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Climate Change Adaption Guidelines for Sea Dikes and Coastal Flood Hazard Land Use Sea Dike Guidelines

27 January 2011

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1 Introduction and Application of this Document

1.1 General

This document provides guidelines for the design of sea dikes to protect low lying lands that are exposed to coastal flood hazards arising from their exposure to the sea and to expected sea level rise due to climate change.

This document will supersede the related sections of the existing “**Dike Design and Construction Guide 2003**”, which means the “Dike Design and Construction Guide – Best Management Practices for British Columbia”, July 2003, published by the Province of British Columbia, Ministry of Water, Land and Air Protection (now the Ministry of Environment).

This document provides guidelines intended to assist diking authorities, design professionals and others in fulfilling dike design requirements as legislated under the British Columbia *Dike Maintenance Act*. This guideline document presents design standards relating to sea level rise and consequential aspects in a generalized form only. Application of this information for specific projects, which include new, repaired, upgraded or changed sea dikes, requires site specific design and expert advice. This guideline document does not specifically address geotechnical design, structural design or construction standards, which may be indirectly affected by some aspects of sea level rise. Qualified professionals with specialist engineering or environmental expertise must be involved and retained to design specific project components and to facilitate agency approvals.

This document, and the companion document “**Guidelines for Management of Coastal Flood Hazard Land Use 2010**”¹ are specific to flood hazards arising from the exposure of BC lands to the sea. In some locations, specifically river estuaries, the lands will also be exposed to other sources of flooding. These new documents are companion documents to the existing guideline documents which address flooding hazard from rivers². Analysis of flooding hazard from all sources – rivers and the sea - will be required in estuaries.

The Sea Level Rise projections and potential responses described in this document are drawn from the **Policy Discussion Paper 2010**³.

1.2 Acknowledgement

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

¹ “Guidelines for Management of Coastal Flood Hazard Land Use”- Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use in BC. Rev 0”. Prepared by Ausenco Sandwell for the British Columbia Ministry of Environment.

² “Dike Design and Construction Guide – Best Management Practices for British Columbia”, July 2003, published by the Province of British Columbia, Ministry of Water, Land and Air Protection (now the Ministry of Environment)

³ “Draft Policy Discussion Paper - Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use in BC. Rev 0”. Prepared by Ausenco Sandwell for the British Columbia Ministry of Environment.

2 Background

2.1 Scope

This guideline document describes the principles of determining the total water level and sea dike crest elevations for sea dikes, as legislated under the British Columbia *Dike Maintenance Act*. Design will be performed at different levels of detail:

- Conceptual design
- Feasibility design
- Detailed design.

This guideline is aimed at serving the conceptual design stage.

2.2 Definitions

A summary of definitions and terminology used in this document is provided in Appendix A.

Where possible the same terminology and definitions as used in the existing documents; **Dike Design and Construction Guide 2003**² and **Land Use Guidelines 2004**⁴ are used; however, as the existing terminology and definitions sometimes need modification, clarification or expansion to be appropriate for coastal conditions, in some cases new or revised terminology and definitions are proposed. It is recommended that the reader of the updated documents familiarize themselves with the updated terminology and definitions in Appendix A as necessary.

2.3 Reference Documents

This Guideline document refers to several publications that are recognized as current examples of best practice for the design of coastal engineering structures, including sea dikes. Where such reference is made it is intended to refer to the most current edition, as listed below, and to all amendments or updates published thereto. It should be noted that a Building Code or Standard does not exist in Canada for coastal engineering structures.

The referenced publications and Standards listed below are intended to provide guidance on internationally accepted best practice. In some cases inter-comparison of documents will reveal several approaches may apply. In these situations; theoretical analysis, evaluation of the approaches for application to the specifics of British Columbia coastal waters and recognized engineering practise should be used to select among alternative methods.

Direct measurement of specific parameters, over appropriate intervals of time, may also be necessary or advisable.

Detailed site or structure specific engineering investigations may also provide equivalent guidance for design.

2.3.1 Standards

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

⁴ “**Land Use Guidelines 2004**” means the Flood Hazard Area Land Use Management Guidelines, May 2004, prepared by the Ministry of Water, Land and Air Protection.

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

2.3.2 Guideline Documents

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

US Army Corps of Engineering, 2002. *Coastal Engineering Manual.* EM 1110-2-1100.

EA, ENW, KFKI. 2007. *EurOtop. Wave Overtopping of Sea Defenses and Related Structures: Assessment Manual.*

2.3.3 Specific References

Battjes, J A and Groenendijk, H W. 2000. *Wave Height Distributions on Shallow Foreshores.* Coastal Engineering.

Hydraulic Engineering Division, Rijkswaterstaat, (1998). *Dikes and Revetments – Design, Maintenance and Safety Assessment.*

3 Design Criteria

3.1 General Requirements

The primary function of a sea dike is to protect the people and assets behind the dike against the effects of flooding or inundation. A sea dike is not intended to protect the shoreline or the adjacent seabed against erosion, although this may become a secondary aspect of the sea dike design, or the sea dike may be incorporated into a larger project with erosion protection, shoreline restoration or marine habitat preservation as concurrent objectives.

Design criteria that are required but not specifically addressed in this guideline document include:

- The safety standard, design and service objectives to be achieved by the dike
- The design life of the dike
- Inspection, maintenance and replacement or decommissioning of the dike.

Guidance regarding these design criteria is provided in the companion document: **Policy Discussion Paper 2010**³.

3.2 Design Environment

3.2.1 General

This section describes the evaluation of physical environmental conditions that will be required to define the main functional or geometric aspects of a sea dike.

3.2.2 Location of Facility (Reference elevation – depth of water)

The water depths and terrestrial elevations at the location of a sea dike shall be determined from site-specific bathymetric and topographic surveys referenced to a common vertical and horizontal datum. Where bathymetric and topographic surveys are undertaken with respect to a separate datum, the relationship between the bathymetric datum and the topographic datum shall be defined over the entire project area.

The relationship between the bathymetric survey datum, the topographic survey datum and the tidal datum for the area shall also be defined over the project area⁵.

3.2.3 Sea Level Rise

Global Climate Change Sea Level Rise

Sea Level Rise is predicted to be moderate in the period from 2010 to 2025. However, the rate is predicted to increase more quickly in the period leading up to 2100, and then continue to increase steadily. For the purpose of this document the current definition of the expected Sea Level Rise is provided in Figure 3-1. The basis for this definition is provided in the policy document: **Policy Discussion Paper 2010**³.

⁵ In 2010 the vertical reference plane in Canada is in the process of being changed from a MSL related datum plane – technically known as CGVD28 – to a geoid based datum plan. The update program is described at http://www.geod.nrcan.gc.ca/hm/index_e.php. For the purpose of this document we use the term CGD to mean the datum as defined in 2010 and approximately equal to MSL.

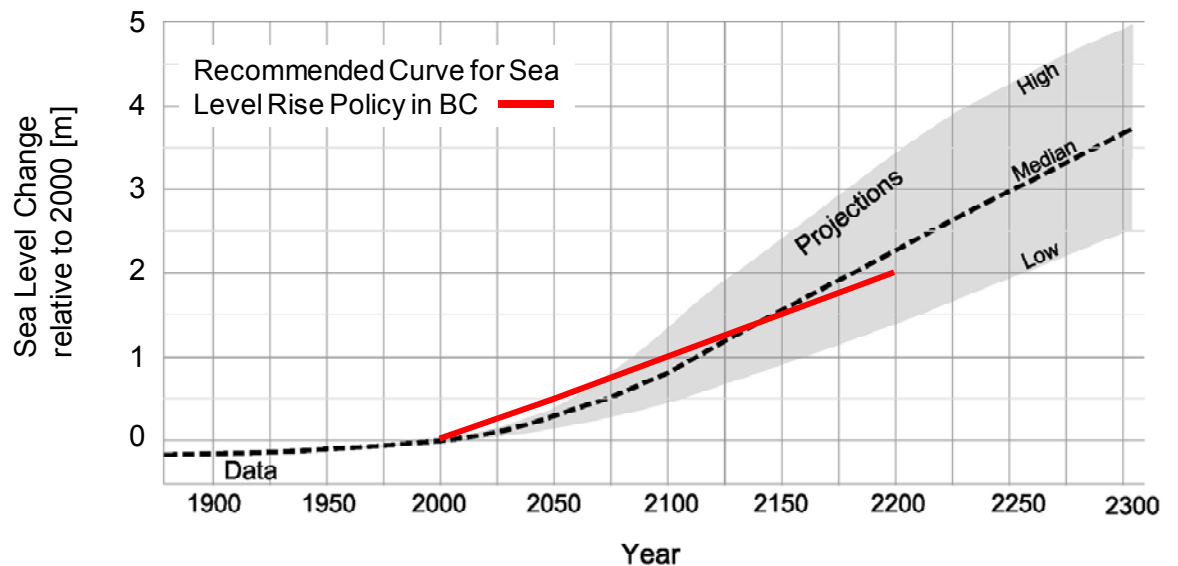


Figure 3-1: Projections of Sea Level Rise
source: Policy Discussion Paper (2010)

Figure 3-1 illustrates the range of uncertainty in projections, showing a median projection, as well as a range in projections from low to high. The uncertainty increases into the future. As described in the policy document: **Policy Discussion Paper 2010**³, it is recommended that sea dike design and assessment be based on the Recommended Curve for Sea Level Rise Policy in BC, shown on Figure 3-1.

Unless scientific information warrants an earlier review, the Recommended Curve should be updated in five years and then again by 2025, as well as at least once every 25 years thereafter.

Regional Sea Level Rise

Global sea level rise expectations must be adjusted to account for regional variations and for crustal movements particular to the area under consideration. Regional variations to be considered include:

- Variations particular to the Pacific Ocean Basin and to the NW Pacific portion;⁶
- Variations particular to coastal British Columbia waters;
- Local variations caused by crustal movement, leading to land uprising or subsidence, which may offset or exacerbate the sea level rise.

The **BC Sea Level Report (2008)** provides the most recent summary of expected regional or local climate change effects on sea level rise. Recommended local variations for crustal movement are

⁶ Available satellite measurements of recent sea level rise show considerable variation around the globe compared to the often quoted global means. Specific information on the regional variation expected over the North Pacific and offshore coastal British Columbia during upcoming climate change is not as readily available at this time. This regional effect remains an element of uncertainty.

provided in Chapter 3.0 - **BC Sea Level Report (2008)**. Additional detail on subsidence rates for specific areas of coastal BC area are provided in Appendix B.

In general terms, for most of coastal British Columbia, with the exception of the Lower Mainland area and the Richmond – Delta regions in particular, vertical land movement is positive (rising) at rates between 1 and 3 mm/yr. Over a period of 100 years this will decrease the expected global SLR by 0.1 to 0.3 m, but not enough to overcome the expected effects of climate change.

Subsidence is expected in the Richmond-Delta region at average rates of 1 to 2 mm/yr. Over a period of 100 years these rates will increase the expected sea level rise due to global SLR by 0.1 to 0.2 m.

3.2.4 Astronomical Tides

Predictions of expected water levels due to astronomical tides are available throughout coastal British Columbia from the Canadian Hydrographic Service (CHS), Fisheries and Oceans Canada and are published annually under the authority of CHS. Volumes 5 through 7 of the Canadian Tide and Current Tables (issued annually) provide sufficient information on astronomical tidal characteristics for planning and preliminary design throughout most of BC coastal areas, through a combination of Principal Reference Ports and numerous Secondary Ports.

As the tidal information at Secondary Ports is often based on limited durations of observations (typically one month or possibly less), they may not be current and as they only provide corrections for times and heights of specific tide parameters, project specific tidal measurement programs must be undertaken for all projects, at the project location, prior to detailed design.

Indicative tidal ranges are summarized in Table 3-1. The published data in Volumes 5 through 7 of the Canadian Tide and Current Tables for specific areas within each general region should be consulted as tidal ranges can vary by 1 m or more within each region. Tidal ranges within a river estuary will also vary significantly; both by location within the estuary and according to river discharge. Guidelines are available in Volume 5 for the Fraser River.

The tide ranges given in Table 3-1 have additional variation as noted below:

- Inter-annual variation due to the 18.6 year cycle of tides (typically of the order of ± 0.1 m)
- Intra-annual (seasonal) variation due to the particulars of the astronomical bodies and orbits driving the tidal forcing

In coastal British Columbia waters, the mean tidal water level during the typical stormy winter season (approximately mid-October through mid-January) will not be equal to the MWL from the CHS published information as represented below in Table 3-1.

Definition of the Designated Flood Level for the design of a sea dike will require definition of a combination of appropriate tidal water levels and meteorological related water levels.

Joint probability analysis methods are often used to define appropriate combinations of tide and storm surge that reflect the times of occurrence of the two processes; however, as tide is totally independent of storm occurrence and resulting storm surge, reasonable and valid estimates can be made by treating the statistics of each process as independent. In this case, the combined probability is simply the product of the probability of high tide during the time period of interest and the probability of the Designated Storm.

Guidance for defining appropriate combinations of storm surge is provided below in Section 3.2.5.

