologies. Further, specific site studies in highly critical areas may benefit from the increased accuracy that may be achieved through a ground survey.

Ground surveys are also required to establish the ground and floodproofing elevation at a specific site where the FCL has been derived from a floodplain map. The floodplain map topography should not be relied upon for establishing specific building elevations.

3.6 SPECIFICATIONS

A draft Provincial specification exists for LIDAR survey, and was reviewed for this project. The specifications for LIDAR surveys for acquisition of flood mapping data are set forth in Appendix D.

Should photogrammetry be used to acquire floodplain map data, the specifications to apply are those as set forth by BC Base Mapping for the scales specified. These include the following:

- Specifications for Aerial Photography (April 2008)
- Specifications for Aerial Photographic Products (April 2008)
- Specifications for Aerial Photography Database Files (April 2008)
- Specifications for Digital Aerial Photographic Images (April 2008)
- Specifications for Aerial Photographic Indexing (April 2008)

As the specifications are updated on an as required basis, the latest applicable specifications should be acquired from the BC Base Mapping website (http://geobc.gov.bc.ca/) at the time LIDAR is commissioned.

Section 4

Summary

4. SUMMARY

The production of coastal floodplain maps involves two main tasks:

- estimation of the Flood Construction Level; and
- representation of the Flood Construction Level on a topographic map.

Preceding sections of this report outline a proposed methodology to estimate Flood Construction Levels that incorporate anticipated sea level rise. Certain components of the FCL are anticipated to be relatively straightforward to estimate. However, others will require site-specific engineering studies, as identified in this report and the accompanying appendices.

In addition, the report also provides recommended standards for topographic mapping that will be used to create coastal floodplain maps.

4.1 REPORT SUBMISSION

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Original signed by:

John Readshaw, P.Eng.
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Reviewed by:

Original signed and sealed by:

David Sellars, P.Eng.
Senior Water Resources Engineer

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References

ASPRS. ASPRS LIDAR Guidelines: Horizontal Accuracy Reporting. 47 pp + appendices.

Ausenco Sandwell, 2011a. Draft Policy Discussion Paper. Report prepared for BC Ministry of Environment. 45 pp + appendices.

Ausenco Sandwell, 2011b. Guidelines for Management of Coastal Flood Hazard Land Use. Report prepared for BC Ministry of Environment. 25 pp + appendices.

Ausenco Sandwell, 2011c. Sea Dike Guidelines. Report prepared for BC Ministry of Environment. 15 pp + appendices.

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Environment Canada, 1976. Survey and Mapping Procedures for Floodplain Delineation. Water Planning and Management Branch, Inland Waters Directorate, Environmental Management Services, Ottawa, ON.

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FEMA.[5] 2004. Final Draft Guidelines for Coastal Flood Hazard Analysis and Mapping for the Pacific Coast of the United States. Available online at: http:/www.fema.gov/fhm/gs_main.shtm.

FEMA.[5] 2008. Guidance for Coastal Flood Hazard Analyses and Mapping in Sheltered Waters – Technical Memorandum. Available online at http:/www.fema.gov/fhm/gs_main.shtm.

National Research Council, 2007. Report in Brief: Elevation Data for Floodplain Mapping. 4 pp. http://dels.nas.edu/resources/static-assets/materials-based-on-reports/reports-in-brief/floodplain_mapping_final.pdf

[5] Note: the FEMA documents do not have official citations and are described within the documents as "living" documents that will be updated whenever FEMA determines that changes are appropriate. The documents, which exist as DRAFT documents are presently under review. FEMA will post a new version on the website: http:/www.fema.gov/fhm/gs_main.shtm, as a collection of .pdf files.

Glossary and Acronyms

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Glossary & Acronyms

CGVD28: Canadian Geodetic Vertical Datum.

DEM: Digital Elevation Model.

EMBC: Emergency Management BC.

FCL: Flood Construction Level.

The elevation established for habitable buildings at which to set the underside of a wooden floor system or top of a concrete slab. In the case of a manufactured home, the ground level of top of concrete or asphalt pad, on which it is located, shall be equal to or higher than the FCL.

FEMA: Federal Emergency Management Agency (United States).

HHWLT: Higher High Water Large Tide.

As defined by the Canadian Hydrographic Service, which collects the data, the HHWLT is the average of the highest high waters, one from each of 19 years of predictions.

LIDAR: Light Detection and Ranging.

A system, typically airborne, made up of three core components: (1) a scanning laser, (2) a positioning system, and (3) an attitude system. The system collects a set of measurements (laser range, x, y, and z coordinates of the airframe, and roll, pitch, and heading), which together allow the three-dimensional coordinates of the ground point to be computed.

MFLNRO: BC Ministry of Forests, Lands and Natural Resource Operations.

NAD83: North American Datum of 1983.

The North American Datum is the official horizontal datum used for the primary geodetic network in North America.

RMSE: Root Mean Square Error.

SLR: Sea Level Rise.

TIN: Triangulated Irregular Network.

Appendix A

Scope of Work for Site-Specific Coastal Engineering Studies

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APPENDIX A: SCOPE OF WORK FOR COASTAL ENGINEERING

1.1 INTRODUCTION

This Appendix provides a summary of the coastal engineering investigations that are required to create new coastal floodplain maps for B.C. coastal waters. The summary is intended help local governments, land-use managers approving officers and service professionals request, review or propose engineering services to be provided in conjunction with the preparation of new coastal floodplain maps. This summary is intended as a guideline and specific projects may require or justify site specific investigations or assessments. Qualified professionals with specialist expertise must be involved and retained to define specific project approaches, scope or approval.

The scope outlined in this Appendix is described in Section 2.5 of the main document and this Appendix provides guidance for Tasks 5 through 11 of the following overall scope (Table A-1). Guidance for Tasks 1 through 4 is provided in Section 2.3 of the main document.

Table A-1: Required Tasks to Develop Coastal Floodplain Mapping

Task	Description
1	Select the Design Standard for the area to be mapped (e.g. see Table 2-1, main document).
2	Define the elevation of HHWLT for the area to be mapped.
3	Define the regional sea level rise for the area to be mapped.
4	Define the deepwater storm surge for the Design Standard (Table 2-1, main document).
5	Identify the general character of the area.
6	Define the required particulars of the Designated Storm that meets the Design Standard (i.e. wind speed and direction during the storm, and seastate at the project specific shoreline).
7	Define the general character of the near-shore bathymetry and the shoreline of the area to be mapped and identify any subsections of the area to be mapped that need to be assessed.
8	Define the Designated Flood Level (DFL) for each of the subsections identified in Task 7.
9	Define the expected wave effects for each of the subsections identified in Task 7.
10	Verify that the shoreline considered in Steps 8 and 9 at the elevation of the DFL plus expected wave effects is consistent with available mapping and repeat Tasks 8 and 9 as necessary.
11	Define the appropriate freeboard and the resulting FCL for each subsection of shoreline.

1.2 TASK 5: GENERAL CHARACTER OF THE AREA

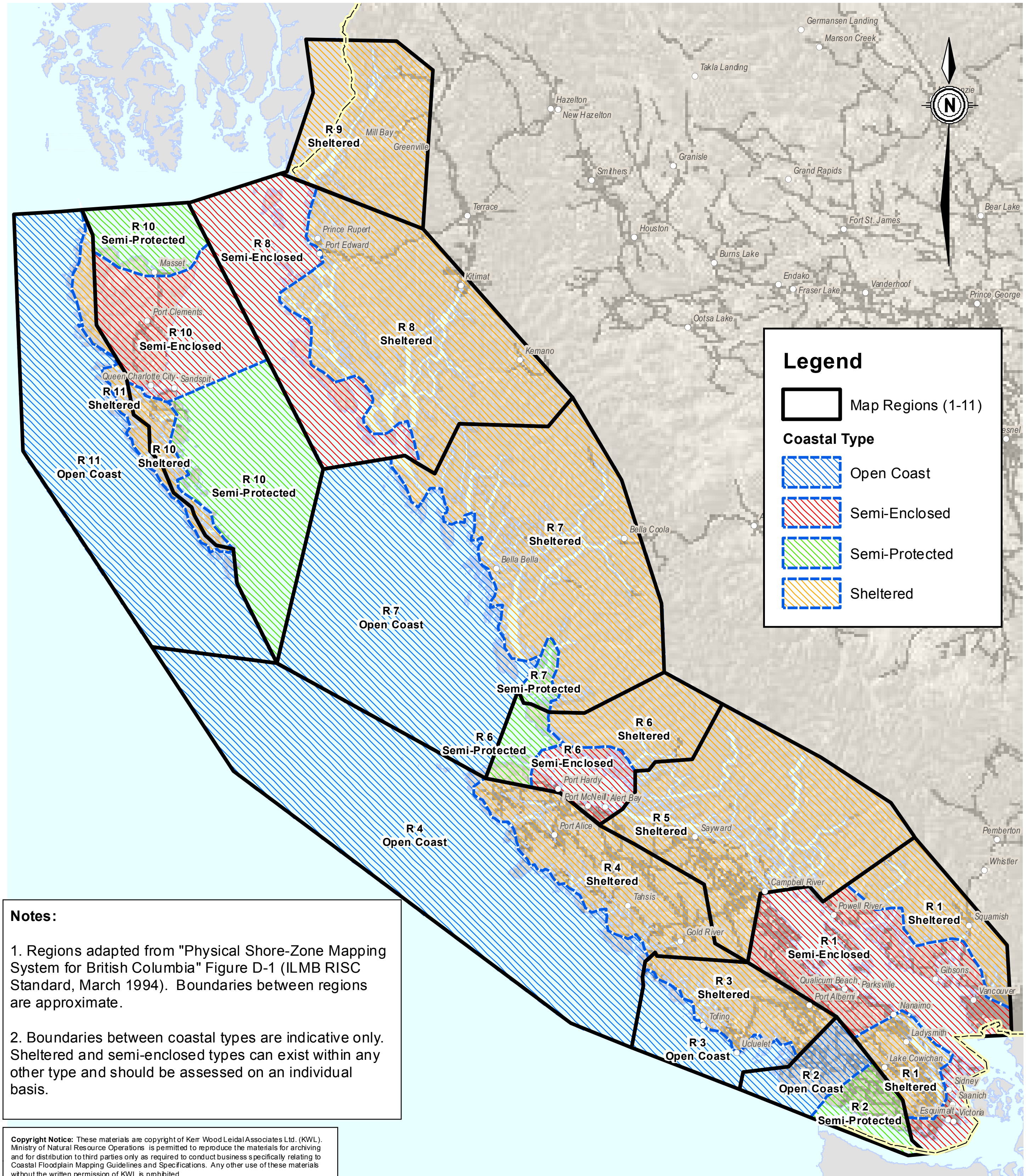
The approach required to provide the necessary coastal engineering input will depend on the general exposure of the area to be mapped. These areas can be grouped into four basic classes:

a. Open Coast;
b. Semi Protected Coast;
c. Semi Enclosed Coast; and
d. Sheltered Coast.

Initial guidance for assignment of the basic class is provided in FigureA-1 as follows:

a. Open Coast: Areas, outer portion of 2, 3, 4, 7, and 11;
b. Semi Protected Coast: 2, 6, and 10;
c. Semi Enclosed Coast: 1, parts of 6, 8, and parts of 10; and
d. Sheltered Coast: 5, 9, inshore portions of 3, 4, 6, 7, 8, 10, and 11.

This guidance is general in character and for a specific site and on specific examination a short portion of any shoreline can be reclassified.



Notes:

1. Regions adapted from "Physical Shore-Zone Mapping System for British Columbia" Figure D-1 (ILMB RISC Standard, March 1994). Boundaries between regions are approximate.

