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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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Contents

1	Introduction and Application of this Document	1
1.1	General	1
1.2	Acknowledgement	1
2	Background	2
2.1	Scope	2
2.2	Definitions	2
2.3	Reference Documents	2
3	Design Criteria	4
3.1	General Requirements	4
3.2	Design Environment	4
4	Sea Dike Design	12
5	Bibliography	15

Appendix A – Definitions, Terminology and Acronyms

Appendix B – Uplift and Subsidence Rates

Appendix C – Sea Dike Examples

Appendix D – Storm Surge in BC Coastal Waters - Background

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.

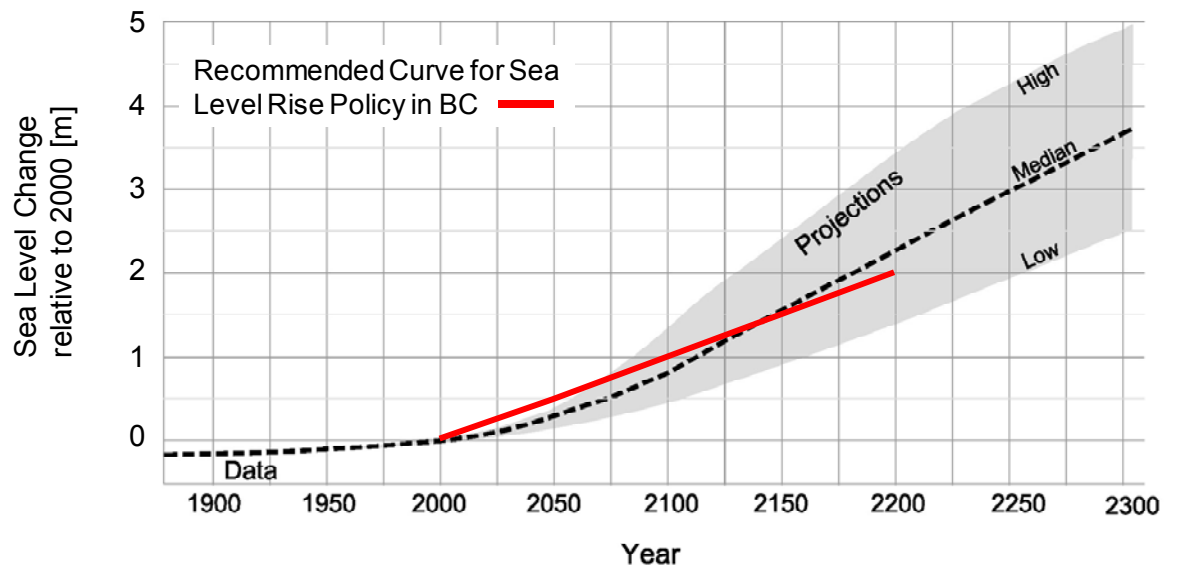


Figure 3-1: Projections of Sea Level Rise
source: Policy Discussion Paper (2010)

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".

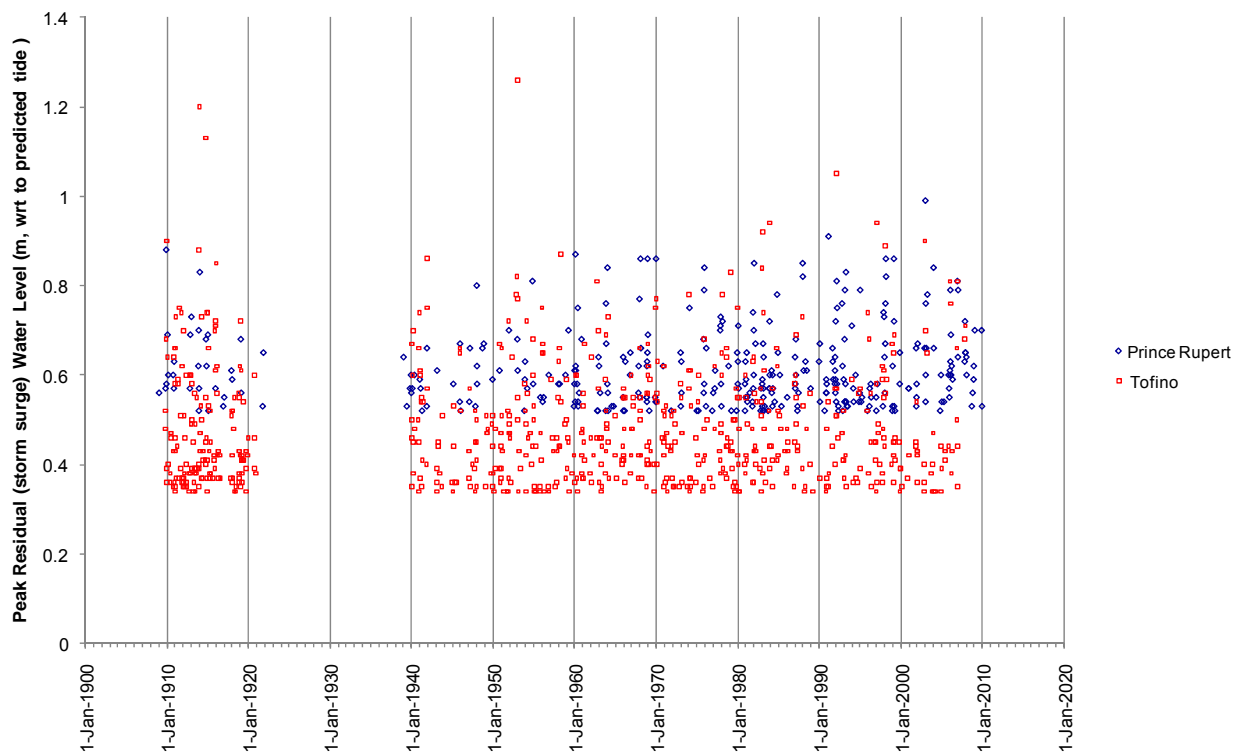


Figure 3-2: Residual Water Levels – Coastal British Columbia

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 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

Battjes, J A and Groenendijk, H W. 2000. Wave Height Distributions on Shallow Foreshores. *Coastal Engineering*. 2000, Vol. 40, pp. 161-182.

BC Sea Level Report 2008 means the report, "An Examination of the Factors Affecting Relative and Absolute Sea Level in Coastal British Columbia" by R. Thomson, B. Bornhold, and S. Mazzotti, 2008, Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC, Canadian Technical Report of Hydrography and Ocean Sciences 260, 2008.

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

CIRIA; CUR; CETMEF. 2007. *The Rock Manual. The Use of Rock in Hydraulic Engineering (2nd Edition)*. London, UK : C683, CIRIA, London, 2007.

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

Hydraulic Engineering Division, Rijkswaterstaat. (1998). *Dikes and Revetments - Design Maintenance and Safety Assessment*. (K. W. Pilarczyk, Ed.) Rotterdam, The Netherlands: A.A. Balkema.

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

US Army Corps of Engineering. 2002. *Coastal Engineering Manual*. Washington, DC : s.n., 2002. Vol. in six volumes. EM 1110-2-1100.

Appendix A – Definitions, Terminology and Acronyms

Appendix B – Uplift and Subsidence Rates

Appendix C – Sea Dike Examples

Appendix D – Storm Surge in BC Coastal Waters - Background