Table 3-1: Tidal Ranges for General Regions
Source: Canadian Tide and Current Tables – Volumes 5, 6 and 7 (2010)

Tide Parameter	West Coast Vancouver Island	Juan de Fuca Strait	Georgia Strait	Central Coast	Northern BC
	Meters with respect to CGD				
HHWLT	2.0	1.5	2.0	2.7	4.2
HHWMT	1.3	0.6	1.3	1.7	2.9
MWL	0	0	0	0	0
LLWMT	-1.5	-1.0	-1.9	-1.0	-2.1
LLWLT	-2.2	-1.9	-3.1	-2.9	-3.4
Data for General Regions based on:					
West Coast Vancouver Island: Tofino parameters can vary up to ± 0.3 m along the coast					
Juan de Fuca Strait: Victoria parameters can vary up to ± 0.4 m along the strait					
Georgia Strait: Point Atkinson parameters can vary up to ± 0.4 m over the strait					
Central Coast: Bella Bella parameters can vary up to ± 1.0 m along the coast					
Northern BC: Prince Rupert parameters can vary up to ± 2.5 m along the coast					
Note:					
- Tide parameters on the west coast of the Queen Charlotte Islands (Haida Gwaii) are more similar to the Central Coast than to Northern BC.					
- Ranges based on MWL as published by CHS ≈ 0.0 m CGD					

3.2.5 Meteorological Water Level Effects

Sea levels along coastal British Columbia are also affected by meteorological and oceanographic conditions specific to the area that result in differences between the predictable astronomical tides (Section 3.2.4) and the actual water level at a given time. These conditions include:

- Sea level change due to changes in atmospheric pressure.
- Sea level change due to the effects of strong winds blowing over the water surface.
- Sea level change due to wave momentum effects in shallow water
- Sea level change due to changes in ocean currents or temperature.

The integrated effect of these forcing mechanisms can be seen in measured water level data by removing the predicted astronomical tide, which then defines a residual water level that reflects all of the forcing mechanisms outlined above.

In coastal British Columbia waters, the characteristics of residual water levels can be defined with the assistance of the long term measured water level records available from several long term CHS tide recording stations along the coast. Long records of recorded total water levels are available at the stations summarized in Table 3-2.

Table 3-2: Summary of Long-Term Tidal Stations in BC

Region	Station	CHS Station ID	Years of Coverage	Comments
West Coast	Tofino	8615	1909 - present	Gaps between 1920 and 1940
West Coast	Bamfield	8545	1969 – present	–
Juan de Fuca Strait	Victoria	7120	1909 – present	Gaps between 1914 and 1950
Georgia Strait	Point Atkinson	7795	1914 – present	Gaps between 1923 and 1927 and 1939 - 1944
Northern Georgia Strait	Campbell River	8074	1958 – present	Gaps between 1958 and 1972
Central Coast	Bella Bella	8976	1906 – present	Gaps between 1907 and 1962
Northern BC	Prince Rupert	9354	1909 – present	Gaps between 1928 and 1939
Haida Gwaii	Queen Charlotte City	9850	1957 – present	Gaps between 1959 - 1964

A preliminary review and evaluation of the residual water levels resulting from these stations is provided in the support materials provided in Appendix D.

Regional Meteorological Effects

A preliminary review of the residual water levels achieved at each station (Appendix D) indicates that the general characteristics of residual water levels can be summarized on a regional basis as follows:

- West Coast Vancouver Island – Juan de Fuca Strait and Georgia Strait: Tofino
- Central Coast – Queen Charlotte Islands – North Coast: Prince Rupert

The larger residual water levels recorded at the Tofino and Prince Rupert tide gauge locations are shown in Figure 3-2, which shows the peak water level after the predicted tide is removed. For clarity the only events shown are those over a threshold chosen so that at least one event is present for every year of record. A review of the higher events from each data set confirmed that the events were not spikes, with limited (one or two hours) duration above the threshold, and that they correspond to known severe storms on the coast.

A preliminary extreme value analysis of the available data sets at Tofino and Prince Rupert, using a Peak over Threshold extreme value methodology, after ensuring that at least 72 hours exists between each event, and after considering the effect of various threshold values, gives the estimates of expected residual water levels for a range of annual exceedance probabilities (or return periods) summarized in Table 3-3.

A comparison of inter-station residual time series during large events indicates that the peak residual values vary approximately ± 0.1 m among the stations within the two groups indicated above.

Reference is also made to section 8.2.4, item 2 of the Draft Policy Discussion Paper - Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use in BC. Rev 0".

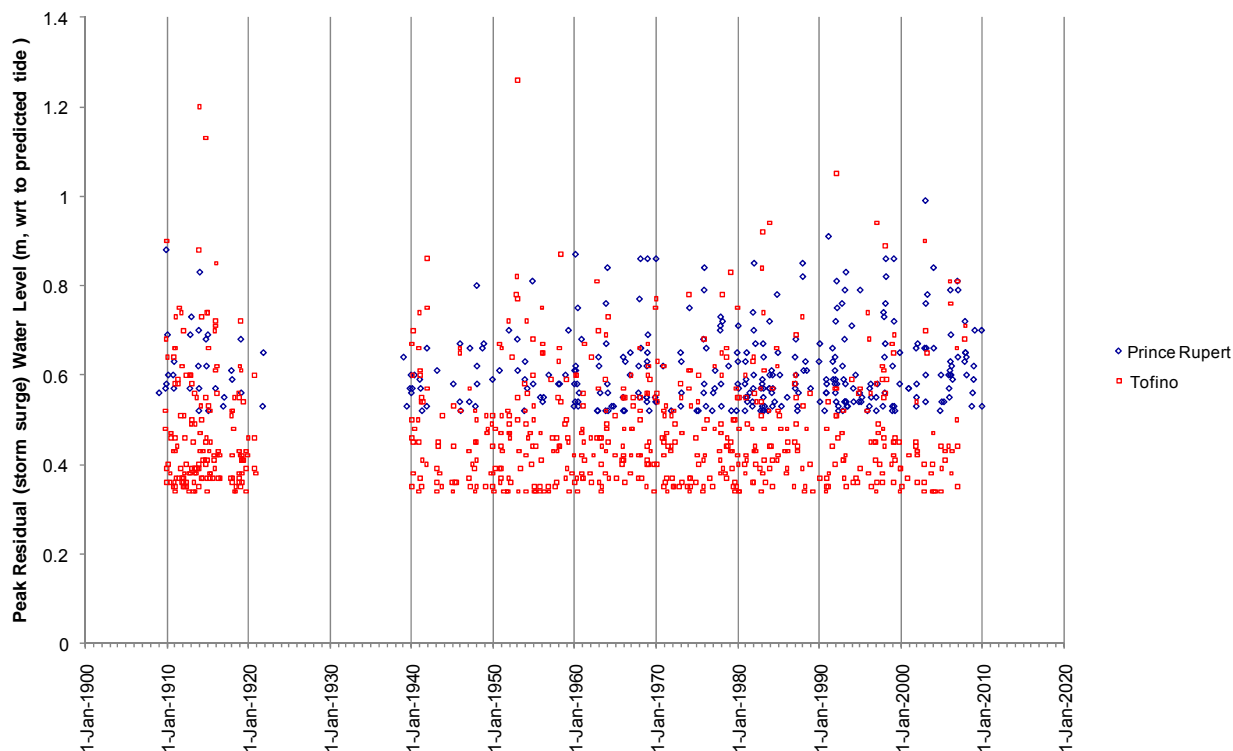


Figure 3-2: Residual Water Levels – Coastal British Columbia

Table 3-3: Expected Magnitude of Residual Water Level Events

AEP (per cent)	AEP (1/years)	West Coast Vancouver Island	Juan de Fuca Strait	Georgia Strait	Central Coast	North Coast BC
50%	Annual	0.73	Same as West Coast	Same as West Coast	Same as North Coast	0.75
20%	1/5 yr	0.83				0.81
10%	1/10 yr	0.9				0.86
4%	1/25 yr	1.0				0.91
2%	1/50 yr	1.1				0.95
1%	1/100 yr	1.2				1.0
0.2 %	1/500 yr	1.3				1.1
0.1 %	1/1000 yr	1.4				1.1

Local Meteorological Effects

The tide gauges used for the analyses summarised above are generally located within harbours or on the open coast in deep water. Many sea dikes will be located inshore of the inter-tidal profile and may have extensive areas of shallow water or drying inter-tidal banks – ie: Boundary Bay or

the West Richmond sea dikes - offshore of the dike. In these situations the effect of strong winds and waves may further increase the water level during storms and site specific analysis will be required.

Methodologies for assessing the magnitude of additional surge are outlined in the Reference Publications.

Examples of the magnitude of these local effects are provided in the sample cases in Appendix C.

3.2.6 Wave Climate

Incident Deepwater Wave Climate

Definition of appropriate sea dike crest elevations will require specification of the incident wave climate during storms that are consistent with the selected design criteria. For most sea dikes, with their seaward face situated at or above normal high tide elevations, the design wave climate will generally be controlled by the depth of water a short distance seaward of the toe. Specification of the appropriate location to define the design wave climate is generally unique to the design methodology being used for a specific component of the dike.

Reference must be made to the specific requirements in the Reference Publications.

Local Wave Climate at the Dike

As a preliminary guideline, the maximum seastate⁷ that can exist in a given depth of shallow water can be estimated using the procedures outlined in CIRIA; CUR; CETMEF (2007) or US Army Corps of Engineering (2002).

The seastate that can exist at a sea dike depends strongly on the water depth at the toe of the sea dike, the slope of the foreshore in front of the sea dike and in some cases on the seaward slope of the sea dike itself. As guidance, the maximum seastate (H_s)⁷ may be between approximately 0.5 and 1.2 times the depth of water. In general, an iterative procedure will be required during design to define the seastate.

It will also be necessary to check that the seastate at the toe of the dike is consistent with the Designated Storm for the annual exceedance probability specified for the sea dike planning or design process.

The details of the design seastate that are required for planning or design can be defined using the procedures outlined in EA, ENW, KFKI (2007) or specifically in Battjes, et al. (2000).

3.2.7 Scour

Waves and currents may cause scour to occur on the seabed adjacent to a sea dike. The scour depth that may occur either during the design life of the sea dike or during the Designated Storm should be considered and either allowed for in defining the necessary sea dike crest elevation or scour protection should be provided as necessary.

⁷ The term “seastate” is used in this document to encapsulate, in a general way, all of the parameters and characteristics that may be needed during design to define the waves at a given instant in time. The sea state is the general condition of the free surface of a body of water—with respect to wind waves and swell—at a certain location and moment. The sea state is characterized by statistics, including wave height(s), period(s), distribution and power spectrum. The sea state varies with time, as the weather or oceanographic factors change. For engineering purposes the seastate is often characterized by the significant wave height, H_s .

3.2.8 Freeboard

It is common practice in offshore and coastal engineering codes and standards of practice to include provision for uncertainties by specifying a minimum freeboard or similar allowance. Generally the freeboard accounts for the known uncertainties in technical elements of the design methodology, i.e., the appropriate wave theory for the depth of water or variations in seabed conditions along the shoreline, among others.

In the specific case of the sea level rise to be considered for design, the problem is compounded by uncertainties surrounding the present estimates of the future extent of climate change, the resulting sea level rise, the time frame over which a particular decision is being made and in some cases for the actions or consequences of other stakeholders or property owners that may directly affect a particular shoreline area.

A more detailed review of issues related to appropriate freeboard allowances is provided in the companion policy document: **Policy Discussion Paper 2010**³.

As a minimum, it is recommended that the present freeboard allowance of 0.6 m should be included in sea dike design, above and beyond any specific allowances adopted to deal with the known uncertainties for the area in question. These known uncertainties should be explicitly stated during design.

4 Sea Dike Design

4.1.1 Crest Elevation

General

The crest elevation of a sea dike shall be established to provide the protection required during the Designated Storm.

The Sea Dike Crest Elevation can be defined based on the following:

Designated Flood Level + Wave Run-up + Freeboard

or:

Designated Flood Level + Acceptable Crest Height

where:

Wave Run-up = vertical distance above the mean water level exceeded, by no more than 2% of the waves at the toe of the sea dike

Acceptable Crest Height = vertical distance above the mean water level required to keep any wave overtopping below the chosen criteria for acceptable rates of overtopping, as summarized below in Table 4-1 or Table 4-2.

Alternatively an Acceptable Crest Height can be defined based on the results of a Quantitative Risk Analysis (QRA) process that identifies an acceptable amount of inundation during the Designated Storm.

In general, a Sea Dike Crest Elevation is established so that any overtopping that occurs during the Designated Storm is within limits set to ensure that inundation behind the dike during the storm is acceptable, that it is within the limits considered during the design of the dike armour components, on the seaward and landward faces, and on the sea dike crest, and that it is consistent with any requirement for personnel to be present on the dike during the Designated Storm Event.

The total quantity of overtopping during the Designated Storm should be defined to ensure that it is consistent with the FCL defined for inundation behind a Sea Dike.