2. Boundaries between coastal types are indicative only. Sheltered and semi-enclosed types can exist within any other type and should be assessed on an individual basis.

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Project No.	Date
2785-001	May 2011

50 0 50 Kilometers
1:4,000,000

BC Coastal Regions and Types

Figure A-1

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Author: EEllis

1.3 TASK 6: DEFINITION OF THE DESIGNATED STORM

The Designated Storm is used to estimate local effects on storm surge, as well as wave effects. Definition of the Designated Storm and its required particulars, including wind speed and direction during the storm and seastate at the project specific shoreline, requires long-term summaries of the wind and wave climates. Ideally, 30 or more years of reliable data are required but in practical terms data of this duration does not exist, especially for semi-protected, semi-enclosed and sheltered areas. Sources of data and approaches are outlined below.

In B.C. coastal waters, the Designated Storm is a storm that can be associated with the deepwater storm surge described in Section 2.3 of the main body of this report.

a. Open Coast Areas:

Wind and wave climate data are available for these areas form the **GFNEPAC: Canadian Waters Archive**, which is a special Canadian Waters Archive of the GROW (Global Reanalysis of Ocean Wave) North East Pacific Oceanweather hindcast product. The GFNEPAC product was developed for an approximately 35 km x 35 km grid covering the entire North East Pacific, east of the International Dateline and north of the Equator. Results at grid points adjacent to and in Canadian waters are contained in this archive. The data presently cover the 30 year period 1980-2009. The archived grid point coverage is shown in Figure A- and the archived data is available from ISDM and MSC Climate Services.

In most cases the GFNEPAC wave data will need to be transformed to the particular shoreline(s) of interest.

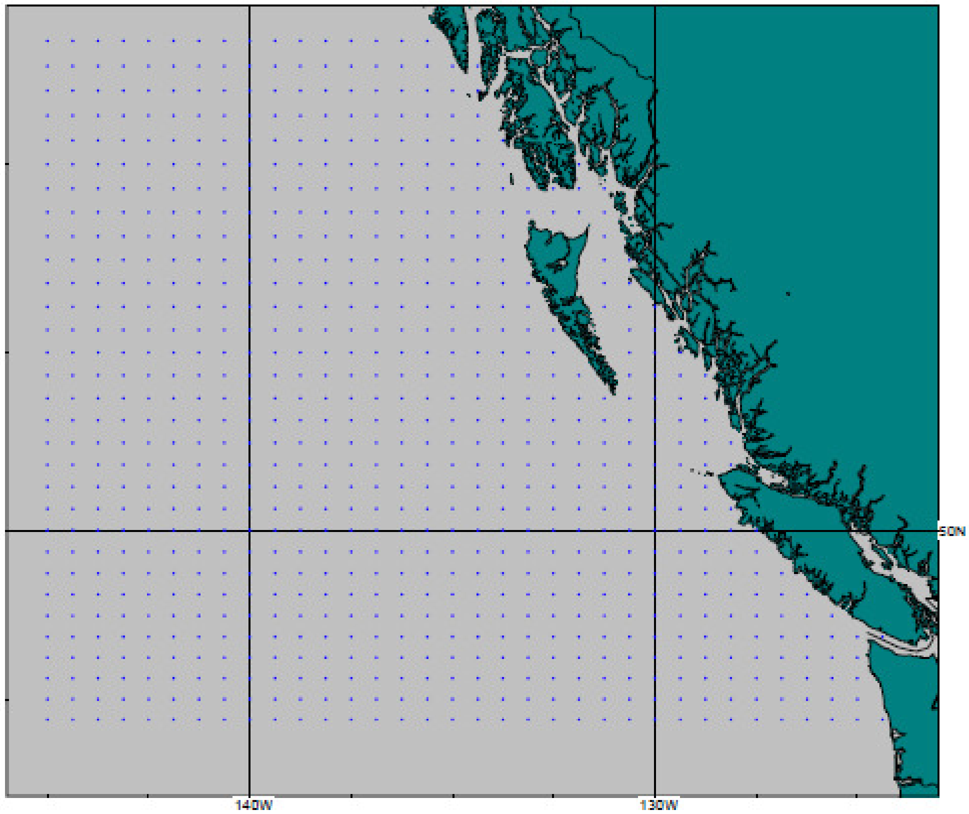

Figure A-2: Grid Point Map for GFNEPAC Canadian Waters
source: Oceanweather Inc.

b. Semi-Protected Coastlines:

Along semi-protected coastlines it is likely that both the open coast winds and waves will be modified by regional scale effects such as orographic forcing or re-direction of winds and by sheltering or modification of the open coast wave climate as it propagates into the specific area of interest. The local regionally modified winds may also generate seastates that combine with or override the open coast wave climate.

Coastal engineering investigations and judgment will be required in these situations. Rational guidance can be obtained from the use of regional scale 2D wave propagation and wave transformation models. The choice of appropriate wave transformation models depends upon two main considerations:

- the complexity of the bathymetry in the region; and
- the manner in which the model results will be used to estimate the conditions in the breaker zone(s) along the shore and the supporting shoreline related calculations such as wave setup, wave run-up and shoreline or coastal erosion.

In specific cases regional scale 2D models may need to include wave generation to produce realistic results.

The scope of work and the supporting documentation or reports should outline study specific factors leading to the choice of the model.

c. Semi-Enclosed Coastlines:

Along semi-enclosed coastlines it is most likely that the overwater wind fields are highly influenced by the topography and related orographic effects of the coastline. On the other hand it is unlikely that wave climate from the open coast propagates into the areas of interest. For specific projects in these areas local wave generation and wave propagation and transformation modeling will likely need to be undertaken.

In some B.C. waters (Strait of Georgia and Hecate Strait) 15 to 10 years of recorded wind and wave data are available; however the recording stations tend to be located in mid-strait and in deepwater and the wave data measured at the available stations are non-directional. Assumptions are required to use the recorded data at any particular shoreline and use of these data will require regional scale 2D models including definition of the 2D wind fields and the detailed bathymetry data to provide reliable results.

In semi-enclosed bodies of water it is likely that regional scale modeling will be warranted that encompass several areas of interest.

In the short-term, until regional scale modeling is completed and the results archived in a similar fashion to the GFNEPAC datasets described above, representative information can be obtained by judicious use of:

- 1D and 2D wave generation, propagation and transformation models;
- long-term recorded wind data from government or equivalent wind recording stations, including any necessary correction or adjustment for the location of the recording station;
- 2D wind models to assist in defining local or regional scale wind forcing over the open water between the recording stations and the shorelines of interest; and
- available recorded wave data, adjusted and interpreted to account for the limitations outlined above.

The scope of work and the supporting documentation or reports should outline study specific factors leading to the choice of the approach and the models.

d. Sheltered Coastlines:

In the sheltered coastlines of BC identified above both the wind and the wave climate is likely defined by local factors including the orientation of the open water body adjacent to the coastline of interest, the degree of topographic related orographic effects on the winds and the local shoreline bathymetry.

Nearby recorded wind data from long-term government or equivalent wind recording stations, including any necessary correction or adjustment for the location of the recording station, in combination with 1D wave generation, propagation and transformation models will generally provide a suitable degree of reliable wind and wave climate data.

The scope of work and the supporting documentation or reports should outline study specific factors leading to the choice of the approach and the models.

1.4 TASK 7: DEFINITION OF THE SHORELINE CHARACTER

Understanding and characterization of the shoreline character of a specific mapping project shoreline is required so that appropriate wave transformation modeling approaches can be defined and so that appropriate calculations of the expected wave effect(s) along the shoreline can be undertaken.

The supporting documentation or reports should detail study specific factors leading to the schematization or sub-division of the specific project areas.

1.5 TASK 8: DEFINITION OF THE DESIGNATED FLOOD LEVEL (DFL)

The designated Flood Level (DFL) along a shoreline consists of the sum of the Future Sea Level Rise (SLR), maximum high tide (HHWLT) plus the total storm surge expected during the designated storm. The total storm surge includes the deepwater storm surge that approaches the B.C. coast (and tends to propagate into the interior waters without significant modification) plus any additional local surge generated by the winds during the designated storm at the time of the arrival of the deepwater storm surge.

In general terms any additional local surge is only generated when there is a substantial body of shallow water (< 30 m water depth) in front of the shoreline of interest. For large areas of interest a body of shallow water may only exist in front of a portion of the shoreline – for instance, in general, the delta of a river discharging in the area.

Local effects on storm surge can usually be quantified in coastal B.C. waters using simplified 1D surge models.

The scope of work and the supporting documentation or reports should outline study specific factors leading to the choice of the approach and the models

1.6 TASK 9: DEFINITION OF THE EXPECTED WAVE EFFECT

In almost all cases additional effects of waves that can lead directly to flooding along a shoreline including wave-setup, wave run-up or wave overtopping, or indirectly due to substantial coastal erosion and subsequent wave-setup, wave run-up or wave overtopping will occur. The magnitude of the wave-setup, wave run-up and wave overtopping will depend on the character of the shoreline as noted above.

Guidance for estimating the expected wave effect(s) are provided in many coastal engineering reference documents that are internationally recognized as current examples of best practice. It should be noted that a Building Code or Standard does not exist in Canada for coastal engineering structures or for coastal processes and procedures. The standards, guideline documents and specific publications listed below are intended to summarize the internationally accepted best practice. In some cases inter-comparison will reveal several approaches may apply. In these situations, theoretical analysis, evaluation of the specifics for application to BC coastal waters and recognized engineering practice should be used to select among alternative methods.

Direct calibration or validation by measurement or modeling may also be advisable or necessary. Detailed site specific engineering investigations, surveys and measurement may also provide equivalent guidance.

STANDARDS

International Organization for Standardization, 2007. *Actions from Wave and Currents on Coastal Structures. ISO 21650:2007(E).*

British Standards Institution. 2000. *British Standard Code of Practice for Maritime Structures. BS 6349.*

GUIDELINE DOCUMENTS

CIRIA; CUR; CETMEF. 2007. *The Rock Manual. The Use of Rock in Hydraulic Engineering (2nd Edition).*

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Pilarczyk, K.W. (Editor). 1998. *Dikes and Revetments – Design, Maintenance and Safety Assessment*.

The scope of work and the supporting documentation or reports should outline study specific factors leading to the choice of the approach and the analyses used to define the Expected Wave Effect(s) along the shoreline.

1.7 TASK 10: REVIEW AND VERIFICATION OF CALCULATIONS

In many cases, especially where the coastal lands are low lying or there are coastal bluffs located close to the existing shoreline, the estimated water level, including the effect of waves, may encounter land which is noticeably different than that assumed to calculate components of the water level. For example; low lying lands may be submerged and the Expected Wave Effects will be defined by the maximum seastate that can exist in the flooded area rather than by wave runup. A similar effect to be considered is that an existing shoreline may change in character due to the slow but perceptible effect of a rising sea level over time. As an example lands located on a coastal spit may be significantly affected by geomorphologic changes between the present and the future year(s) in question. These changes can materially change the seastate that penetrates into shorelines that were protected by the coastal spit.

In some situations it may be necessary to specify different FCLs along various portions of the study coastline.

The scope of work and the supporting documentation or reports should outline the review of the implications of any water level components that was undertaken and outline the corresponding measures undertaken.

1.8 TASK 11: CHOICE OF FREEBOARD

The freeboard allowance used to define the FCL should be the greater of:

- 0.6 m
- Freeboards appropriate for any flood proofing or buildings in the flooded area
- The runup elevation of the appropriate tsunami hazard.