Overtopping of a sea dike can take two main forms. If wave runup is high enough, relative to the crest elevation of the dike, water can pass over the dike as a nearly continuous sheet or plume of water. In the second case, as waves break against the seaward face, a mixture of air and water droplets – spray – can be carried over the dike, either by the momentum of the breaking wave or by the added effect of entrainment into the onshore winds. Over time, if left undrained, the volume of water contained in the spray can accumulate and result in flooding (inundation) behind the dike.

In general, it is usually uneconomic to design a sea dike with a crest elevation high enough to prevent all overtopping. In many cases, other factors, including available land, existing land uses, soil conditions, access, visibility over the dike or habitat issues may limit the sea dike crest elevation.

Guidance on acceptable limits for overtopping is available in the Reference Publications. As initial guidance, the average or mean overtopping discharges summarized below in Table 4-1 and Table 4-2 can be used. The criteria in Table 4-1 apply to a conventional sea dike with gentle seaward slopes. The criteria in Table 4-2 can be used to estimate the crest elevation required for a vertical seawall that starts at or near the high tide elevation.

It should be noted that these criteria do not cover all possible configurations of sea dikes, or all issues that may be pertinent, and detailed engineering investigations may be required in specific cases.

Table 4-1: Available Criteria for Acceptable Rates of Overtopping at a Sea Dike

Hazard and Reason	Mean Discharge liters/s/m	source
No damage if sea dike crest or rear slope is well protected	50 - 200	EA, ENW, KFKI (2007)
No damage if sea dike crest or rear slope is a grass covered clay embankment	1-10	EA, ENW, KFKI (2007)
No damage if sea dike crest or rear slope is not protected	0.1	EA, ENW, KFKI (2007)
Note: The mean discharge (q) is defined at the crest of the sea dike.		

Table 4-2: Available Criteria for Acceptable Rates of Overtopping at a Vertical Seawall

Hazard and Reason	Mean Discharge liters/s/m	source
No damage expected to building structural elements for a building located behind the seawall. (q is defined at the building)	1	EA, ENW, KFKI (2007)
No damage to Equipment set back 5 – 10 m from edge of seawall crest. (q is defined at the sea dike)	0.4	EA, ENW, KFKI (2007)
Note: The existing criteria are vague on the definition of a building structural element.		

The criteria in Table 4-1 were partially validated in 2007 by tests using an overtopping simulator on a real sea dike in the Netherlands. The dike had an landward slope of 1:3 (V:H) and was constructed of clay (less than 30 per cent sand) with a thick grass sod cover. The sea dike successfully withstood a series of simulated 6 hour storms, up to a mean overtopping rate of 50 liters/s/m.

After the first test, the grass sod was removed and the sequence of simulated storms was repeated. It was found that erosion damage started on the “unprotected” dike at an overtopping rate of 0.1 liters/s/m. After 6 hours of overtopping at a mean rate of 10 liters/s/m, the sea dike was considered “*not too far from initial breaching*”.

Similar testing has also found that if knowledgeable people (for instance; maintenance or inspection crews) or vehicles (for inspection during storms) are present on the dike, then safety considerations may limit acceptable rates of overtopping to between 1 and 50 liters/s/m⁸.

Along a dike of approximately 1000 m length, a limit of 10 liters/s/m implies that during a six hour storm the total volume of water overtopping the sea dike could amount to:

$$10 \text{ liters/s/m} \times 1000 \text{ m} \times 6 \text{ h} \times 3600 \text{ sec/hr} = 216 \text{ million liters} = 216,000 \text{ m}^3$$

This volume of water will amount to approximately 2 m of standing water over a land area of 10 hectares, unless it can be drained away.

In the case of the criteria in Table 4-2, it must be noted that reliable guidance does not exist to define the effect of distance on the decay rate of overtopping and therefore it may not be clear how far behind a given dike or seawall a building must be to satisfy the 1 liter/m/s threshold. Site specific engineering investigations are warranted in many situations.

Specification of a suitable Sea Dike Crest Elevation will generally be an iterative process as the volume of overtopping for a given Dike Designated Storm will be significantly influenced by the design of the seaward face of the sea dike. Acceptable quantities of overtopping may also be significantly influenced by the design of the landward face of the sea dike, especially if space or land use does not permit the 1:3 (V:H) landward slope implied by the criteria in Table 4-1. Case specific engineering investigations will be warranted in many situations.

Examples of the application of the threshold conditions in Table 4-1 and Table 4-2 are provided in Appendix C.

4.1.2 Seaward Face Design

General

The seaward face of a sea dike shall be designed to be stable and not vulnerable to breaching during the Designated Storm. The design of the seaward face shall take into consideration any scour or erosion that may occur in front of the dike during the Designated Storm.

Guidance

Guidance for the design of the seaward face of a sea dike is provided in the Reference Publications.

4.1.3 Landward Face Design

General

The landward face of a sea dike shall be designed to be stable and not vulnerable to erosion or scouring by overtopping water during the Designated Storm.

Guidance

Guidance for the design of the landward face of a sea dike is provided in the Reference Publications.

It should be noted that design guidance for the landward face of a sea dike that is exposed to overtopping is, in general, limited in scope. Structure specific detailed engineering investigations will likely be required if the design is different from the 1:3 (V:H) landward slope implied by the criteria in Table 4-1 and Table 4-2.

⁸ These limits represent the extreme range that might be applicable. An upper limit of 10 liters/s/m may be more appropriate if personnel are outside of a vehicle.

5 Bibliography

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Appendix A – Definitions, Terminology and Acronyms

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1 Definitions

The incorporation of climate change related sea level rise considerations into existing BC Ministry of Environment documents is structured into three documents:

- **Draft Policy Discussion Paper 2010**
- **Sea Dike Guidelines 2010**
- **Guidelines for Management of Coastal Flood Hazard Land Use 2010.**

The definitions in these documents follow, where possible, the definitions and terminology that are either consistent with the existing documents or consistent with existing practise worldwide. In some cases existing definitions or terminology require modification or clarification for application to coastal flooding or sea dike application in a climate change driven sea level rise scenario.

Existing definitions are provided below in italics followed by any necessary modification, clarification or addition to the definitions or terminology in the existing documents.

Acronyms associated with the definitions that are used in the text are shown in brackets.

1.1 Annual Exceedence Probability (AEP)

The probability, likelihood or chance of a particular event (e.g., a storm or a storm surge) being equalled or exceeded in any one year. It is defined either as a number between 0 and 1 or as a corresponding percentage.

An AEP of 0.01 means there is a 1% chance of an event, of a given magnitude or larger, occurring in any single given year. An AEP of 0.01 or 1/100 yr also suggests that on average, under certain conditions, the Average Return Period, or interval between recurrences of this event, is approximately 100 years.

1.2 Average Return Period

Over a long period of time, the average number of years between occurrences of a particular event. In general, the average return period is the reciprocal of the AEP – the relationship is illustrated in the following table:

AEP probability	AEP per cent	Average Return Period (years)	Probability decreases ↓
0.5	50%	2	
0.1	10%	10	
0.01	1%	100	
0.005	0.5%	200	
0.001	0.1%	1000	
0.0005	0.05%	2000	
0.0002	0.02%	5000	
0.0001	0.01%	10000	

Using AEP to define the likelihood of hazard events is preferable to the average return period as return period can lead to a false sense of security created by the belief that the indicated number of years will pass before the next event of that magnitude occurs.

1.3 Designated Flood

A flood, which may occur in any given year, of such a magnitude as to equal a flood having a 200-year recurrence interval based on a frequency analysis of unregulated historic flood records or by regional analysis where there is inadequate streamflow data available. Where the flow of a large watercourse is controlled by a major dam, the designated flood shall be set on a site-specific basis.

In coastal areas, the existing definition of a Designated Flood is not appropriate as the probability of flooding from the sea is the result of the joint occurrence of tide and a storm crossing the coastal waters of British Columbia and at some time in the future, sea level rise due to climate change.

In estuaries, where a river discharges into the sea, the definition of the Designated Flood applies to the river.

In these documents the definition “Designated Flood” is replaced with the term “Designated Storm” as defined below.

1.4 Designated Flood Level (DFL)

The observed or calculated elevation for the Designated Flood and is used in the calculation of the Flood Construction Level.

In coastal areas, the Designated Flood Level (DFL) includes the appropriate allowance for future sea level rise, tide and the total storm surge expected during the designated storm.

1.5 Designated Storm (DS)

A storm, which may occur in any given year, of such a magnitude as to equal a storm having the designated annual exceedence probability (AEP).

The Designated Storm has several phenomena associated with it that will define components of the Designated Flood Level, including storm surge, wind set-up, wave run-up and overtopping for the storm. These include:

- A time series of atmospheric pressure during the passage of the storm over the area in question
- A time series of wind speed and direction during the passage of the storm over the area in question
- A time series of wave conditions, including wave heights, periods and directions during the passage of the storm in question.

1.6 Diking Authority

- (a) The commissioners of a district to which Part 2 of the Drainage, Ditch and Dike Act applies,*
- (b) A person owning or controlling a dike other than a private dike,*
- (b1) If the final agreement of a treaty first nation so provides, the treaty first nation in relation to dikes on its treaty lands,*

(c) *A public authority designated by the minister as having any responsibility for maintenance of a dike other than a private dike, or*

(d) *A regional district, a municipality or an improvement district.*

1.7 Flood Construction Level (FCL)

Uses the Designated Flood Level plus an allowance for Freeboard to establish the elevation of the underside of a wooden floor system or top of concrete slab for habitable buildings. In the case of a manufactured home, the ground level or top of concrete or asphalt pad, on which it is located, shall be equal to or higher than the above described elevation. It also establishes the minimum crest level of a Standard Dike. Where the Designated Flood Level cannot be determined or where there are overriding factors, an assessed height above the natural boundary of the water-body or above the natural ground elevation may be used (as defined in the Land Use Guidelines 2004).

In coastal areas the FCL does not relate to the crest level of a sea dike, nor does it relate to the crest level of flood proofing fill exposed directly to the designated flood level. The FCL does; however, include wave – structure interaction effects, to be determined at the location of the site of the building.

1.8 Flood Construction Reference Plane (FCRP)

The vertical elevation of an estimated future Natural Boundary from which the FCL is determined.

1.9 Flood Plain

A lowland area, whether diked, flood proofed, or not, which, by reasons of land elevation, is susceptible to flooding from an adjoining watercourse, ocean, lake or other body of water and for administration purposes is taken to be that area submerged at the Designated Flood Level.

In coastal areas the concept of the Flood Plain has been extended to a “Sea Level Rise Planning Area”; defined below. Special measures may be warranted in this area.

1.10 Flood Proofing

The alteration of land or structures either physically or in use to reduce flood damage and includes the use of building setbacks from water bodies to maintain a floodway and allow for potential erosion. Flood Proofing may be achieved by all or a combination of the following:

- *Building on fill, provided such fill does not interfere with flood flows of the watercourse, and is adequately protected against floodwater erosion*
- *Building raised by structural means such as foundation walls, columns, etc.*
- *A combination of fill and structural means.*

In coastal areas exposed to flooding, construction of fill as a flood proofing measure may substantially increase the freeboard required to define the FCL, if the fill is directly exposed to the Designated Flood Level. In this case, the FCL must be equivalent to the crest level of a sea dike with the same characteristics as the seaward face of the fill..

1.11 Freeboard

A vertical distance added to the Designated Flood Level. Used to establish the Flood Construction Level.

In coastal areas, the vertical distance to be added to a Designated Flood Level is site and structure specific.

1.12 Natural Boundary

Means the visible high watermark of any lake, river, stream or other body of water where the presence and action of the water are so common and usual and so long continued in all ordinary years as to mark upon the soil of the bed of the lake, river, stream or other body of water a character distinct from that of the banks thereof, in respect to vegetation, as well as in respect to the nature of the soil itself (Land Act, Section 1). In addition, the natural boundary includes the best estimate of the edge of dormant or old side channels and marsh areas. For coastal areas, the natural boundary shall include the natural limit of permanent terrestrial vegetation.

Natural Boundary is an established concept in BC law – and reflects a change in vegetation and soil based on effects of the sea. In the **Flood Hazard Area Land Use Guidelines 2004**, building setbacks were established from Natural Boundary, on the unstated assumption that the location of Natural Boundary is relatively static (other than erosions and accretions).

Natural boundary is, in practice, often difficult to determine in the field or from remote survey. In coastal areas, the Natural Boundary reflects a snapshot historical record of tide, storm surge and wave runup effects, which may be the mark of a recent storm in an ordinary year or it may be the mark of the most severe storm in recent times. There is no way of knowing for certain. A technical basis for the Natural Boundary in coastal areas is site and time specific. In the future the location and elevation of a Natural Boundary will change from time to time due to changes associated with sea level rise and it will likely lag sea level rise. It is also unlikely to immediately reflect the action of the water, especially the storm surge and waves, during a Designated Storm.

1.13 Project Life

The number of years a particular project; including a sea dike, a building or a community, is intended to serve before it is replaced, upgraded or dismantled. Regular maintenance to ensure the project provides the intended purpose is expected during the project life.

1.14 Sea Dike

A dike, floodwall or any other thing that prevents flooding of land by the sea. As defined in the Dike Maintenance Act, “dike” means “an embankment, wall, fill, piling, pump, gate, flood box, pipe, sluice, culvert, canal, ditch, drain”.

1.15 Sea Dike Crest Elevation

Sea Dike Crest Elevation has essentially the same meaning as “*dike crest height*” in the existing document “**Dike Design and Construction Guide 2003**”. However, the existing definition of dike height suggests that consideration of wave run-up and set-up is optional. The term Sea Dike Crest Elevation is defined to specifically cover scenarios where wave run-up, overtopping and wind and wave setup must be included in defining the height of the dike.

1.16 Sea Dike System

A system of: dikes, dunes, berms or natural shorelines that provide a similar function; and associated engineering works (e.g., tidal gates, outfalls, outlet structures, seawalls, quay walls, ramps, adjacent building features, etc.) used to protect land from flooding or inundation.

In the Netherlands where dike systems are highly evolved, a dike system is termed a “dike ring” that forms the flooding defence for a region. There are approximately 95 such rings in

the Netherlands and each ring is the responsibility of a separate organizational entity, subject to national overview.

In BC, multiple Diking Authorities may share responsibility for the same sea dike system.

1.17 Sea Level Rise (SLR)

An allowance for increases in the mean elevation of the ocean associated with future climate change, including any regional effects such as crustal subsidence or uplift.

1.18 Sea Level Rise Planning Area (SLR Planning Area)

An area of land that may be subject to future flooding due to Sea Level Rise. This area defines a future coastal flood plain. The SLR Planning Area extends from the existing Natural Boundary landward to the highest predicted point of potential flooding related to SLR plus flooding expected from the combination of high tide, total storm surge and expected wave runoff during the Designated Storm.

Predictions of SLR for the SLR Planning Area definition shall use best predictions for minimum periods of 90-100 years and 200 years forward. From time to time, both the Natural Boundary and the predictions for SLR are subject to change, and therefore the extent of a SLR Planning Area may be revised at regular intervals in the future.

1.19 Seastate

The term “seastate” is used to encapsulate, in a general way, all of the parameters and characteristics that may be needed during design to define the waves at a given instant in time. The sea state is the general condition of the free surface of a body of water—with respect to wind waves and swell—at a certain location and moment. The sea state is characterized by statistics, including wave height(s), period(s), distribution and power spectrum. The sea state varies with time, as the weather or oceanographic factors change. For engineering purposes the seastate is often characterized by the significant wave height, H_s .

1.20 Setback

Means withdrawal or siting of a building or landfill away from the natural boundary or other reference line to maintain a floodway and to allow for potential land erosion.

1.21 Standard Dikes

Dikes built to a minimum crest elevation equal to the Flood Construction Level and meeting standards of design and construction approved by the Ministry of Environment and maintained by an ongoing authority such as a local government body.

1.22 Storm Surge

A change in water level caused by the action of wind and atmospheric pressure variation on the sea surface. The typical effect is to raise the level of the sea above the predicted astronomical tide level, although in some situations, such as when winds blow offshore, the actual water level may be lower than that predicted. The magnitude of a storm surge on the BC coast will be dependent on the severity and duration of the storm event in the North Pacific, its track relative to the BC coast and the seabed bathymetry at the site.

1.23 Total Storm Surge

The combination of the storm surge generated in deep water plus the additional local surge or wind setup generated by the effect of the winds during the Designated Storm over shallow

water at a particular site. In general the deep water storm surge is nearly the same as that recorded at a tidal gauging station. Additional surge may occur at other sites. For planning purpose, winds during a Designated Storm will start to generate local surge in water depths less than 30 m.

1.24 Wave Run-up

The vertical distance that waves run-up the seaward slope of a structure or a shoreline. The vertical distance is measured from the mean water level, which is the same as the Designated Flood Level.

For coastal flooding hazard management the Wave Run-up is taken as 50 per cent of the calculated run-up elevation on the natural shoreline. This ratio is based on analysis completed for this assignment (2010) and may be revised as more information becomes available.

For defining a Sea Dike Crest Elevation the Wave Run-up is taken to be the vertical distance exceeded by no more than 2% of the waves during the Designated Storm at the toe of the sea dike

1.25 Wave Set-up

An increase in mean water surface close to the shoreline caused by wave action; important during storm events as it results in a further increase in water level above the tide and surge levels, landward of the location where waves start to break. Wave set-up will lead to larger waves existing at the seaward toe of a sea dike than might otherwise be expected.

1.26 Wave Overtopping

The passage of water over the top of a sea dike as a result of wave runup or related surge and setup. Water overtopping a sea dike may pass over the dike as a flow of water or as spray and the specific characteristics are site and structure specific.

1.27 Wind Set-up

A rise of the water surface above the water level on the open coast due to the local action of wind stress on the water surface.

2 Acronyms and Symbols

2.1 CD

Tide and chart datum – in Canadian waters the plane below which the tide will seldom fall. Tide datum and chart datum is usually the same provided the chart is the largest scale available chart for area. For a site specific survey tide and chart (sounding) datum may be different and the specifics should be stated explicitly.

2.2 CGD

Canadian Geodetic Datum. In 2010 the vertical reference plane in Canada is in the process of being changed from a MSL related datum plane – technically known as CGVD28 – to a geoid based datum plan. The update program is described at http://www.geod.nrcan.gc.ca/hm/index_e.php. The term CGD is taken to mean the datum as defined in 2010 and approximately equal to MSL.

2.3 CHS

Canadian Hydrographic Service

2.4 CIRIA; CUR; CETMEF

European agencies sponsoring the “Rock Manual”

2.5 DPA

Development Permit Area

2.6 EA, ENW, KFKI

European agencies sponsoring the “EurOtop” Manual

2.7 GCM

Global Climate Model

2.8 GHG

Green house gases

2.9 $H_{1/10}$

Mean height of the highest 10 per cent of waves in a given seastate

2.10 H_s

Significant wave height – the mean height of the highest 1/3 of waves in a given seastate – approximately equal to the wave height estimated at sea by experienced observers.

2.11 HHWLT

Higher high water large tide

2.12 HHWMT

Higher high water mean tide

2.13 IPCC

International Panel on Climate Change

2.14 LLWLT

Lower low water large tide

2.15 LLWMT

Lower low water mean tide

2.16 MWL

Mean water level

2.17 QRA

Quantitative Risk Analysis

2.18 $R_{2\%}$

Wave run-up height exceeded by 2% of waves in a given seastate

Appendix B – Uplift and Subsidence Rates

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1 Uplift and Subsidence Rates

1.1 Introduction

This Appendix provides a brief summary of the available information on subsidence and uplift rates along the British Columbia coast.

The **BC Sea Level Report (2008)** – Chapter 3 - provides a description of crustal movements along the coast of British Columbia and a brief summary of rates for selected locations. More specific site detail is provided in Table 1-1 based on an unpublished addendum to the **BC Sea Level Report (2008)** provided by BCMOE.

1.2 Site Specific Data

The data in Table 1-1 summarizes the rates of uplift (positive) or subsidence (negative) and the standard error based on relative sea-level rates corrected for eustatic sea level rise (tide gauge stations) or on absolute trends of vertical motion (GPS stations).

Table 1-1: Table of Current (2010) Uplift and Subsidence Rates for Tide Gauge and GPS stations in British Columbia

Station					Uplift / Subsidence Rate	
Name	Data Type	Lat.	Lon.	T	V uplift (+)	σ
	TG = tide gauge station GPS = GPS station	°N	°W	Years of record	(mm/yr)	
Prince Rupert	TG	54.317	130.324	77	0.5	0.2
Queen Charlotte City	TG	53.252	132.072	45	2.2	0.3
Bella Bella	TG	52.163	128.143	45	2.3	0.4
Winter Harbour	TG	50.513	128.029	18	1.7	0.8
Zeballos	TG	49.979	126.846	13	5.1	1.6
Gold River	TG	49.679	126.126	13	0.7	1.8
Tofino	TG	49.154	125.913	58	2.7	0.3
Port Alberni	TG	49.233	124.814	40	2.5	0.6
Bamfield	TG	48.836	125.136	37	1.6	0.4
Port Renfrew	TG	48.555	124.421	27	-0.4	0.6

Station					Uplift / Subsidence Rate	
Name	Data Type	Lat.	Lon.	T	V uplift (+)	σ
	TG = tide gauge station GPS = GPS station	$^{\circ}$ N	$^{\circ}$ W	Years of record	(mm/yr)	
Port Hardy	TG	50.722	127.489	43	2.5	0.4
Alert Bay	TG	50.587	126.931	33	3.5	0.4
Campbell River	TG	50.042	125.247	37	4.1	0.5
Little River	TG	49.741	124.923	25	3.0	0.6
Point Atkinson	TG	49.337	123.253	73	1.3	0.2
Vancouver	TG	49.287	123.110	58	1.2	0.2
New Westminster	TG	49.200	122.910	38	4.6	2.0
Fulford Harbour	TG	48.769	123.451	40	1.4	0.2
Patricia Bay	TG	48.654	123.452	31	1.7	0.8
Victoria	TG	48.424	123.371	98	1.2	0.2
Sooke	TG	48.370	123.726	12	3.3	0.9
Albert Head (Colwood)	GPS	48.390	123.487	10.8	0.6	0.7
Bamfield	GPS	48.835	125.135	4.5	3.9	1.5
Langley	GPS	49.104	122.657	3.9	-0.7	0.9
Richmond	GPS	49.115	123.147	3.9	-2.1	0.9
Telegraph Cove	GPS	50.544	126.843	6	4.0	1.0
Port Hardy	GPS	50.686	127.375	5.5	3.9	1.3
Surrey	GPS	49.192	122.860	3.9	0.7	0.9
Vancouver	GPS	49.276	123.089	3.8	-0.3	1.0
Eliza (W of Zeballos)	GPS	49.873	127.123	6.2	1.0	1.1
Esquimalt	GPS	48.429	123.429	6.6	1.4	0.8

Station					Uplift / Subsidence Rate	
Name	Data Type	Lat.	Lon.	T	V uplift (+)	σ
	TG = tide gauge station GPS = GPS station	$^{\circ}$ N	$^{\circ}$ W	Years of record	(mm/yr)	
Holberg	GPS	50.640	128.135	10.8	2.4	0.9
Nanoose Bay	GPS	49.295	124.086	10.8	2.1	0.8
Nootka Island	GPS	49.592	126.617	6.2	3.2	1.0
Patricia Bay	GPS	48.648	123.451	7.1	1.4	0.8
Port Alberni	GPS	49.256	124.861	4.5	3.7	1.0
Chemainus	GPS	48.923	123.704	3.4	2.0	1.3
Ucluelet	GPS	48.926	125.542	10.8	2.6	0.8
Prince Rupert	GPS	54.277	130.435	2.0	-1.7	1.7
Sandspit	GPS	53.254	131.807	1.8	2.0	1.9
Bella Bella	GPS	52.158	128.110	1.7	3.8	2.0

Notes:
Source: "Addendum to Thomson, R.E., Bornhold, B.D., and Mazzotti, S. 2008. An Examination of the Factors Affecting Relative and Absolute Sea Level in Coastal British Columbia. Can. Tech. Rep. Hydrogr.Ocean Sci. 260: v + 49 p" – provided by BCMOE, T Neale, 23 March 2010

Appendix C – Sea Dike Examples

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1 Examples of Sea Dike Guidelines

1.1 Introduction

The sea dike examples shown in this Appendix are intended solely as examples of the application of the Sea Dike Guidelines and are not intended as specific guidelines for dike requirements at any of the locations. Simplifying assumptions have been made in the development of these examples, especially with regard to design criteria, solely for the purpose of developing examples. A detailed planning or design process will need to undertake site specific investigations to develop the appropriate design criteria. The examples illustrated in this section also do not consider environmental or land-use issues and the dike footprints shown in these examples do not reflect any consideration of these important issues. No consideration is given to the stages of design, approval or construction that might be necessary to implement these examples nor do the examples reflect any consideration of alternate designs that might be suitable based on detailed site specific requirements or design.

1.2 Boundary Bay Sea Dike

1.2.1 Location

The existing Boundary Bay sea dike is located along the south boundary of the Corporation of Delta (Delta) and the north shore of Boundary Bay, Figure 1-1. The dike, which runs from approximately 17A Ave. in Tsawwassen to the boundary with Surrey in the east, generally protects low lying agricultural land. The protected area also includes the Boundary Bay airport and the Delta Heritage Airport.

The dike is directly exposed to long-term sea level rise, tides, storm surge and to the local wind setup and the wave climate generated by SE through SW winds associated with severe storms in the south end of the Strait of Georgia and across Boundary Bay, Figure 1-2. The maximum direct exposure is due S across to Orcas Island in the US Gulf Islands; however, wave generation may occur over the open water extending SE towards Rosario Strait, located east of Orcas Island. The maximum available fetch is limited to approximately 45 km.

The seaward slope of the existing dike is armoured with a conventional armour stone protection system. A gravel road (with some paved sections) is located on the crest, Figure 1-3 and Figure 1-4. The landward slope is planted with grass, Figure 1-5.

The existing dike cross-section in the vicinity of this example is shown in Figure 1-6.