As the definition of a coastal floodplain is not building or lot specific it may be sufficient to use a freeboard allowance of 0.6 m, provided that appropriate notation is provided on the Floodplain map. The chosen allowance must be explicitly stated.

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FEMA.[1] 2008. Guidance for Coastal Flood Hazard Analyses and Mapping in Sheltered Waters – Technical Memorandum. Available online at http:/www.fema.gov/fhm/gs_main.shtm.

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[1] Note: the FEMA documents do not have official citations and are described within the documents as "living" documents that will be updated whenever FEMA determines that changes are appropriate. The documents, which exist as DRAFT documents are presently under review. FEMA will post a new version on the website: http:/www.fema.gov/fhm/gs_main.shtm, as a collection of .pdf files.

Appendix B

Recommended Tsunami Planning Levels (PEP)

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RECOMMENDED TSUNAMI PLANNING LEVELS

The following recommended tsunami planning levels for communities are provided as guidance to emergency managers for determining evacuation areas, evacuation routes and safe areas for preparing emergency response plans and in providing public education to their communities. These planning levels have been developed based on current science and are intended to provide a margin of error by incorporating the probable maximum wave height, consideration for wave run-up, earthquake subsidence and a safety margin.

The recommended planning levels for communities are based on the most current scientific data available and have taken into consideration:

1. Observed data (where available);
2. Numerical model results (where available);
3. Sedimentary core samples (where available); and
4. Knowledge of the source regions.
5. The Cascadia subduction zone has not accumulated sufficient strain for a maximum earthquake at this time.

Primary contributors to this document have been Natural Resources Canada, Fisheries and Oceans Canada, local authorities and the Provincial Emergency Program.

The following recommended planning levels represent the worst case-scenario for a distant earthquake and tsunami and a local major earthquake and tsunami event. All levels are to be measured from the **normal highest tide** at each location. All values are in metres.

ZONE	WAVE HEIGHT	RUN-UP (x 2.0)	SAFETY (x 1.5)	SUBSIDENCE	PLANNING LEVEL
Zone A (North Coast)	2.0	4.0	6.0		**6**
Zone B (Central Coast)	2.0	4.0	6.0		**6**
Zone C (West Coast Vancouver Is)	3.0	6.0	9.0	1.0	**10**
Zone D (Juan de Fuca Strait)	1.3	2.7	4.1		**4**
Zone E (Strait of Georgia)	0.5	1.0	1.5		**2**

Wave height represents the best consensus of scientific estimates of wave height at this time.

Run-up allows for run-up which is expected to be less than a factor of 2 except at the heads of some inlets.

Safety adds a safety factor of 50% to allow for uncertainties in scientific interpretation and non-tidal variations in sea level (e.g. storm surge, El Nino).

Subsidence allows for subsidence that will occur during a Cascadia subduction earthquake.

Planning level is the sum of the values *Safety* plus *Subsidence.*

Tsunami wave heights can vary due to location, shape of the coastline, effects of offshore bathymetry and/or onshore topography and tide. This variation can occur over very short distances and it is impossible to predict accurately what these localized variations will be without additional modeling work. Detailed modelling of run-up and inundation is not currently available for most areas of coastal British Columbia.

In some localized areas wave heights may exceed the recommended planning levels. Of most concern would be areas at the heads of inlets or those areas with unique bathymetric features, for example, in Zone C at Port Alberni.

Large earthquakes can trigger landslides which could produce local waves larger than the stated planning levels. Large landslide induced waves can also happen on lakes. These situations are not addressed in this document.

Appendix C

Background Information on Mapping Technologies

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APPENDIX C: MAPPING TECHNOLOGIES

The following sections provide a description of the strengths and weaknesses of the technologies most suited for use in floodplain mapping.

1.1 GROUND SURVEY

Ground surveys still remain the most accurate and reliable technique for capturing topographic data. Accuracies of better than 5 cm in all three dimensions can be readily achieved. GPS used in a quick static mode allows for the collection of hundreds of points per day at levels of high accuracy. Where vegetation, or other above-ground features, may obstruct the view of GPS satellites, total stations may be utilized to ensure high levels of accuracy are maintained. With the benefit of being able to collect discrete points, accurate breakline information can be collected. With a large number of ground based survey companies in existence, procuring competitively priced services is straightforward with minimal mobilization costs.

For a project where only hundreds of points are required, a conventional ground survey is a very attractive option. However where dense DEM data are required over a large area, the cost of data collection from ground surveys is impractical considering the other technologies currently available. There is however, a continued need for ground surveys as they remain the most reliable and practical way of checking and quantifying data collected from alternate methods.

1.2 PHOTOGRAMMETRY

Photogrammetry uses stereo-paired air photographs to capture three-dimensional data. Therefore photogrammetric accuracies are dependant on the scale of the photography, which is directly related to the height at which the images are acquired. The height at which the survey is flown also has an impact on the overall cost of the survey. Photogrammetry can provide an accuracy of less than 10 cm in all three dimensions in instances where the highest accuracy is desired. Additionally, as a 3D image is present, breaklines can readily be collected.

Another expense associated with photogrammetric data is the requirement of ground control throughout the job site compared to other technologies. The ground control requirement can vary depending on the project location, but for remote areas, costs can be substantial. Acqisition of aerial photography must be conducted during daylight hours with optimal sun angles, without cloud cover or dense fog. This may have an impact on the time required to capture the survey area but the resulting data are uniform in lighting and shadow conditions, allowing for seamless tone, colour balancing and image mosaicing.

1.3 LIDAR DERIVED DEM

An airborne LiDAR system is defined as a system being comprised of three core components; a scanning laser, a positioning system, and an attitude system. The scanning laser includes a laser ranging system and a scanning system that directs the laser ranging system over a swath as the airframe passes over the terrain. The range from aircraft to ground is calculated by measuring the time it takes for the emitted light (LiDAR return) to reach the earth's surface and reflect back to the onboard LiDAR detector. The positioning system provides the three-dimensional coordinates of the airframe. The attitude system provides the roll, pitch and heading components of the airframe. The combined set of measurements; laser range, x, y, and z coordinates of the airframe, and roll, pitch, and heading permit the computation of three-dimensional coordinates of the ground point to be computed.

Vertical accuracy of airborne LiDAR now approaches sub-decimetre levels and horizontal accuracy approaches the one to two decimetre levels. Laser repetition rates have also increased significantly, providing the capability to acquire highly dense data sets with sub-metre point spacing. Also, with systems now capable of recording multiple returns from one shot, penetrating vegetation is possible with encouraging results. Efficient breakline derivation from a LiDAR dataset still remains to be a challenge. Breakline extraction is possible from LiDAR data derived from either the raw point cloud or using a technique called LiDARgrammetry, which uses stereo LiDAR intensity image pairs in a process similar to that of traditional photogrammetery.

As with photogrammetric techniques, the accuracy of LiDAR data varies with flying height. Point density, scan line spacing also vary with flying height and speed. Collection of LIDAR data costs fractions of a penny per point, which is far cheaper than any other competing technology. As a result, LiDAR is particularly well suited for applications requiring highly accurate and detailed surface modelling.

Depending on the purpose of the data, a high degree of processing may be required to remove unwanted points. Although processing algorithms are becoming more robust and digital imagery is implemented as a quality control tool, considerable effort is still required to obtain desired results. While the density of the dataset may necessitate extra effort to define the bare ground, conversely, having access to such a dense dataset provides the added benefit of obtaining additional data such as building heights and tree heights at no additional cost.

In addition to acquiring LIDAR data, some systems also concurrently acquire digital imagery. This imagery may be orthorectified using elevation information derived from the LIDAR data and then merged as a mosaic to produce a seamless image of the project area. The benefit of these systems is that they provide the capability to acquire both the data for a dense terrain model and the imagery necessary to provide 2D mapping of breaklines (the height information related to the breakline coming from the LIDAR data).

Typical pixel resolutions are on the order of 10 cm to 40 cm, and appropriate resolutions for breakline identification would be in the 20 cm to 30 cm range. However, other uses of the imagery are also considered when selecting the resolution. Typical accuracies are in the order of ±2 to 4 pixels. Digital imagery also has the advantage of a wider acquisition window since it may be obtained at lower flying heights than that required for aerial photography.

Appendix D

LiDAR Mapping Specifications

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APPENDIX D: LIDAR SPECIFICATIONS

1. USAGE OF SPECIFICATIONS

This specification is intended for use by coastal communities tendering projects for flood plain mapping, which require acquisition of airborne LiDAR data. This appendix provides the specifications necessary to assure the map dataset produced by the LiDAR survey will be of sufficient quality to be used in flood modeling and analysis. These specifications are based largely on "FEMA LiDAR Specifications for Flood Hazard Mapping, Appendix 4B" (2010), modified for local practice and with metric equivalents, and the British Columbia Ministry of Agriculture and Lands, Integrated Land Management Bureau (ILMB) Base Mapping and Geomatic Services Branch, 2006. "LiDAR Specifications" V 0.05.

2. AIRBORNE LIDAR SYSTEMS

2.1 GENERAL DESCRIPTION

An airborne LiDAR system is defined as a system being comprised of three core components; a scanning laser, a positioning system, and an attitude system. The scanning laser includes a laser ranging system and a scanning system that directs the laser ranging system over a swath as the airframe passes over the terrain. The range from aircraft to ground is calculated by measuring the time it takes for the emitted light (LiDAR return) to reach the earth's surface and reflect back to the onboard LiDAR detector. The positioning system provides the three-dimensional coordinates of the airframe. The attitude system provides the roll, pitch and heading components of the airframe. The combined set of measurements; laser range, x, y, and z coordinates of the airframe, and roll, pitch, and heading permit the computation of three-dimensional coordinates of the ground point to be computed.

LiDAR systems may also incorporate other sensors such as video or digital imagery, which can add value to the overall data collection mission.

2.2 SPECIFICATIONS

AIRFRAME

Either rotary or fixed wing aircraft may be used for acquisition of the LiDAR data.

POSITIONING SYSTEM

High accuracy dual-frequency GPS receivers must be used both at ground reference stations and on board the airframe to ensure the required accuracy of the ground points.

ATTITUDE SYSTEM

The IMU (inertial measurement unit) must be a high accuracy unit capable of high frequency output to ensure small changes in airframe attitude which effect the accuracy of the ground returns are adequately captured. Since the inaccuracy in the ground returns due to the error in aircraft attitude increases with flying height, the accuracy of the IMU must be compatible with the flying height planned for the project.

LASER SCANNING SYSTEM

The laser scanning system must provide the following measurements; first return, last return, number of returns, and a minimum of first or last return intensity. Intermediate returns may be of use in other applications (e.g. forestry) but are not necessarily required for flood mapping. The intensity provides a form of imagery essential to aid in the interpretation of the returns from the laser.

ADDITIONAL SENSORS

Simultaneous collection of video or digital imagery for aiding in the interpretation of the LIDAR data is recommended but not essential.

2.3 MINIMUM RECOMMENDED REQUIREMENTS

In order to ensure adequate accuracy of the LiDAR survey, the following are the minimum recommended requirements for LiDAR systems.

- horizontal point accuracy: better than 60% of specified map accuracy; and
- vertical point accuracy: better than 60% of specified map accuracy.

LiDAR ground point accuracies vary with flying height due to the nature of some component error sources. Proponents must, therefore, demonstrate that the combination of the accuracy of their system components and their proposed flying height meet the above requirements. (Refer to ILMB 2006 Specifications and the LiDAR Error Propagation Calculator.)

Where systems that fall outside of these requirements are proposed the proponent must demonstrate that the system has the capability to meet the required specifications for map accuracy.