Land elevations in the area behind the dike are reported to be subsiding at a rate of approximately 1-2 mm/year. Typical present (2010) land elevations behind the dike are approximately 1.5 to 1.8 m CGD.

The net expected (including land subsidence) regional sea level rise by 2100 for this area is 1.2 m.

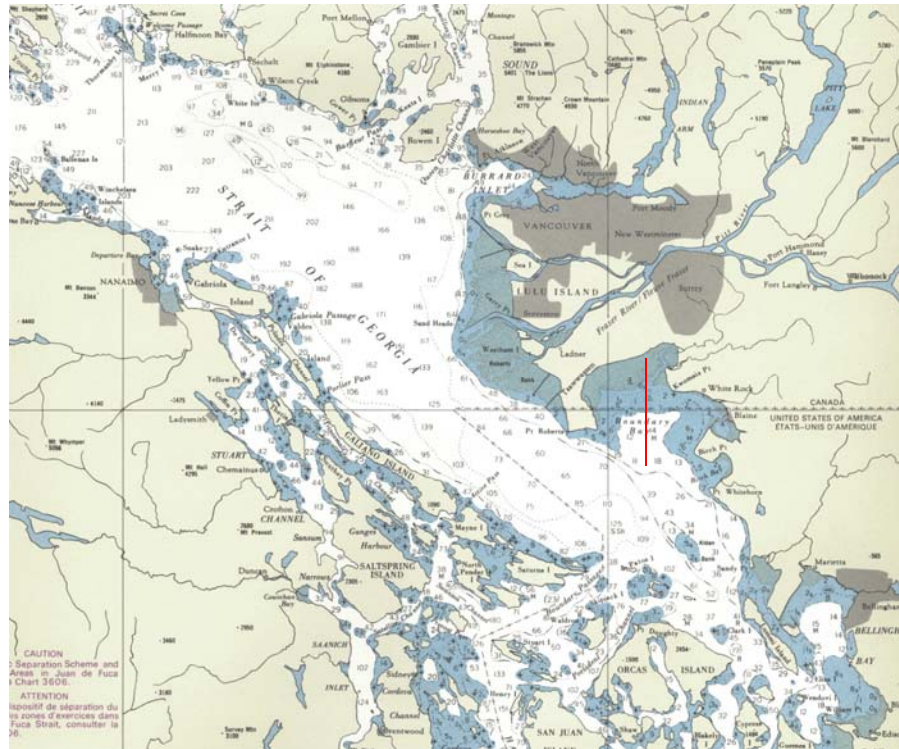


Figure 1-1: Location of Boundary Bay Sea Dike Example
source CHS Chart 3001 – Not for Navigation



Figure 1-2: View from Existing Dike Looking S (mid-tide)
Dike toe in foreground – Orcas Island in background to the right.



Figure 1-3: View Looking W along Seaward Face of Dike



Figure 1-4: View looking W along Existing Dike Crest



Figure 1-5: View Looking W at Lands behind Dike

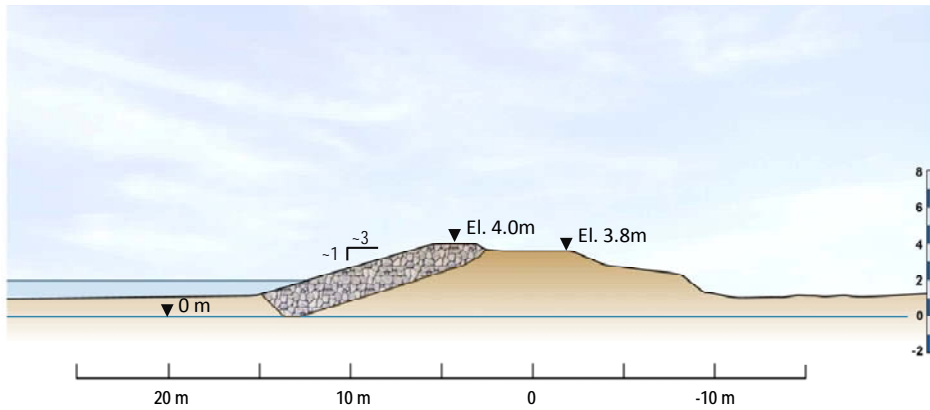


Figure 1-6: Typical Cross-Section of Existing Dike
source: Corporation of Delta Engineering
elevations: CGD

1.2.2 Assessment of Dike Design Guidelines – Boundary Bay Sea Dike

1.2.2.1 Design Basis

- AEP for Designated Storm: 1/200 for 2010 (Existing Guidelines), 1/500 for 2100 and 2200 (Updated Guidelines)
- Tides: Based on CHS Tide Tables, Vol 5, Secondary Port: 7579 Crescent Beach
- Designated Storm assumed to have storm force winds (≥ 48 knots); depth limited waves at toe of dike and peak winds, storm surge and seastate maxima occur simultaneously.
- Storm Surge during Designated Storm as per Table 3-3, this document.
- Wave set-up is included in the determination of Wave Runup.
- Cross section slope and armour details are taken to be the same general type as on the existing dike except that a 1:3 grass protected interior slope is implicitly assumed to be present to conform with available acceptance criteria for mean overtopping rates, Table 4-1, this document.

**Table 1-1: Summary of Sea Dike Crest Elevations
Boundary Bay**

CASE	2010 “existing” Guideline	2100 “ updated” Guideline	2200 “updated” Guideline
Reference vertical plane	CGD = MWL = +2.8 m CD		
Elevation of Toe of Sea Dike	+1.6 m CGD		
Regional SLR (m, wrt MWL)	0	1.2	2.4
Reference Tide level (HHWLT) (m)	+1.8	+1.8	+1.8
Storm Surge AEP	1/200	1/500	1/500
Storm surge height (m)	1.25	1.3	1.3
Local wind set up (m)	0.4	0.5	0.5
Designated Flood Level (m, CGD)	3.45	4.8	6.0
Wave Runup (R 2%) m	1.4	2.6	3.6
Runup elevation for “green” water alone (m, CGD)	4.9	7.4	9.6
Crest Elevation for 10 L/s/m (m, CGD)	4.4	6.9	9.3
Crest Elevation for 1 L/s/m (m, CGD)	5.0	7.8	10.5
Freeboard (m)	+0.6	+0.6	+0.6
Comment: The values in the Table above Designated Flood Level are site specific and those shown are guideline values for these examples. The values in the Table below Designated Flood Level result from the site specific values based on the procedures defined in the Standards and Guidelines referenced in this document			

The resulting crest elevations in Table 1-1 show clearly how careful evaluation of the acceptance criteria for overtopping volumes of water is critical to the design of a sea dike that can be expected to provide the required degree of safety to the community located behind the dike.

1.2.3 Conceptual Dike Arrangement

An example dike cross-section for the year 2100, as per Table 1-1 above, is shown below in

Figure 1-7 where the range of dike elevations, not including a freeboard allowance, is indicated for overtopping acceptance criteria of 1 L/s/m and 10 L/s/m. The example section is positioned directly over the crest of the existing dike for illustration purposes only.

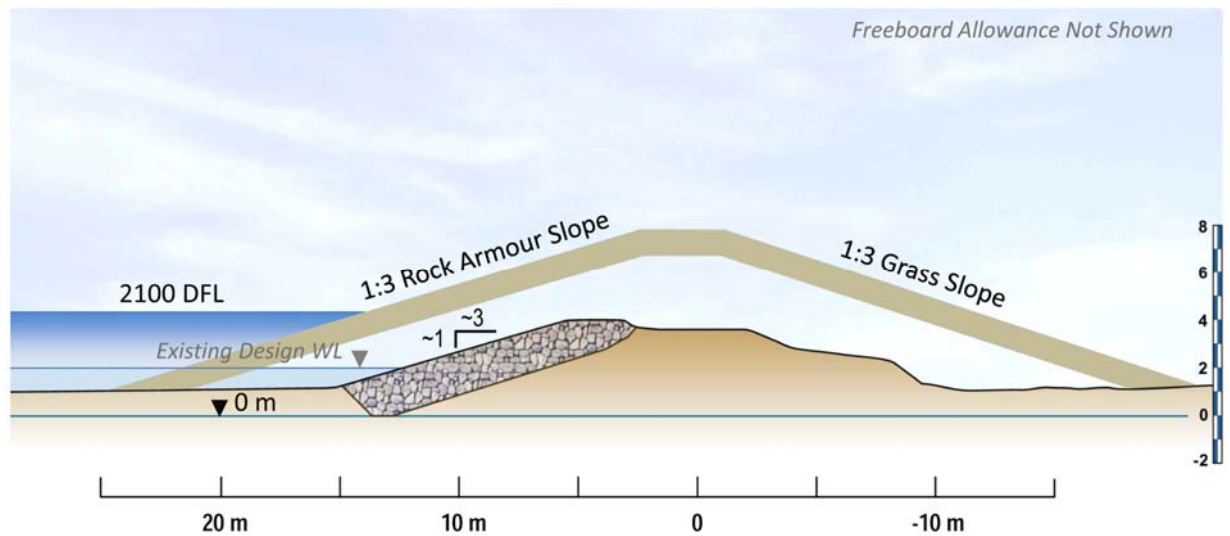


Figure 1-7: Example Sea Dike for 2100 – Boundary Bay
elevations: CGD

1.3 Richmond – Sturgeon Bank Sea Dike

1.3.1 Location

The Richmond-Sturgeon Bank Sea Dike is located on the shoreline of West Richmond and protects the City of Richmond from inundation by storm surge and associated wave effects from the Strait of Georgia, Figure 1-8. The sea dike is one part of the dike system that surrounds Richmond.

The dike is directly exposed to sea level rise, storm surges and only indirectly to the wave climate in the Strait of Georgia as some protection is provided by the extensive inter-tidal flats of Sturgeon Bank, by the jetties located on the main and north arms of the Fraser River and by the Iona jetty. This site is most exposed to severe NW winds that follow in the wake of severe storm systems; however at a detailed stage of evaluation, consideration about the present and future degree of protection against SE and S winds provided by the Steveston Jetty will be required.

The seaward slope of the existing dike consists of a grass covered 1:5 slope with a steep grass covered landside slope leading to a drainage channel, Figure 1-9 and Figure 1-10. The existing dike cross-section in the vicinity of this example is shown in Figure 1-11.

Land-use immediately behind the dike consists mainly of residential and recreational (golf course) land uses, Figure 1-12. Some areas of the adjacent lands have recently been redeveloped to a higher density than the historical single-family housing,

Land elevations in the area are reported to be subsiding at a rate of approximately 1-2 mm/year.

The net expected (including land subsidence) regional sea level rise by 2100 for this area is 1.2 m.

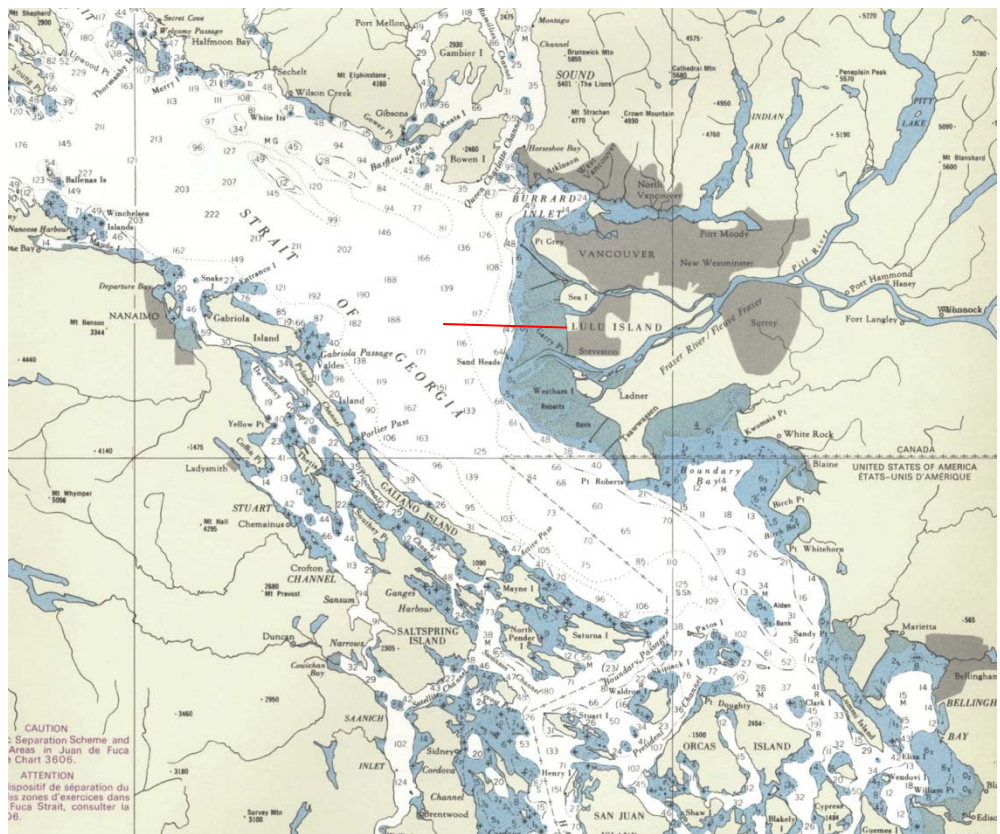


Figure 1-8: Location of West Richmond Sea Dike Example
source CHS Chart 3001 – Not for Navigation



Figure 1-9: View of Seaward Face



Figure 1-10: View of Landward Face

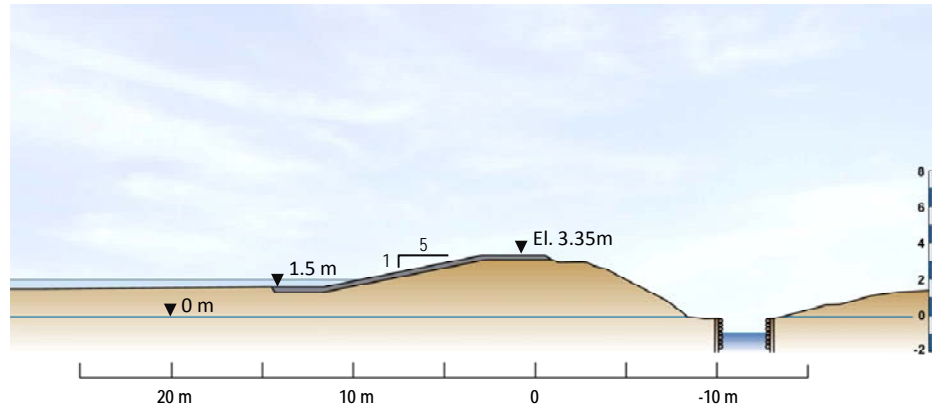


Figure 1-11: Existing Dike Cross-Section (typical)
elevations CGD



Figure 1-12: View of Land Use behind Dike

1.3.2 Assessment of Dike Design Guidelines – Richmond West Sea Dike

1.3.2.1 Design Basis

- AEP for Designated Storm: 1/200 for 2010 (Existing Guidelines), 1/500 for 2100 and 2200 (Updated Guidelines)
- Tides: Based on CHS Tide Tables, Vol 5, Secondary Port: 7594 Sand Heads
- Designated Storm assumed to have storm force winds (≥ 48 knots); depth limited waves at toe of dike and peak winds, storm surge and seastate maxima occur simultaneously.
- Storm Surge during Designated Storm as per Table 3-3, this document.
- Wave set-up is included in the determination of Wave Runup.
- Cross section slope and armour details are taken to be the same general type as on the existing dike except that a 1:3 grass protected interior slope is implicitly assumed to conform with available acceptance criteria for mean overtopping rates, Table 4-1, this document.
- The mean overtopping rate criteria in Table 4-1 are assumed to apply for a seaward slope of 1:5.

**Table 1-2: Summary of Sea Dike Crest Elevations
Richmond West**

CASE	2010 “existing” Guidelines	2100 “updated” Guidelines	2200 “updated” Guidelines
Reference vertical plane	CGD = MWL = +2.9 m CD		
Elevation of Toe of Sea Dike	+1.5 m CGD		
Regional SLR (m, wrt MWL)	0	1.2	2.4
Reference Tide level (HHWLT) (m)	+2.0	+2.0	+2.0
Storm Surge AEP	1/200	1/500	1/500
Storm surge height (m)	1.25	1.3	1.3
Local wind set up (m)	0.3	0.4	0.4
Designated Flood Level (m, CGD)	3.55	4.9	6.1
Wave Runup (R 2%) m	1.5	2.7	3.8
Runup elevation for “green” water alone (m, CGD)	5.1	7.6	9.9
Crest Elevation for 10 L/s/m (m, CGD)	4.6	6.8	8.7
Crest Elevation for 1 L/s/m (m, CGD)	5.1	7.8	10.6
Freeboard (m)	+0.6	+0.6	+0.6
Comment: The values in the Table above Designated Flood Level are site specific and those shown are guideline values for these examples. The values in the Table below Designated Flood Level result from the site specific values based on the procedures defined in the Standards and Guidelines referenced in this document			

The resulting crest elevations in Table 1-2 show clearly how careful evaluation of the acceptance criteria for overtopping volumes of water is critical to the design of a sea dike that can be expected to provide the required degree of safety to the community located behind the dike.

Changes to the dike cross-section, including details of the toe protection that might be considered, the slope of the seaward and landward faces and the surface treatment of both slopes will result in different crest elevations from those presented in Table 1-2.

1.3.3 Conceptual Dike Arrangement

An example dike cross-section for the year 2100, as per Table 1-2 above, is shown below in Figure 1-13 where the range of dike elevations, not including a freeboard allowance, is indicated for overtopping acceptance criteria of 1 L/s/m and 10 L/s/m. The example section is positioned directly over the crest of the existing dike for illustration purposes only.

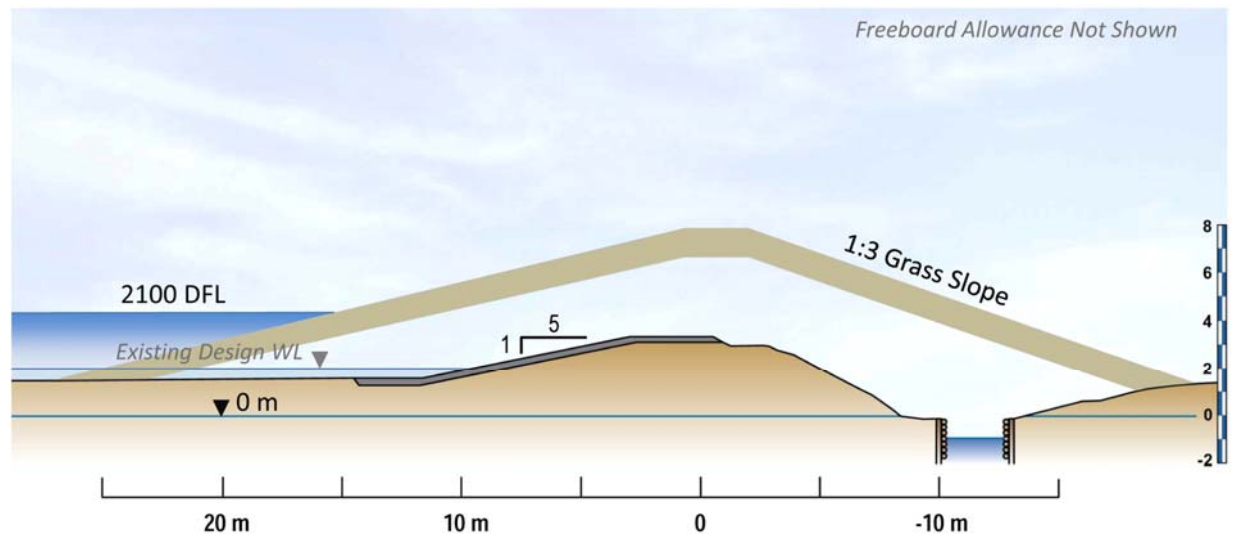


Figure 1-13 Example Sea Dike for 2100 – West Richmond
elevations: CGD

1.4 Granville Island

Granville Island is a popular and developed urban site located inside False Creek in Vancouver, BC, Figure 1-14. At present, the area is not diked and flooding has not been experienced during storms on the existing grade slab, which has an elevation of approximately + 4 m CGD. As sea level rises over the next century, the area will become exposed to an increasing risk of flooding and measures will need to be taken to adapt to the risk. If protection of the existing land-use is adopted as the option, a sea dike will be required.

For the purpose of this example the west end of Granville Island, which is partially exposed to English Bay, Figure 1-15 and Figure 1-16, is considered.

Land elevations in the area are reported to be stable, neither rising nor subsiding.

The net expected (including land subsidence) regional sea level rise by 2100 for this area is 1.0 m.

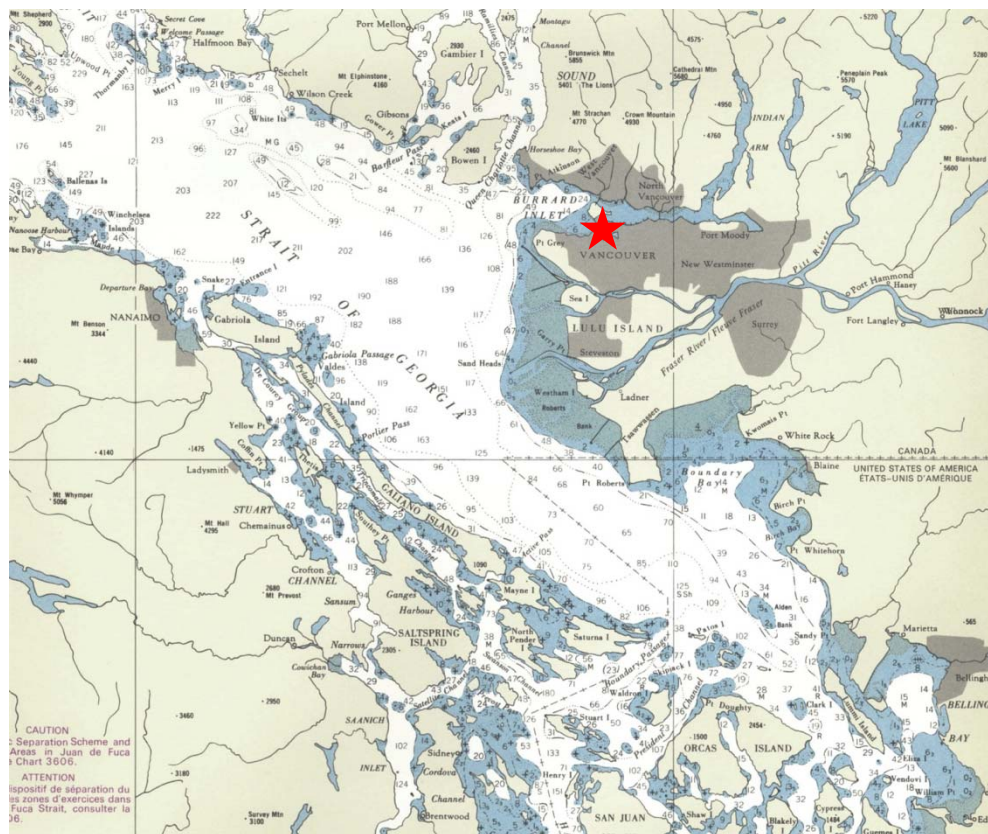


Figure 1-14: Location of Granville Island Sea Dike Example
source CHS Chart 3001 – Not for Navigation



Figure 1-15: View Looking NW from Granville Island showing Exposure to English Bay



Figure 1-16: View Showing Exposed NW Corner of Granville Island

1.4.1 Assessment of Dike Design Guidelines – Granville Island

1.4.1.1 Design Basis

- AEP for Designated Storm: 1/200 for 2010 (Existing Guidelines), 1/500 for 2100 and 2200 (Updated Guidelines)
- Tides: Based on CHS Tide Tables, Vol 5, Secondary Port: 7710 False Creek
- Designated Storm assumed to have storm force winds (≥ 48 knots); the maximum seastate present at the wall is taken to be 0.6 m and storm surge and seastate maxima occur simultaneously.
- Storm Surge during Designated Storm as per Table 3-3, this document.
- Wave set-up is included in the determination of Wave Runup.
- A near vertical seawall was adopted for the sea dike in this example due to the close proximity of highly used public buildings near the edge of the existing island slope. For simplicity, the presence of the overhanging timber deck platforms was not considered.
- The mean overtopping rate criteria in Table 4-2 are assumed to apply for a seaward slope consisting of a vertical seawall located at the top of the existing rock armoured slope.

**Table 1-3: Summary of Sea Dike Crest Elevations
Granville Island**

CASE	2010 “existing” Guidelines	2100 “updated” Guidelines	2200 “updated” Guidelines
Reference vertical plane	CGD = MWL = +3.0 m CD		
Elevation of Granville Island grade slab	+4.0 m CGD		
Regional SLR (m, wrt MWL)	0	1.0	2.0
Reference Tide level (HHWLT) (m)	+2.1	+2.1	+2.1
Storm Surge AEP	1/200	1/500	1/500
Storm surge height (m)	1.25	1.3	1.3
Local wind set up (m)	0.1	0.2	0.2
Designated Flood Level (m, CGD)	3.45	4.6	5.6
Wave Runup (R 2%) m	1.7 ^a	0.6	0.6
Runup elevation for “green” water alone (m, CGD)	-	5.2	6.2
Crest Elevation for “no damage 10m away” (m., CGD)	-	6.2	7.6
Freeboard (m)	-	+0.6	+0.6
Comment: a: The assumed conditions for 2010 have not been experienced during the lifetime of the present Granville Island development. The values in the Table above Designated Flood Level are site specific and those shown are guideline values for these examples. The values in the Table below Designated Flood Level result from the site specific values based on the procedures defined in the Standards and Guidelines referenced in this document			

1.4.2 Conceptual Dike Arrangement

An example seawall dike cross-section for the year 2100, as per Table 1-3, is shown below in Figure 1-17 where the top of the seawall, not including a freeboard allowance, is designed for an overtopping acceptance criteria of 0.4 L/s/m, which is expected to keep any spray loads at or below the capacity of the adjacent buildings. This acceptance threshold is higher than might be appropriate if untrained casual pedestrians were expected to be present during storms. The example seawall is located on the existing grade slab on Granville Island of approximately +4 m CGD. Foundation considerations have not been addressed in this example.