2.4 SYSTEM CALIBRATION

The LiDAR system must undergo a documented calibration procedure during data acquisition to ensure any systematic errors are identified and accounted for in processing. A minimum of two calibration datasets shall be collected; one prior to the commencement of data acquisition and one following completion of data acquisition. If the program is longer than 2 days additional intermediate calibration flights should be carried out. (Refer also to the ILMB 2006 Specifications.)

3. DATA ACQUISITION REQUIREMENTS

3.1 POINT SPACING

In order to ensure the required map accuracy is achieved, the maximum nominal pulse spacing should not exceed 50% of the squared DEM post spacing specified for the project. Nominal pulse spacing shall be calculated as follows:

$$\text{Nominal pulse spacing} = \frac{\text{area covered by a complete scan}}{\text{total number of laser shots within a complete scan}}$$

Therefore,

$$\text{Nominal pulse spacing} <= 0.50\ (\text{DEM Post Spacing})^2$$

Maximum pulse spacing shall not exceed the DEM post spacing in either along-track or cross-track components.

Proponents must demonstrate that the combination of their laser pulse rate, scan speed, maximum scan angle, and planned flying height will meet this requirement.

3.2 GPS BASE STATIONS

Base station receivers must be high accuracy dual frequency units. BCACS control should be used for the base stations. In the absence of BCACS control stations within acceptable baseline lengths to the aircraft, other survey control may be used. If used, other survey control must be verified by processing the base station data with BCACS data.

For 1:2000 mapping, baseline lengths shall be kept to a 20km maximum, for 1:5000 scale mapping, the maximum baseline length shall be 50km.

3.3 MAP DATA ELEVATIONS

Since the objective of the mapping is flood analysis, deriving correct orthometric height of the map data is critical. GPS provides an ellipsoidal height; therefore, the proponent must provide a plan for recovering the vertical datum and modeling the geoidal corrections from ellipsoidal to orthometric height within the project area.

3.4 FLIGHT PLANNING

For quality control purposes, a minimum of one perpendicular cross flight line shall be flown over the project area. Sidelap shall be sufficient to ensure there is no uplift of the data at the edges of the scan due to improper calibration. Flight lines shall minimize shadowing due to tall structures. If necessary, additional cross flights shall be conducted to cover shadowed areas. (Refer also to the ILMB 2006 Specifications.)

3.5 SURVEY CONDITIONS

The LiDAR survey may be conducted either during the day or at night if imagery is not required. Due to difficulty with obtaining flight permits for certain areas during daylight hours, night flying may be a preferred alternative.

The survey should not be conducted during periods of high wind or during periods of snow, rain, fog, or heavy smog. The latter must be avoided as particulate matter and aerosols below the aircraft can generate spurious returns that may be difficult to remove from the data. Any other condition, which would significantly diminish the quality of the data, must also be avoided. It is recommended that a no-fly clause be included in project contracts to ensure data is captured under optimum conditions.

Where the project includes substantial areas of deciduous trees or dense tall crops such as corn it is recommended that the LiDAR survey be conducted during leaf off or crop of condition to ensure the best possible bare earth model is obtained. Further, since standing water only yields minimal returns typically from directly below the airframe, wherever possible flights should be undertaken during periods when standing water is at a minimum

4. DATA PROCESSING

For flood analysis, the LiDAR data shall be processed to remove all points collected on vegetation, buildings, and other structures to obtain a subset that contains only bare-earth ground elevation data. In addition to these random mass points randomly a bare-earth TIN shall be produced as well as a DEM with the regular point spacing as specified for the project. When validating the vertical accuracy of the elevation dataset the TIN shall be used with linear interpolation procedures to derive the dataset elevation at the coordinate of the check point. Since the DEM is a derived product of reduced accuracy the accuracy assessments must be performed on the TIN.

If the DEM product has post spacing greater than 1.5 m, breaklines shall be obtained from digital orthophotos, stereo photogrammetry, or existing map sources. The breaklines shall include; stream centerlines, streambanks (top and bottom), ridge lines, and manmade features that constrict or control the flow of water (e.g., drainage ditches, road crowns, bulkheads, levees and curbs). The source and accuracy of breakline data shall be specified. The breaklines shall be merged with the mass points, to enforce TIN triangle edges.

Hydrologic enforcement shall be performed on the elevation data to ensure correct flow may be modeled in the flood analysis. All bridges and major culverts shall be cut with breaklines to ensure the contours, DEMs, or TINs correctly model the flow through the structure. Major culverts shall be defined as any multi-plate structure. All major ditches, natural water courses, and shorelines shall also be checked for hydrologic enforcement through the addition of breaklines to ensure the lowest points along the feature are captured to correctly model the outlet drainage. Major ditches and natural water courses requiring hydrologic enforcement shall be defined as those having a width equal to or greater than 5 m.

DATA VOIDS

Following extraction of bare-earth mass points the ground data must be checked for voids. Voids shall be defined as areas with greater than twice the specified DEM post spacing. Voids for causes other than the removal of manmade structures such as buildings, dense vegetation, water, or other features, which typically absorb the laser frequency such as new asphalt, shall be investigated. Where the voids have occurred due to equipment malfunction or navigation error re-flights must be conducted to fill the voids.

Voids in dense vegetation that are less than 0.25 ha if not in the vicinity of a breakline may be filled in during the creation of the TIN and subsequent products. Larger voids and those less than 0.25 ha in the vicinity of a breakline must be delineated as an indeterminate area. A map showing the boundaries of all indeterminate areas must be submitted with the data. These areas may then be surveyed from the ground if they are determined to be in locations critical to the flood analysis.

DATA ARTIFACTS

The bare earth DEM must be clear of artifacts in the data that represent errors larger than the specified vertical map accuracy. Artifacts may be defined as regions of anomalous elevations (often represented by oscillations or ripples within the DEM) resulting from systematic errors in data collection, environmental conditions, or incorrect/incomplete post-processing. Where such artifacts occur steps must be taken to determine the causes and remove the artifacts from the DEM.

5. QUALITY ASSURANCE / QUALITY CONTROL

QA/QC reviews of the LIDAR derived map data products shall be conducted to demonstrate that the data meets the required map specifications. Two essential areas shall be covered; data completeness and data accuracy.

5.1 DATA COMPLETENESS

Data completeness checks shall consist of the following:

- coverage review to ensure the entire project has been mapped and that there are no gaps within the area;
- range return frequency check in which greater than 90% of the laser pulses should result in a measured range; and
- review of areas of data voids as noted in item 4 above.

(Refer also to the BC ILMB 2006 Specifications.)

5.2 DATA ACCURACY

STANDARDS

The map data must meet the following accuracy standard.

Vertical Accuracy 95%	Horizontal Accuracy 95%
50% of CI	150% of CI

CI – Contour Interval

Should the accuracy not meet the standard, the cause of the errors shall be determined and appropriate corrective measures taken.

TESTING

In order verify the map data meets the required accuracy standard, map data points shall be compared to test points. The map data points shall be derived by linear interpolation of an elevation on the TIN at the coordinate of the test point. The test point coordinates shall be obtained by an independent survey of higher accuracy.

The test points shall comply with the following criteria:

- distributed throughout the project area;
- distributed throughout the acquisition period both within daily mission times and across the duration of the acquisition period (i.e. not all points at best PDOP conditions or from a single day of acquisition);
- be within an are of uniform slope within a 5 m radius and away from breaklines such as bridges or embankments;
- include a minimum of 20 points in each ground cover type that occurs within the project area; and
- include a minimum of 20 points that may be horizontally identified through the LiDAR intensity data.

Ground cover types shall be the following: (per BC ILMB specifications):

- open areas of terrain; and
- other ground cover areas that represent a significant portion of the project area and are critical to flood map development for that area.

REPORTING (REFER ALSO TO BC ILMB 2006 SPECIFICATIONS)

The vertical accuracy of the map data shall be computed as follows:

$$RMSE_z = sqrt\,[\Sigma(z_{data\ 1} - z_{check\ 1})^2/n]$$
$$Accuracy_z \text{ (95\% confidence level)} = 1.96\ RMSE_z$$

The following vertical accuracies shall be reported:

Fundamental Vertical Accuracy (FVA):

- derived from bare earth and low grass ground cover test points; and
- shall meet the specified vertical map accuracy.

Consolidated Vertical Accuracy (CVA):

- derived from all test points; and
- shall be within 150% of the specified vertical map accuracy.

Supplemental Vertical Accuracy (SVA):

- derived from individual ground cover categories.

The reported horizontal accuracy of the map data shall be computed as follows:

$$RMSE_r = sqrt\ [\Sigma((x_{data\ 1} - x_{check\ 1})^2 + (y_{data\ 1} - y_{check\ 1})^2)/n]$$
$$Accuracy_r \text{ (95\% confidence level)} = 1.73\ RMSE_r$$

The horizontal accuracy computation shall only include those points identifiable through the LiDAR intensity data (e.g. edges of features with contrasting intensity such as paint lines at road intersections).

OUTLIERS

For the vertical accuracy, in ground cover types that are not bare-earth or urban areas, errors that are outside of 99% confidence level may be considered as outliers and discarded from the dataset.

ERROR DISTRIBUTION

Since accuracy measurement assumes a zero mean and normal distribution, the mean and coefficient of skew shall be calculated for each set of test points. Where the coefficient of skew exceeds 0.5 for the FVA, it is an indication that the errors are not normally distributed and the data may contain systematic errors. In these cases, a thorough investigation shall be undertaken of the data to determine, document, and correct the cause of the systematic error.

ADDITIONAL ACCURACY TESTS

In addition to the above map accuracy testing, the proponent must be able to demonstrate verifiable GPS positioning of the aircraft relative to the base station to within 5 cm at a 95% confidence interval on a periodic basis throughout the project duration (e.g. through operation of a redundant base station).

Verification of the cross-track vertical accuracy shall also be provided to ensure uniformity of the data perpendicular to direction of the flight lines. Cross track verification shall include areas near both ends and the center of the flight lines and the combined verification shall cover not less than 70% of the average width of the project area. (An example of cross-track verification would be a kinematic GPS survey along a road running perpendicular to the flight lines)

6. DELIVERABLES

The project deliverables shall consist of the data and reports as defined below.

6.1 PROJECT DATA

The following LiDAR data and derived products shall be delivered:

- Unadjusted and unclassified LiDAR points including time-stamp, xyz coordinates, and intensity in LAS 1.1 (per ILMB 2006 Specifications) or ASCII comma delimited file format (if LAS format is not supported by the software used for flood analysis);
- Bare-earth classified LIDAR points including time-stamp, and xyz coordinates in LAS 1.1 (per ILMB 2006 Specifications) or ASCII comma delimited file format (if LAS format is not supported by the software used for flood analysis);
- All other LIDAR points classified as non-ground including time-stamp, and xyz coordinates in LAS 1.1 (per ILMB 2006 Specifications) or ASCII comma delimited file format (if LAS format is not supported by the software used for flood analysis);
- TIN;
- DEM at specified post spacing;
- 0.5 m contours (or as required for specified flood map accuracy):
- breaklines; and
- boundaries of data voids.

6.2 DATA ACQUISITION REPORT

A data acquisition report shall be submitted and at a minimum shall include the following information.

- flight dates and mission start/end times;
- weather conditions;
- aircraft trajectory;
- flying height and airspeed;
- PDOP during each mission;
- system operation parameters; laser pulse rate, maximum scan angle, scan speed;

- ground control including stations, benchmarks, and coordinates used and their source, if control was established, a survey report must also be provided showing the results of the survey; and
- LiDAR system calibration.

6.3 DATA PROCESSING REPORT

A data processing report shall be submitted and at a minimum shall include the following information:

- geoid model used and derivation of undulations for computation of orthometric heights;
- processing procedures used to extract the bare-earth dataset; and
- results of accuracy testing, and if systematic errors were encountered the report must include details on the cause(s) of the errors and the applied correction.

7. REFERENCES

Federal Emergency Management Agency (FEMA). 2010. "LiDAR Specifications for Flood Hazard Mapping, Appendix 4B: Airborne Light Detection and Ranging Systems. Retrieved February 22, 2011: http://www.fema.gov/plan/prevent/fhm/lidar_4b.shtm

British Columbia Ministry of Agriculture and Lands, Integrated Land Management Bureau (ILMB) Base Mapping and Geomatic Services Branch, 2006. "LiDAR Specifications" V 0.05. Retrieved February 22, 2011:
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Appendix E

Design Brief for Sample Floodplain Mapping (Campbell River)

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CONSULTING ENGINEERS

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1911 • 2011

CLIENT: **KERR WOOD LEIDAL ASSOCIATES LIMITED**

PROJECT: **COASTAL FLOODPLAIN MAPPING GUIDELINES AND SPECIFICATIONS**

- **APPENDIX E**
- **CAMPBELL RIVER EXAMPLE**

Prepared by: John Readshaw, P.Eng.

This document contains the expression of the professional opinion of SNC-Lavalin Inc. ("SLI") as to the matters set out herein, using its professional judgment and reasonable care. It is to be read in the context of the agreement dated * (the "Agreement") between SLI and * (the "Client"), and the methodology, procedures and techniques used, SLI's assumptions, and the circumstances and constrains under which its mandate was performed. This document is written solely for the purpose stated in the Agreement, and for the sole and exclusive benefit of the Client, whose remedies are limited to those set out in the Agreement. This document is meant to be read as a whole, and sections or parts thereof should thus not be read or relied upon out of context.

SLI has, in preparing the cost estimates, followed methodology and procedures, and exercised due care consistent with the intended level of accuracy, using its professional judgment and reasonable care, and is thus of the opinion that there is a high probability that actual costs will fall within the specified error margin. However, no warranty should be implied as to the accuracy of any estimates contained herein. Unless expressly stated otherwise, assumptions, data and information supplied by, or gathered from other sources (including the Client, other consultants, testing laboratories and equipment suppliers, etc.) upon which SLI's opinion as set out herein is based has not been verified by SLI; SLI makes no representation as to its accuracy and disclaims all liability with respect thereto.

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Table of Contents

1.0 Introduction

1.1 Project Background, Key Objectives and Location

SNC-Lavalin Inc. (SLI) has been retained by Kerr Wood Leidal Associates Ltd. to provide coastal engineering input into the formulation of a methodology and guidelines and specifications for preparing floodplain maps for coastal communities in British Columbia to use to identify coastal flood hazards that account for expected sea level rise due to climate change.

The overall project is described in the main document to which this report forms a part.

This report summarizes the assessment made of the marine conditions in the vicinity of Campbell River for the express purpose of developing an example coastal flooding map following the guidelines for map preparation described in the main document. This report is intended solely as a record of the design basis used to derive the Flood Construction Levels for the case example mapping and is not intended as a complete assessment that would be undertaken at this location. Simplifying assumptions have been made in the development of the case example. A detailed specific assessment will need to be made prior to producing floodplain mapping for this location.

The City of Campbell River is located at the north end of the Strait of Georgia, which is a semi-enclosed body of water as indicated in Figure A-1 of Appendix A, and extends along the east shoreline of Vancouver Island, south of Quadra Island and north into Discovery Passage, Figure 1. The waterfront is primarily exposed to winds and waves from the southeast in the Strait of Georgia and to tides, currents and storm surges that propagate around both the north and the south ends of Vancouver Island and meet in the waters offshore of the city.

The coastal regime character of the Campbell River waterfront varies considerably along the length of its shoreline, Figure 2, being directly exposed to the southeast at the south end of the community, west of Wilby Shoals and becoming increasingly protected by Quadra Island as one moves north. In the vicinity of the central business district, located mid-frame in Figure 2, the natural shoreline is protected by a series of breakwaters and shoreline rock revetments, becoming more natural again along the shoreline of Tyee Spit, which screens the estuary of the Campbell River.

Tidal currents in the centre of the channel (Discovery Passage) are relatively strong for the British Columbia coast, with normal maximum rates on a spring tide of 6 to 7 knots in front of the city and up to 9 knots at the south end of Discovery Passage where they can interact with waves generated in the Strait of Georgia.

The total length of the Campbell River waterfront varies from a semi-exposed location at the south end of the community to a sheltered site within the tidal portion of the Campbell River estuary.

This case example is focused on that section of the Campbell River shoreline located at the north end of the city.

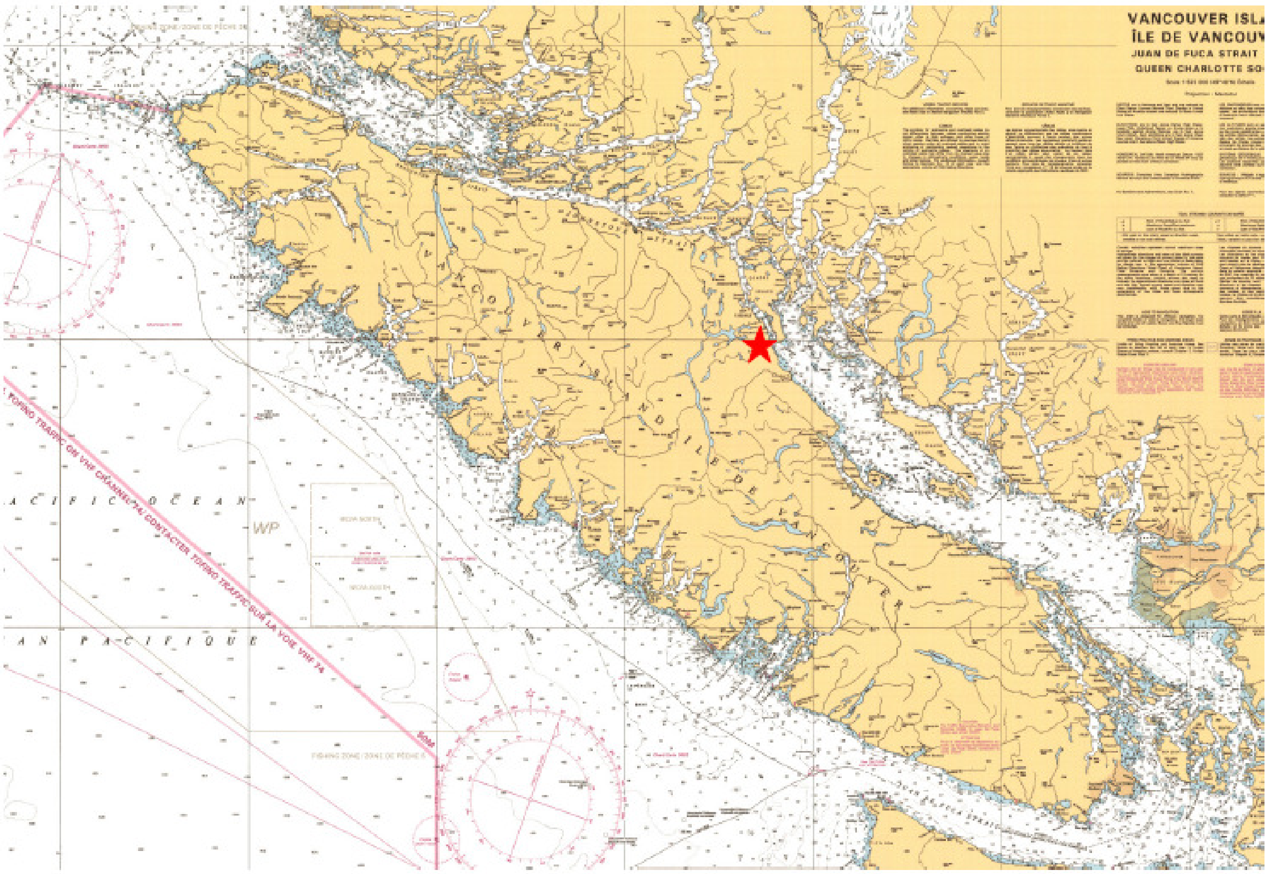


Figure 1: Location of Campbell River
Source CHS Chart 3001 – Not for Navigation

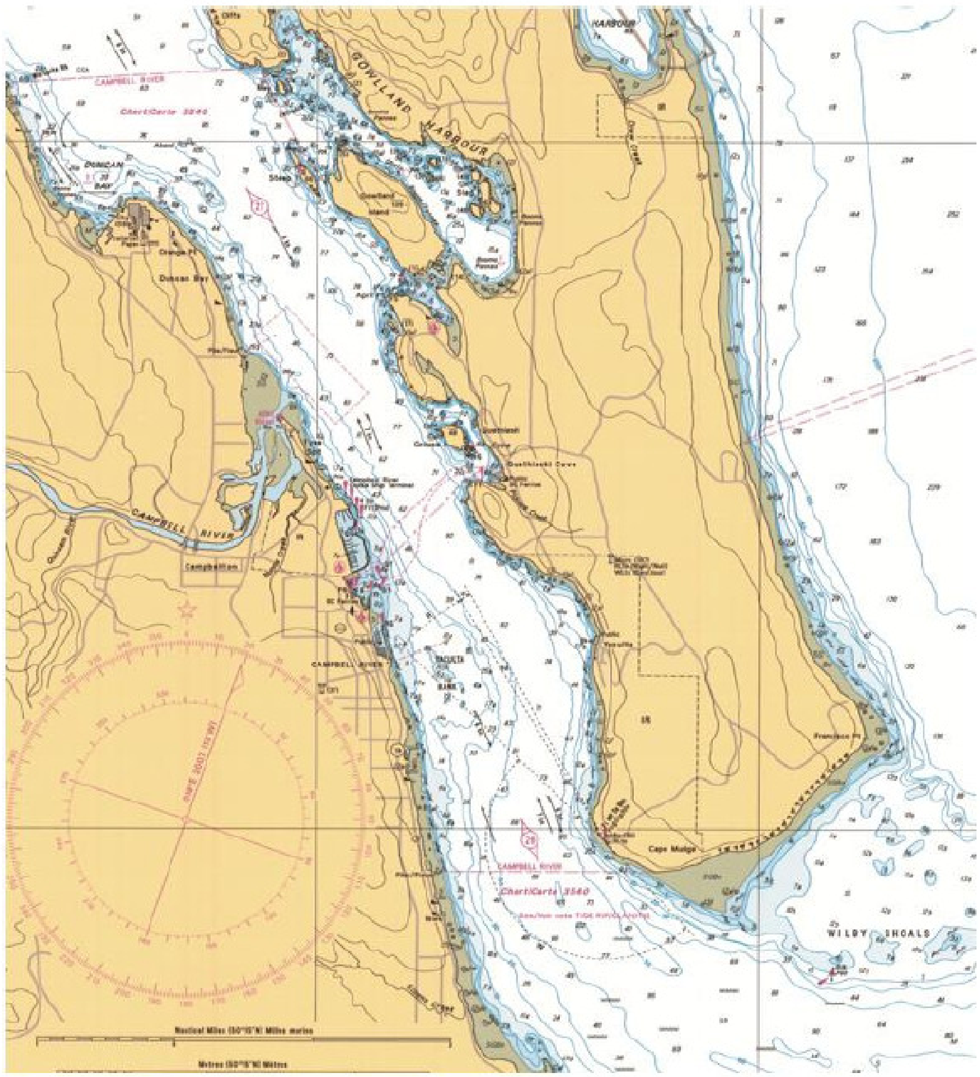


Figure 2: Campbell River Shoreline

Source CHS Chart 3539 – Not for Navigation

1.2 Methodology

The methodology followed for this case example is a simplification of the recommended approach laid out in Appendix A of the main document. The simplified approach was taken solely to provide approximate site related background to the case example of a coastal floodplain map.