Figure 1-17: Example Sea Dike for 2100 – Granville Island
source: BTAworks¹
elevations: CGD

¹ BTAworks is the architectural and urban research and development division for [Bing Thom Architects](#) and provided the conceptual sketch in Figure 1-17 as part of their ongoing interest and Research and Development in climate change influences on the City of Vancouver.

Appendix D – Storm Surge in BC Coastal Waters - Background

Contents

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2.3	Local Storm Surge	4
2.4	Joint Occurrence of Storm Surge and Tide	5
2.5	Joint Occurrence of Storm Surge and Waves	6

1 Introduction

This Appendix provides a brief summary of investigations undertaken to provide guidelines for the preparation of the document: **Sea Dike Guidelines, 2010**.

Further investigations are warranted as noted in each case.

2 Atmospheric Sea Level Rise in BC Coastal Waters

2.1 Introduction

Sea levels along the coastal British Columbia coast are strongly affected by the mid-latitude storm systems in the North Pacific. The strong winds and low atmospheric pressures in the storms result in a large, though low in amplitude, surge wave that affects considerable portions of the Northwest North American coastline at the same time.

A detailed discussion of all aspects of these storm systems is beyond the scope of this document; however a brief discussion is provided as background to the definition of storm surge used in this document.

In particular, the connection between the offshore character of the storms and the resulting storm surge is discussed. As an example, the storm of 12 March – 15 March, 2010 is shown below. This storm entered the Gulf of Alaska near the southern tip of the Aleutian Islands on 12 March 2010, moving in a generally easterly direction along the 50th parallel of latitude, Figure 2-1.

The evolution of the storm over the period up to 15 March 2010 is shown in Figure 2-2, by which time hurricane force winds were expected in the Hecate Strait area of coastal British Columbia. This storm generated gale to storm force winds throughout much of the Gulf of Alaska.

The surface effect of the storm winds on 12 March can be seen in Figure 2-3, where the red shading centred approximately on the 53rd parallel of latitude corresponds to a surge, above tide, of approximately 0.6 m. This large area of surge is being setup by the combination of the inverse barometer affect due to the low atmospheric pressure and to the effect of the gale to storm force winds circulating around the low pressure centre.

In this particular case, the storm crossed the North American coastline north of Dixon Entrance and the surge mainly affected Alaska state coastal waters. A track south of the 50th parallel would have brought the deepwater surge directly onto the British Columbia coast. The length of coastline affected by the storm surge for a storm of this severity is clearly as long or even longer than the west coast of British Columbia.

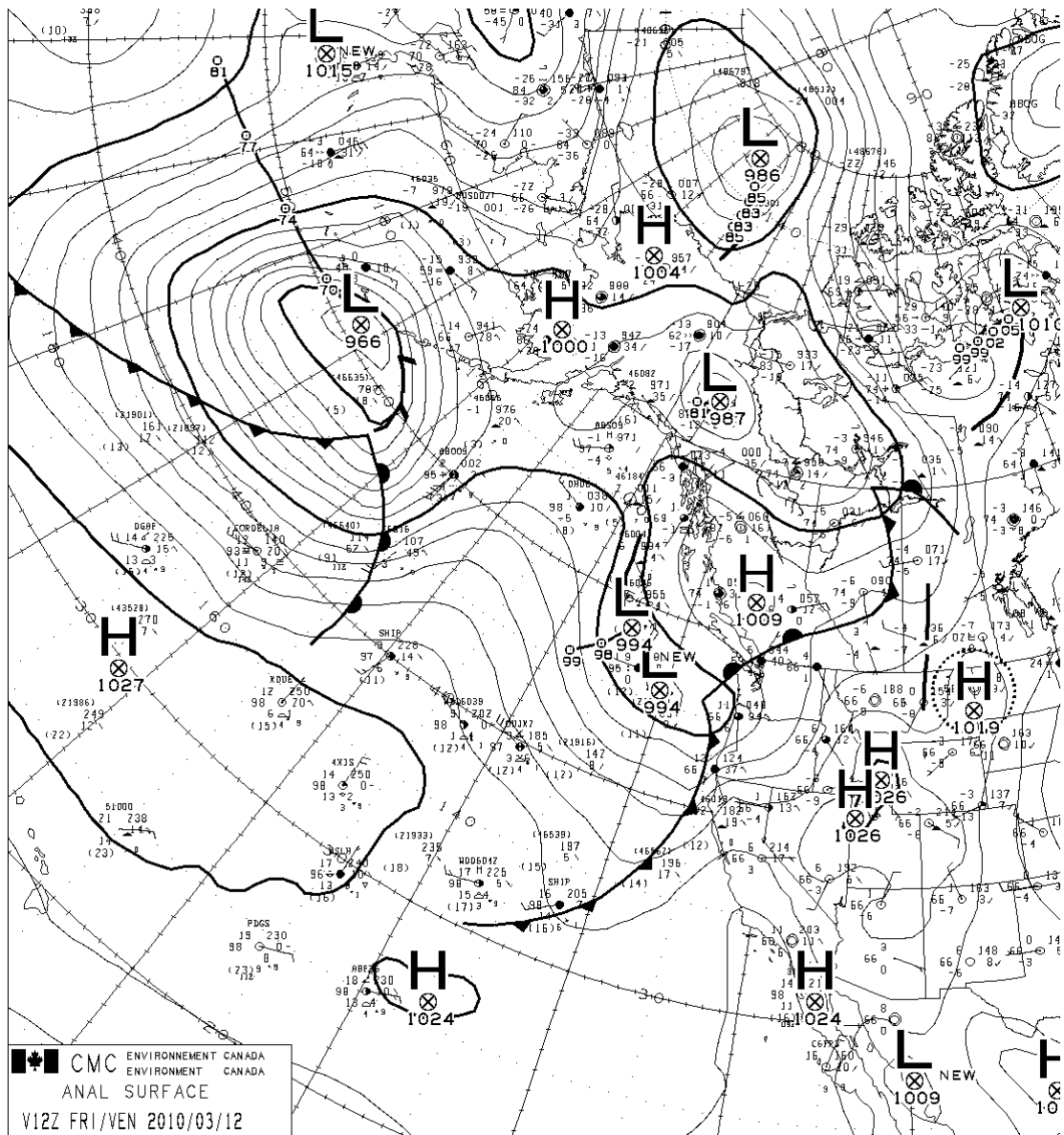


Figure 2-1: Mid-Latitude Extra-Tropical Storm of Mid-March 2010

Note: central pressure = 966 mb

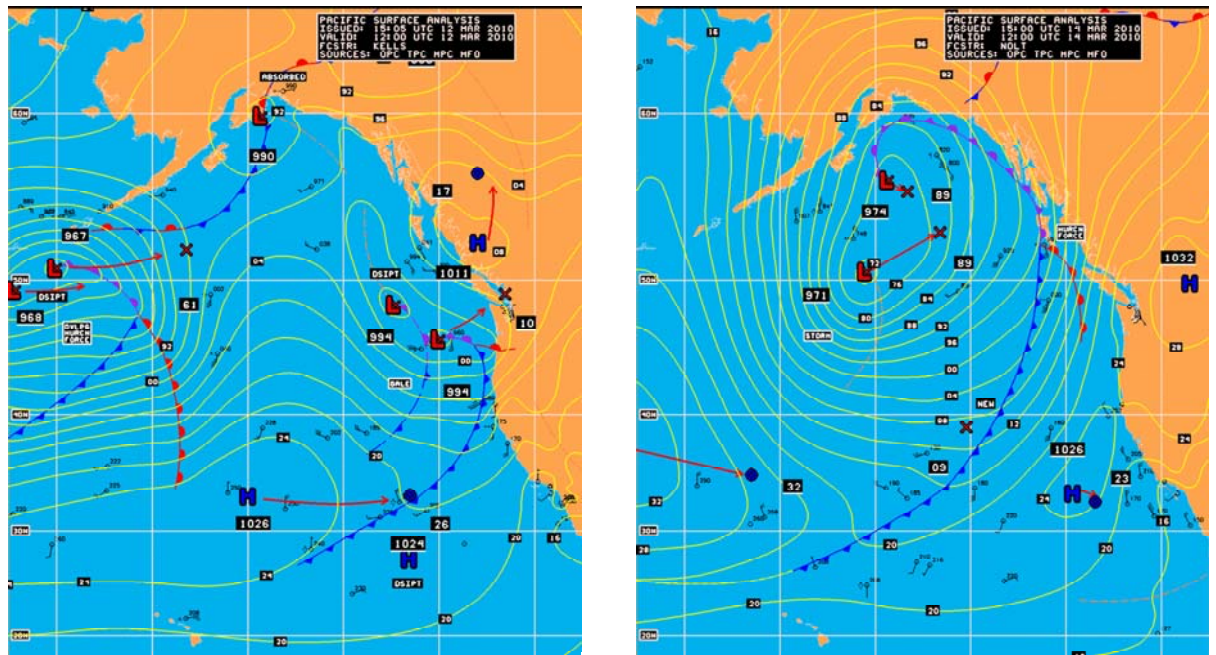


Figure 2-2: Evolution of Storm 12 March – 15 March 2010

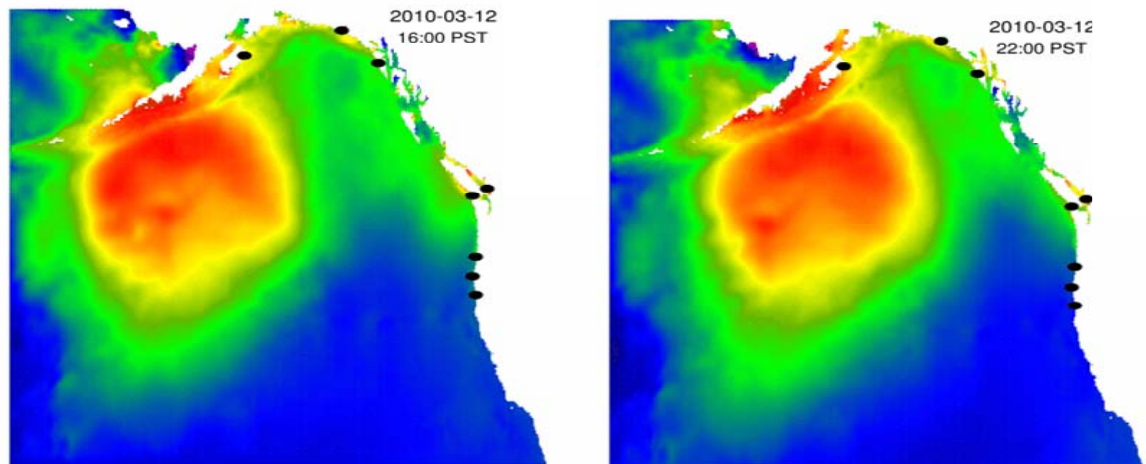


Figure 2-3: Storm Driven Surge in Gulf Alaska

source: BC Storm Surge Model - http://www.pac.dfo-mpo.gc.ca/sci/juandefuca/npac_lr

2.2 Expected Coastal Deepwater Storm Surges for BC

Examination of the surges recorded along the BC coastline has shown that in many, if not in most cases, the deepwater surge generated in the North Pacific, after modification over the continental shelf, arrives relatively unchanged at all stations in the general north coast or south coast areas of British Columbia. An example of the storm surges recorded on the coast for a storm on 9 – 16 December 1995, is shown in Figure 2-4 and illustrates how the surge wave retains its main characteristics all the way from its arrival on the west coast of

Vancouver Island (as recorded at Tofino), its passage up Juan de Fuca Strait (as recorded at Victoria and then into the Strait of Georgia (as recorded at Point Atkinson). The peak of the surge, at approximately 22:00 hr on 12 December at Point Atkinson, occurred 5 hours earlier at Tofino and only increased in magnitude by approximately 0.1 m. The peak of the surge, which is at least 6 hours long (within a 0.1 m tolerance), coincided with a peak in the gale force SE winds that characterised this particular storm.

As part of this assignment, the self-similar characteristics of the incident surge wave from the North Pacific were examined for multiple storms and the trend exhibited in Figure 2-4 is typical. On the basis of these trends the expected magnitudes for the incident deepwater storm surge were grouped and characterized as described in this report.