For the case example, Flood Construction Levels were calculated for a design event with an annual exceedance probability (AEP) of 1/500 years, due to the built-up nature of the downtown core in the case example area.

The expected regional sea level rise for the years in question were determined based on the global sea level rise allowance for the years 2100 (+1 m) and 2200 (+2 m), and the published rate of ground movement in the Campbell River area from Figure 2-3 of the main report (uplift of approximately 4.1 mm/yr).

In this simplified approach, recorded wind and wave data from the Environment Canada meteorological buoy 46131 - Sentry Shoal, located approximately 11 nautical miles southeast of Campbell River, in the Strait of Georgia, were used to define the wind and wave climate. In a detailed site specific study, a 2D wave generation, propagation and transformation numerical model would likely be used to define the wave climate, including the effects of the near shore bathymetry on both sides of Discovery Channel and the influence of the strong currents. In this example case, we have used the recorded data without modification. This simplification may result in an over-prediction of the wave climate along the shoreline; however, as the depth of water close to the shoreline tends to control the wave climate in any regard, this simplification is still likely representative.

The incident deepwater storm surge and the possible role of wind during the design event increasing the incident storm surge due to local effects were captured in this simplified approach by using the recorded water levels directly from the long-term water level recording station at Campbell River: CHS Station 8074 located at latitude 50.042 degree N, 125.247 degrees W.

The recorder is located on the east side of Tyee Spit, just east of the Campbell River estuary, so it seems reasonable that any local effects of strong winds are reflected in the recorded dataset.

2.0 Summary of the Site Specific Conditions

2.1 Tidal Water Levels

Tidal water levels are based on Canadian Hydrographic Service (CHS) data for Campbell River, which are available in Volume 6, Canadian Tide and Current Tables and summarized below in Table 1. At Campbell River, tide datum is approximately 2.9 m below CGVD28, which means the elevation of the Higher High Water, Large Tide (HHWLT) needed to calculate FCLs becomes +1.9 m CGVD28, as indicated in Table 1.

Table 1: Summary of Tidal Water Levels at Campbell River

Water Level	(m, wrt to tide datum)	(m, wrt to CGVD28)
Recorded High Water [a]	5.4	2.5
HHWLT	4.8	1.9
MWL	2.9	0.0
LLWLT	0.2	-2.7
Notes: a: highest recorded total water level – includes predicted tide and all other effects measured at tide gauge location		

The source of the recorded high water elevation of +2.5 m CGVD28 is not known at this time. The archived data for the Campbell River tide gauge (Station 8074) which covers the interval 1965 – 2011, with some missing data, contains a maximum total measured water level of +5.27 m (CD) or +2.37 m CGVD.

2.1.1 Storm Surge

Our preliminary assessment of the recorded water levels at the Campbell River tide gauge (Station 8074) indicates that the residual water levels at this station are generally higher than recorded further south in the Strait of Georgia. The recorded data also indicates that the largest residual water levels do not occur on the same dates as those recorded further south. This difference may be due to two factors:

- The tide gauge is located partway up Discovery Passage and the recorded water levels may include local effects particular to the location
- Campbell River is located at the confluence of tides and storm surges that approach the area around both ends of Vancouver Island. The combined effects of surges from both directions may be responsible for higher water levels and the unique times of largest residual water levels.

Further investigations are warranted; however for this assignment we have used the following results of a peak over threshold extreme value analysis of the 45 highest residual recorded water levels to define the expected peak residual water level (total storm surge) for various annual exceedance probability (AEP) levels.

AEP (per cent chance in one year)	AEP (1/average return period in years)	Total Peak Residual Water Level (m wrt to predicted tide)
50 %	Annual	1.0
20 %	1/5 yr	1.1
10 %	1/10 yr	1.1
4 %	1/25 yr	1.2
2 %	1/50 yr	1.3
1 %	1/100 yr	1.3
0.5 %	1/200 yr	1.4
0.2 %	1/500 yr	1.5
0.1 %	1/1000 yr	1.5

For the purpose of this assignment these peak residual water levels are taken to include any local effects particular to Discovery Passage and the bathymetry between the Strait of Georgia and Campbell River.

A detailed site specific assessment is warranted to verify the differences between residual water levels in the Strait of Georgia and at Campbell River.

2.1.2 Currents

Tidal current data in Discovery Passage are not available; however CHS Chart 3540 reports ebb and flood currents during normal maximum spring tides of approximately 7 knots (3.6 m/s).

The peak residual water levels reported above are considered to include any interaction effects due to the currents on the incoming surges.

The wave climate has been assumed to be controlled by the depth of water at the shoreline during this simplified approach. A comprehensive site specific study may find that the currents influence the wave climate that can exist along the shoreline at the time of the peak storm surge.

2.1.3 Waves

A preliminary assessment of the 13 years of wave climate data recorded at the Sentry Shoal wave recorder, located approximately 20 km southeast of Campbell River, indicates that the largest residual water levels do not coincide with the strongest winds or highest waves.

The concurrent residual water levels (at Campbell River) and seastates (at Sentry Shoal) are shown in Figure 3. This comparison indicates that the largest seastates do not occur at the same time as the largest residual water levels. A comprehensive site specific assessment should check that a combination of a lower water level but a larger seastate does not govern; however, such a combination is not expected to make a significant difference to the simplified approach used in this case example due to the depth limiting assumption made for this case example.

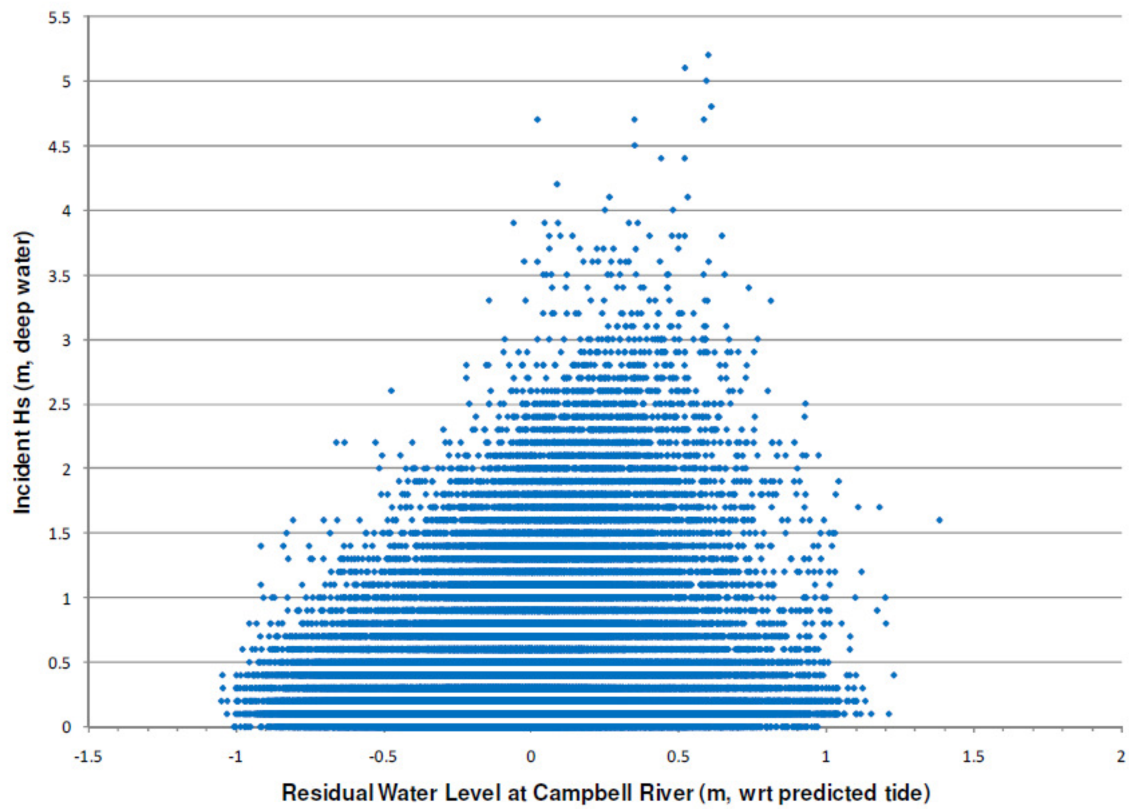


Figure 3: Concurrent Wave Climate and Storm Surge at Campbell River

A comparison of the concurrent residual water levels and the significant wave height measured at the Sentry Shoal buoy during the highest residual water level events that exist in the overlapping period of operation of the two data sources is shown in Figure 4.

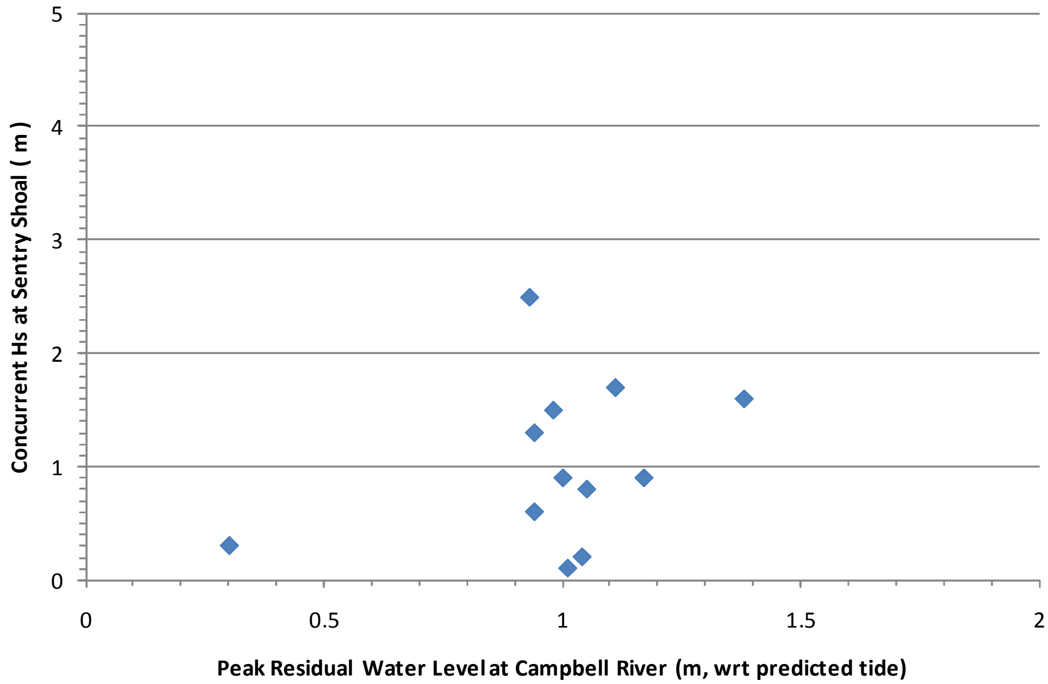


Figure 4: Concurrent Seastate and Storm Surge Parameters

In this case example we have used an incident significant wave height of 2.4 m for the assessment of the expected wave effects during the Designated Storm defined by the occurrence of the design residual water level.

2.1.4 Tsunami

The effects of tsunami waves incident to the Campbell River area were not directly considered in this assessment. Guidance for run-up estimates for planning purposes are provided in Appendix B.

2.1.5 River Discharge

Campbell River drains a 1470 km^2 catchment area on the east side of the Vancouver Island mountains. The river is regulated by three BC Hydro dams, Strathcona, Ladore Falls and John Hart. The dams are operated for hydroelectric power generation and these operations provide flood control for floods with a return period of about 1 in 8 years or less (Klohn-Leonoff, 1989)[1]. For larger floods the routing effects of the reservoirs will also tend to reduce flood peaks. The Quinsam River, with a catchment area of 280 km^2 also flows into the Campbell River estuary.

[1] Klohn–Leonoff, 1989. Design Brief, Floodplain Mapping Program, Campbell and Quinsam Rivers. Report to the BC Ministry of Environment.

During the coastal design storm event, it is likely that there will be a flood on the Campbell and Quinsam Rivers. However, it is unlikely that the peak flow from the rivers will coincide with the peak water level from the coastal flooding event because of the lag effect from routing through the reservoirs. Furthermore, the coastal design storm may not produce an extreme rainfall event over the Campbell River catchment. For these reasons the flood event in the Campbell and Quinsam Rivers coincident with the peak water level from the coastal flood should be based on an estimate of the coincident river flow. In the absence of other information, the mean annual peak daily flow would be a reasonable value to select.

From information in Klohn-Leonoff (1989)1 and Water Survey of Canada recent gauge data[2], the mean annual peak daily flow was estimated to be 400 m^3/s. Although the 200-year design flood and the coastal flood event are unlikely to be coincident, for flood hazard mapping the FCL should be the highest value from either event. The FCL from the 200-year river flood (1573 m^3/s) can be obtained from Klohn-Leonoff (1989)1.

A comprehensive study should include water surface profile modelling on the Campbell River for the selected coincident flood event because of future changes in the downstream boundary condition. In the 1989 study the downstream boundary condition for the 200-year flood was HHWLT, 1.9 m GSC. With sea level rise the downstream boundary condition should be adjusted and the water surface profile recalculated. This detailed modelling was not carried out for this Design Brief. The mapping prepared for this Design Brief was based on the modelling results and FCL values for the Campbell River from Klohn Leonoff (1989)1.

2.2 Existing Bathymetry and Topography

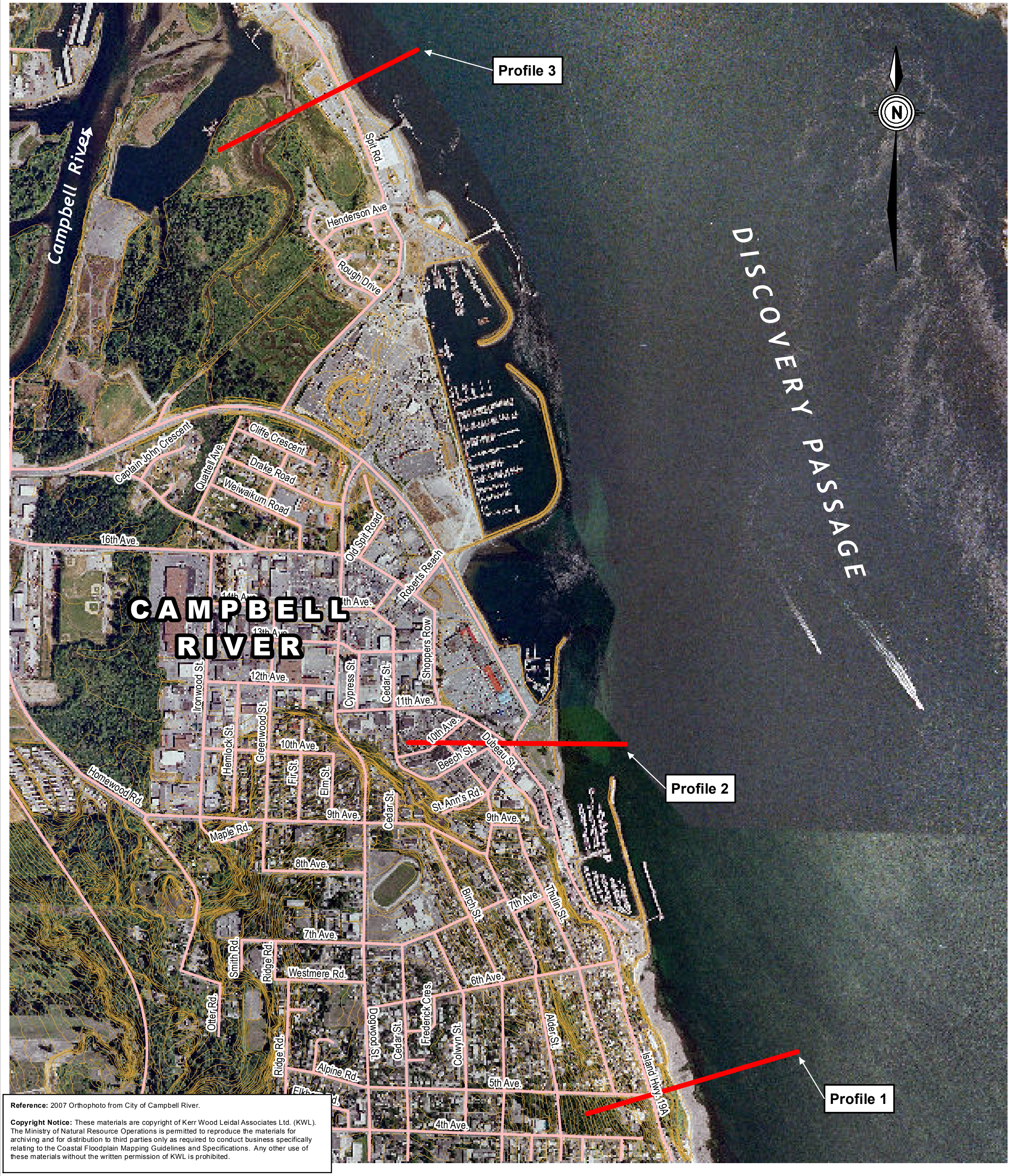
For the purpose of this case example the near shore bathymetry for the City of Campbell River was defined based on Canadian Hydrographic Service (CHS) chart 3539, adjacent to the Campbell River waterfront. Topography was based on 1 m contour mapping provided by the City of Campbell River and composite profiles across the shoreline were assembled taking the shoreline of the chart as having the same elevation as HHWLT. Examination of the resulting merged datasets indicated reasonable ground profiles. A comprehensive site specific mapping assignment should obtain site specific survey data tying both topographic and bathymetric data to a common datum plane.

The present shoreline of the City of Campbell River is complex and includes many natural and anthropogenic features. For this case example we have used three cross-shore profiles assembled at the locations shown in Figure 5 as a simplified representation of the nearshore bathymetry to assess the expected wave effects along the exposed Discovery Channel shoreline. The schematized profiles are provided in Figure 6 through Figure 8. These profile locations were selected primarily because they are not located inside the

[2] http://www.env.gov.bc.ca/wsd/data_searches/fpm/reports/bc-floodplain-design-briefs/campbell_quinsam_rivers.pdf

existing harbour structures that provide a degree of protection to the existing shoreline but whose fate by 2100 is undefined. A comprehensive study to define FCL's throughout the City of Campbell River will need to consider all of the shoreline character and identify subsections that warrant detailed assessment.

As noted below in Section 2-4, the existing ground on profiles 2 and 3 is expected to be underwater during a severe storm surge in 2100. As sea level slowly rises between the present and 2100 it is likely that the existing City of Campbell River shoreline will be slowly modified over time and the present cross-shore profiles may not be representative. It is likely that either significant erosion of the shoreline may have occurred or that existing shoreline protection or structures may have been constructed or further modified. For this simplified assessment we have assumed no change to the shoreline. A comprehensive site specific study will need to consider possible shoreline changes and in particular, for this site, there may be important implications for the wave effects along the shoreline inside the Campbell River estuary.



Reference: 2007 Orthophoto from City of Campbell River.

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Coastal Floodplain Mapping Guidelines and Specifications

Project No.	Date
2785-001	March 2011

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Campbell River Shoreline Profiles

Figure 5

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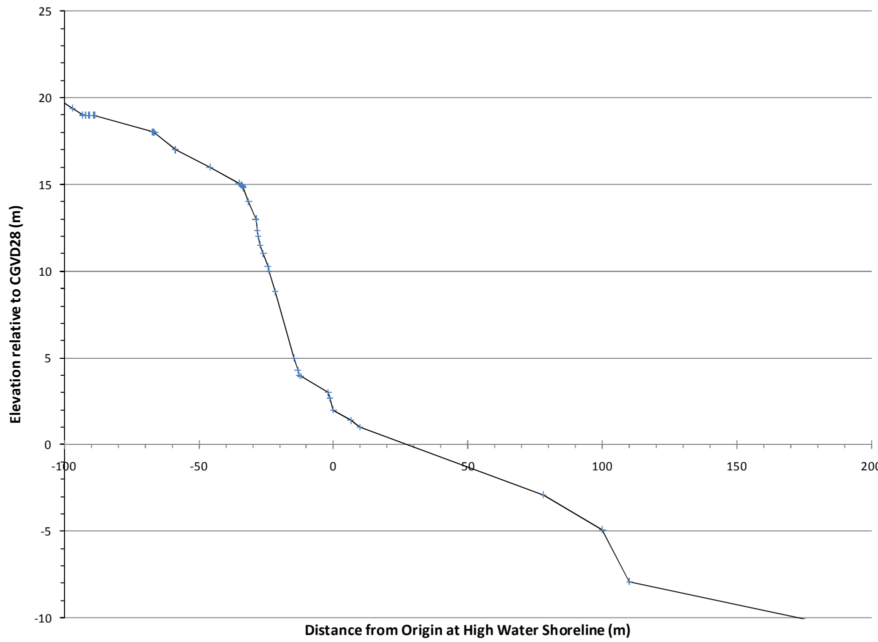