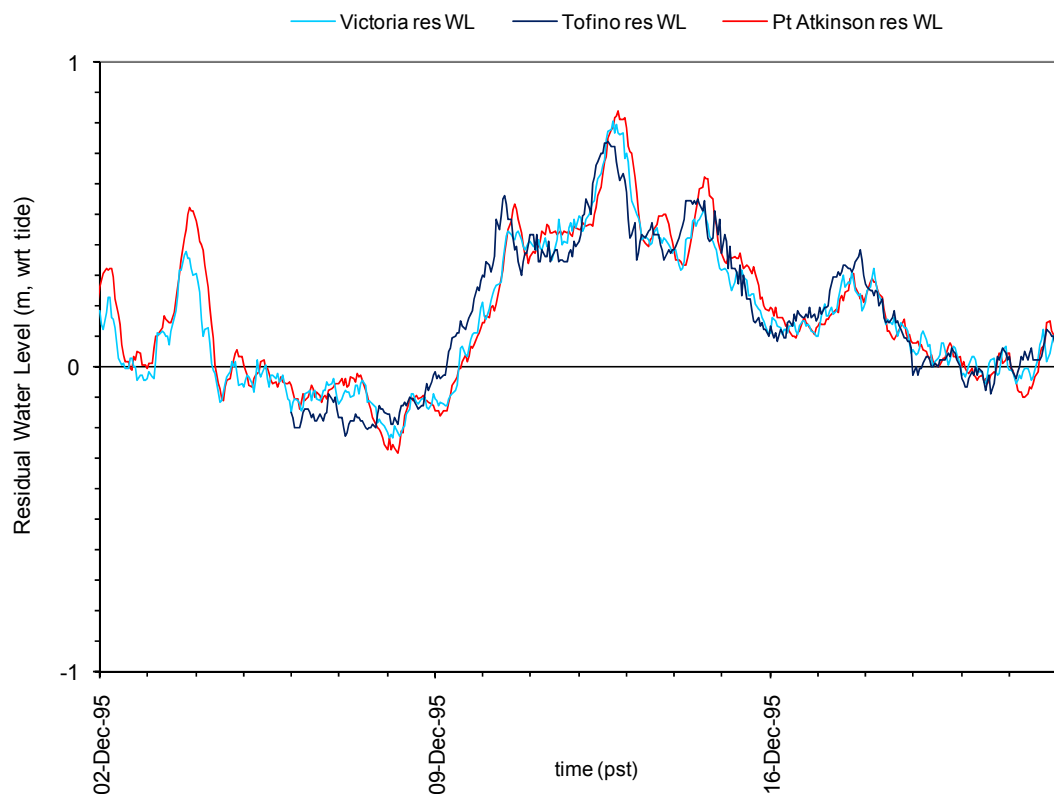


Figure 2-4: Storm Residual Water Level, 9 – 16 Dec 1995

2.3 Local Storm Surge

The incident deepwater storm surge, as illustrated in Figure 2-4, will be further modified as it propagates over shallow water, especially across the extensive tidal flats in the Fraser River Delta. Methods for estimating the additional effects are provided in the Reference Publications.

2.4 Joint Occurrence of Storm Surge and Tide

An important element in the design of a sea dike is establishing the appropriate stage of astronomical tide, for combination with a storm surge, to be used for setting the total water level, and associated wind and wave related effects, for the Designated Flood Level.

This topic is an area of ongoing research and development and warrants additional investigations of its own. For the purpose of this document, which maintains the existing guidance in the **Dike Design and Construction Guide 2003**, that combines the maximum high tide with the appropriate storm surge, the problem becomes one of assigning an AEP to the selection of the storm surge (and the Designated Storm) that is consistent with the total water level or Designated Flood Level.

The problem can be addressed by considering storms and the associated effects, including storm surge, winds and waves, as processes that are totally independent of the astronomical tides. The combined probability, or alternatively, the AEP of the combined effects, becomes simply the product of the probability of the storm and the probability of there being a high tide present on the coast at the same time.

The simultaneous values of residual water levels and the associated astronomical tides recorded at Tofino are shown in Figure 2-5. This data, which covers approximately 66 winter storm periods during the total record shows that the combination of both a high tide (4.1 m) and a high storm surge (residual water level) is quite rare.

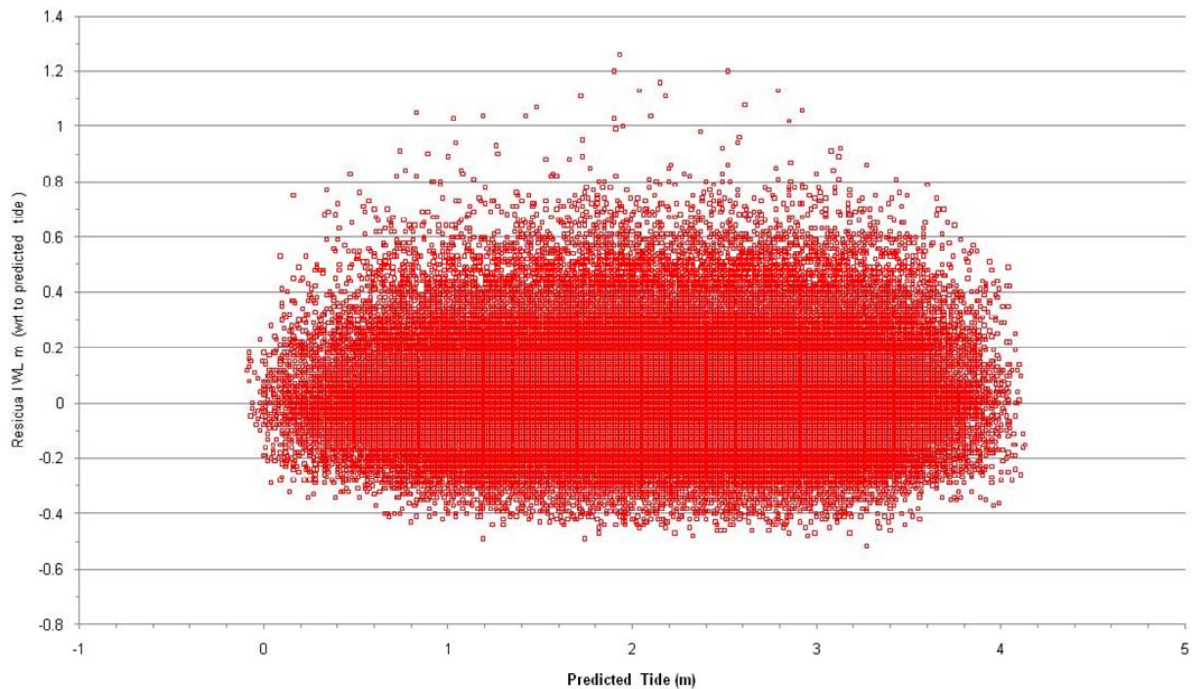


Figure 2-5: Simultaneous Residual Water Levels and Predicted Tide – Tofino
Note: MWL = 2.1 m (predicted tide)

In simple terms, the probability of having a high tide during the winter storm season, which typically spans 3 to 4 months (mid-October to mid-January), is related to the number of days in this period when a high tide is expected – spring tides typically exist for approximately 3

days every 2 weeks and during those three days only exist for 2 to 3 hours (within a range of approximately ± 0.1 m) on each of the three days.

The probability of a high tide window is then approximately:

$$\frac{3 \text{ days} \times 2 \text{ hours/window}}{14 \text{ days} \times 24 \text{ hours/day}}$$

to

$$\frac{3 \text{ days} \times 3 \text{ hours/window}}{14 \text{ days} \times 24 \text{ hours/day}}$$

or between

$$1/56 \text{ to } 1/37$$

As the duration of the peak of a storm surge is typically approximately 6 hours long (within a range of ± 0.1 m), or approximately twice the duration of the high tide then the probability of having the peak of a storm surge at high tide becomes $2/56$ to $2/37$ or $1/26$ to $1/18.5$.

For the purpose of this report we have taken the probability of a high tide window during the occurrence of a storm to be approximately $1/20$. On this basis the total AEP for high tide and a typical winter storm (the annual average expected storm) becomes $1/20 \times 1/2 \approx 1/40$. By the same reasoning the estimated AEP for the total water level during the largest storm surge of record shown in Figure 2-5, occurring at MWL becomes approximately $1 \times 1/300 \approx 1/300$.

The AEP for high tide and a storm with an AEP of $1/200$ years (the current guidance AEP) becomes $1/20 \times 1/200 \approx 1/4000$.

The AEP for a storm that will yield a Designated Flood Level with an AEP of $1/10000$ years becomes $1/500$, which is not significantly greater in actual effect than the current guidance in British Columbia.

2.5 Joint Occurrence of Storm Surge and Waves

The selection of a sea dike crest elevation that satisfies the chosen design criteria requires the identification of the wave climate that is expected to occur during the Designated Storm. Preliminary examination of the joint occurrence of recorded waves and residual water levels (storm surge) from two areas in coastal British Columbia waters suggests that the largest waves are not necessarily associated with the largest storm surges, Figure 2-6 and Figure 2-7.

For the purpose of this assignment it has been assumed for the sea dike examples, that the wave climate present at the sea dike is controlled by the depth of water at the sea dike and that the wave climate in deep water is sufficient to sustain the depth limited conditions. Further investigations are warranted for all areas of coastal British Columbia and will be required during more detailed engineering for sea dikes.

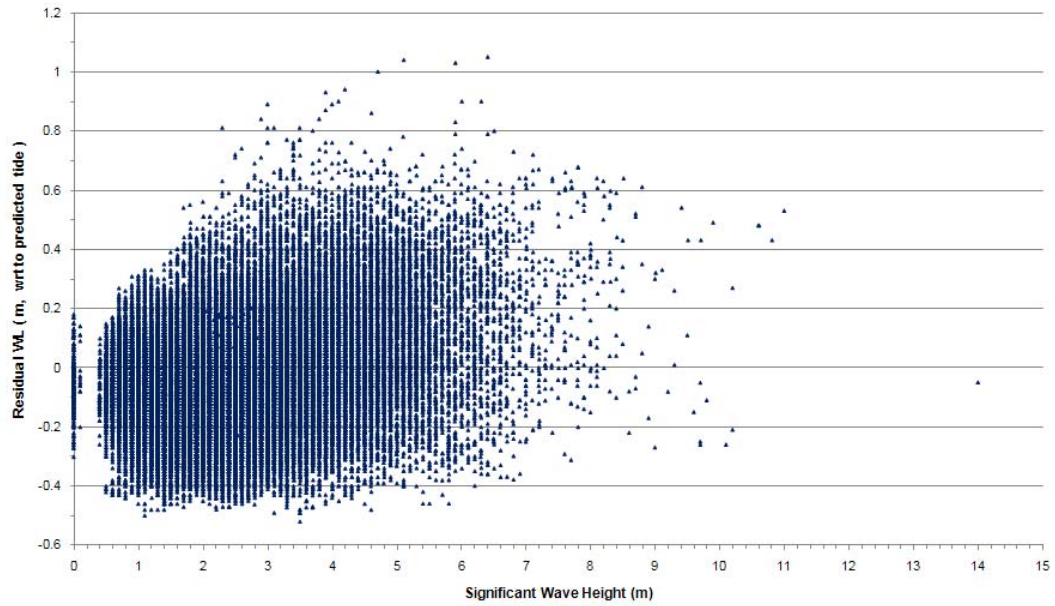


Figure 2-6: Simultaneous Residual Water Levels and Significant Wave Height
Residual Water Level from Tofino – Waves from La Perouse Bank

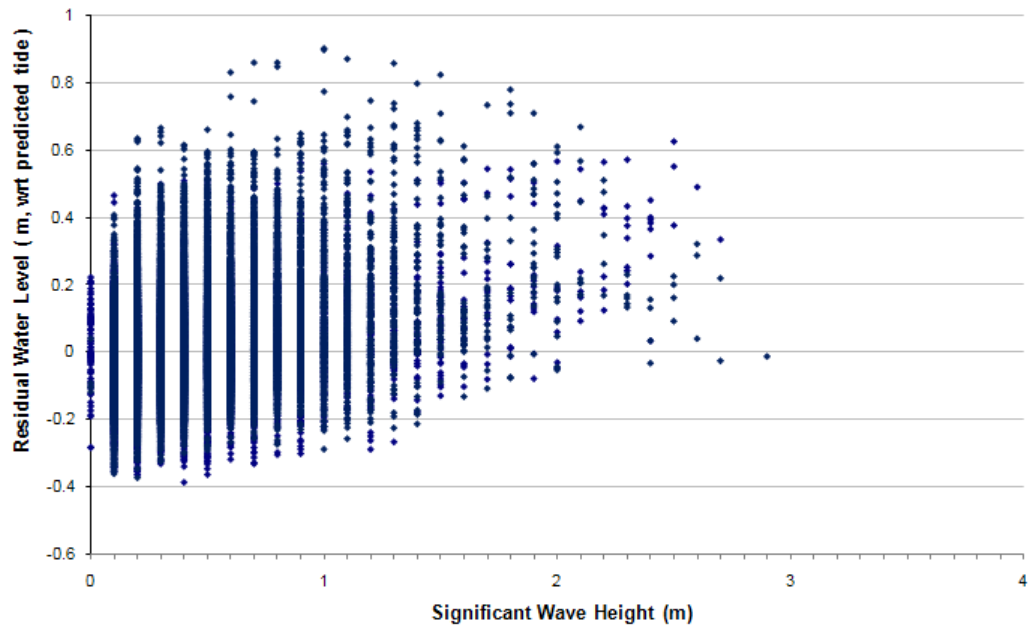


Figure 2-7: Simultaneous Residual Water Levels and Significant Wave Height
Residual Water Level from Point Atkinson – Waves from Halibut Bank