Figure 6: Cross-shore Profile 1 at 5th Avenue

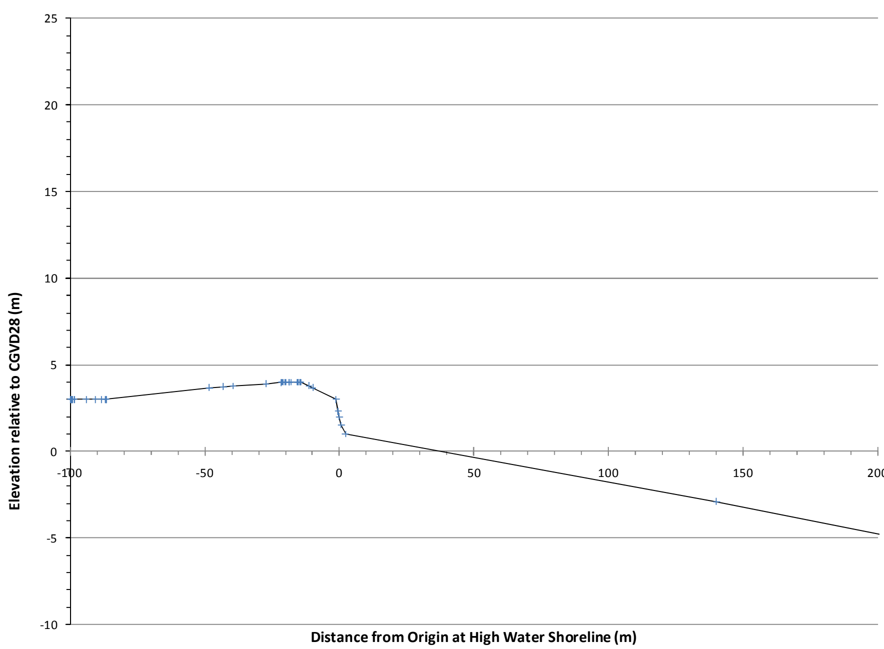

Figure 7: Cross-shore Profile 2 at Robert Ostler Park

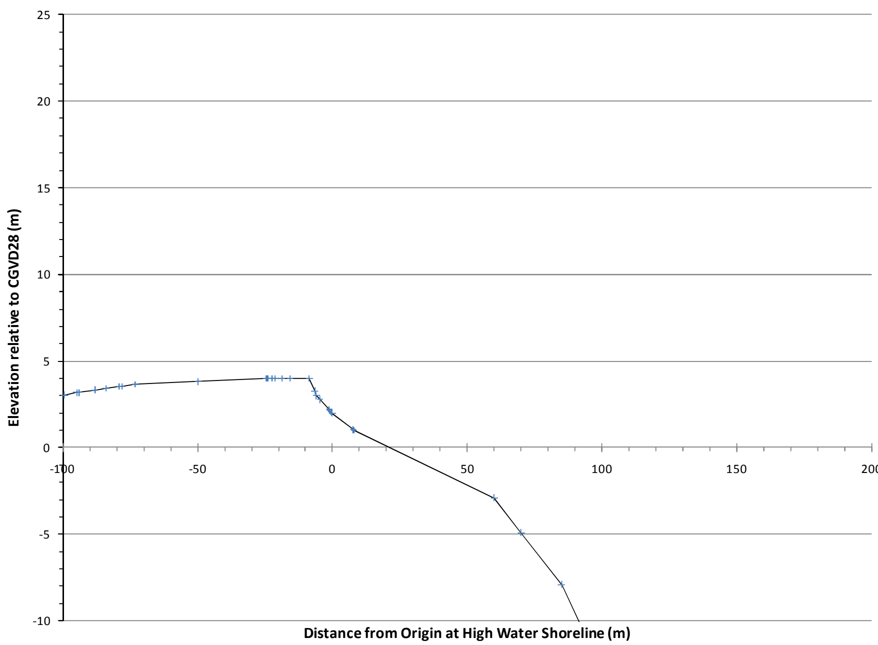

Figure 8: Cross-shore Profile 3 at Tyee Spit

2.3 Wave Related Effects

The wave related effects that can be expected along the Campbell River waterfront shoreline include; wave setup inshore of the breaker zone, which will increase the mean depth of water during the Designated Storm, wave run-up on the shoreline beaches, banks or cliffs, breakwaters and revetments and wave overtopping and subsequent flooding and inundation of the low bank and low lying estuary lands inshore of the coastal margin. Some of these processes may result in actual flooding or inundation[3] of the coastal lands. Some may only result in high wave related loads due either to direct wave loading, spray loading or to high flow velocities. In some cases building foundations may be exposed to scour due to either local high flow velocities or due to geomorphological erosion of the shoreline.

A comprehensive study and identification of coastal flood hazard should consider all of these potential hazards. For this simplified case example we have focussed on the likely wave run-up and subsequent flooding of the coastal margin that may result in inundation leading to the need for construction to an appropriate Flood Construction Level.

As noted in Section 2.1.3 above, we have estimated the wave related effects on the basis that wind and wave conditions during the Designated Storm result in an incident seastate with a significant wave height of 2.4 m. We have also assumed, for simplicity and solely for this case example, that the corresponding wave conditions at the shoreline, where

[3] Inundation can be defined by a depth of standing water above the local ground elevation.

wave related effects must be calculated, will be limited in height by the available depth of water. In a comprehensive study, for a particular place, more detailed analysis, as outlined in Appendix A, will be required.

The elevation of the wave related effects was estimated based on the guidelines in reference document "Guidelines for Management of Coastal Flood Hazard Land Use" (Ausenco Sandwell, 2011b), which defines the reference elevation for coastal flood hazard demarcation as 50 per cent of the calculated wave run-up on the natural shoreline. In this simplified assessment we have used the existing slopes on each profile, at the elevation of the Designated Flood Level (DFL) for a given year to calculate the wave run-up.

In a comprehensive study, consideration will need to be given as to what changes could be expected along the shoreline in response to the slow but perceptible rise in sea level over the years and to the shoreline erosion or the changes in shoreline character that can be expected in many areas along the City of Campbell River shoreline over the years. For this assessment we have assumed that either a natural wave cut scarp or a shoreline protection structure is likely to be present, at or near the high tide line. We have also assumed a lowering of the intertidal profile of 0.5 m.

In this assessment we have calculated the expected run-up based on the elevation reached by 2% of the waves expected in the seastate that can exist in the resulting depth of water at the future shoreline. A check was also made of the elevation at which a mean overtopping rate of 100 L/s/m was expected[4]. This elevation was generally within 0.1 m of the elevation corresponding to 50 per cent of the calculated wave run-up. This comparison suggests that the resulting FCLs, which include a further freeboard allowance of 0.6 m, provide a reasonable predictor of the likely FCLs appropriate for this simplified case example.

2.4 Flood Construction Levels

The resulting Flood Construction Levels for the three shoreline profiles shown in Figure 5 are summarized at the end of this section.

It should be noted that on profile 1, all of the estimated FCL's intersect the cliff, which is located approximately 12 m landward of the top of bank along the shoreline. In a comprehensive study, the setback in this area may need to consider the height of the cliff.

In the future on profiles 2 and 3, the existing land becomes flooded. In 2100, the land is awash, and in 2200 the land is flooded to a depth of approximately 0.6 m, not including the effect of any waves. The FCL's are estimated in these areas based on the wave crest elevations that can be expected. In a comprehensive study, the likely condition of the shoreline and land elevations due to shoreline erosion - or to any responses to the expected slow and perceptible shoreline erosion - should be considered.

[4] A mean overtopping rate of 100 L/s/m is often cited as an overtopping rate that can lead to flooding, to damage to buildings located near the shoreline and to dangerous conditions for pedestrians and vehicles.

The existing FCL for the City of Campbell River along the portion of the shoreline considered in this case example is +3.5 m CGVD28. On review, the existing FCL does not appear to include all the elements of storm surge, estimated wave effects, or freeboard that might be appropriate for the chosen design condition. In particular, the representative Natural Boundary that was identified at the time was estimated to be at an elevation of +2.0 m CGVD28, which is only 0.1 m above HHWLT. This elevation would likely only occur in a well protected location and it is unlikely to represent conditions along the present shoreline. An updated FCL based on the methodology used in this case example, is included in the tables below for the three profiles for information only.

2.4.1 Profile 1 – Vicinity of 5th Avenue

CASE	2010 "Updated" Guideline [a]	2100	2200
Reference Vertical Datum	CGVD28 = 0.0 m = +2.9 m CD		
Regional Sea Level Rise (m)	0	0.63	1.22
HHWLT	1.9	1.9	1.9
Total Storm Surge	1.5 [b]	1.5 [b]	1.5 [b]
Wave Effect	0.5	0.85	1.05
Freeboard Allowance	0.6	0.6	0.6
FCL	4.5	5.5	6.3

Note:
a: Methodology to derive FCL applied as per the case example described in the foregoing text but with no allowance for future sea level rise (i.e. present-day conditions).
b: 1/500 yr annual exceedance probability.

2.4.2 Profile 2 – Vicinity of Robert Ostler Park

CASE	2010 "Updated" Guideline [a]	2100	2200
Reference Vertical Datum	CGVD28 = 0.0 m = +2.9 m CD		
Regional Sea Level Rise (m)	0	0.63	1.22
HHWLT	1.9	1.9	1.9
Total Storm Surge	1.5 [b]	1.5 [b]	1.5 [b]
Wave Effect	0.6	0.5 [c]	0.8 [d]
Freeboard Allowance	0.6	0.6 [e]	0.6 [e]
FCL	4.6	5.1	6.0

Note:
a: Methodology to derive FCL applied as per the case example described in the foregoing text but with no allowance for future sea level rise (i.e. present-day conditions).
b: 1/500 yr annual exceedance probability.
c: land in this area is awash – Wave Effect includes expected wave set-up.
d: land in this area flooded – Wave Effect includes expected wave crest elevation.
e: allowance only - appropriate freeboard is structure dependent.

2.4.3 Profile 3 – Vicinity of Tyee Spit

CASE	2010 "Updated" Guideline [a]	2100	2200
Reference Vertical Datum	CGVD28 = 0.0 m = +2.9 m CD		
Regional Sea Level Rise (m)	0	0.63	1.22
HHWLT	1.9	1.9	1.9
Total Storm Surge	1.5 [b]	1.5 [b]	1.5 [b]
Wave Effect	0.4	0.5 [c]	0.8 [d]
Freeboard Allowance	0.6	0.6 [e]	0.6 [e]
FCL	4.4	5.1	6.0

Note:
a: Methodology to derive FCL applied as per the case example described in the foregoing text but with no allowance for future sea level rise (i.e. present-day conditions).
b: 1/500 yr annual exceedance probability.
c: land in this area is awash – Wave Effect includes expected wave set-up.
d: land in this area flooded – Wave Effect includes expected wave crest elevation.
e: allowance only - appropriate freeboard is structure dependent.

Ministry of Forests, Lands and Natural Resource Operations

Coastal Floodplain Mapping Guidelines and Specifications

Legend

- Municipal Boundary
- Reserve Boundary
- Contour (Major)
- Interpolated Contour (Minor)
- Tsunami Evacuation Limit
- Year 2010 Floodplain Limit
- Year 2100 Floodplain Limit
- Year 2200 Floodplain Limit
- 5.0 River Flood Isolines and FCL (Including 0.6 m Freeboard)

Use and Limitations of Floodplain Map:

1. Under the provisions of the Flood Hazard Statutes Amendment Act, 2003 (Bill 56), local governments have the role and responsibility for making decisions about local floodplain development practices, including decisions about floodplain bylaws within their communities. Information on floodplain management guidelines can be found in the BC Flood Hazard Area Land Use Management Guidelines.
2. Users must note the dates of base mapping, aerial photography, ground or bathymetric surveys and issue of mapping relevant to dates of development in the map area. Subsequent developments or changes within the floodplain or channel will affect flood levels and render site-specific map information obsolete.
3. The accuracy of the location of a floodplain boundary as shown on this map is limited by the base topography.
4. The floodplain limits are not established on the ground by legal survey. A site survey is required to reconcile property location, ground elevations and designated flood level information. Building and floodproofing elevations should be based on field survey and established benchmarks.
5. Flooding may still occur outside the defined floodplain boundary and the local government does not assume any liability by reason of the failure to delineate flood areas on this map.
6. The required or recommended setback of buildings from the natural boundaries of watercourses to allow for the passage of floodwaters and possible bank erosion is not shown. This information is available from the local government. In addition, site-specific setbacks from the floodplain limit must be considered.
7. Flood construction level is based on a global sea level rise of 1 m by the year 2100 and 2 m by the year 2200. May need to be revised in the future - see accompanying Design Brief dated March 31, 2011).
8. Coastal Flood Construction Levels (FCLs) estimated for areas South and North of 6th Avenue, as shown on map.

Notes on Map Data:

a. 2007 orthophotos provided by City of Campbell River.
b. 1 m contours provided by City of Campbell River (accuracy not available). Contour lines contain areas of missing data, which have not been filled. 0.5 m contours have been interpolated based on the source data.
c. Campbell River 200-Year Return Period flood isolines from GeoBC WMS data.

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Project No.	Date	Drawn By
2785-001	May 2011	JL

Sample Floodplain Map

City of Campbell River:

Downtown Area