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

Draft Policy Discussion Paper

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Ausenco Sandwell

Revision Status

Revision	Date	Description	Contributors		Reviewer		Approver		Signature
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Executive Summary

Emerging information from scientists and agencies around the world indicates that in the near future and continuing thereafter for some time, anticipated climate change will result in increased rates of sea level rise. Rising sea levels will increase the risk of coastal flooding and the associated consequences.

The purpose of this project is to develop policies and updated guidelines for sea dike design and coastal flood hazard land management to address climate change factors in coastal waters of British Columbia. Specific objectives are to update the sea dike section of the ministry's existing "**Dike Design and Construction Guide**", July 2003, and the coastal section of the current "**Flood Hazard Area Land Use Management Guidelines**" May, 2004.

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**
- **Guidelines for Management of Coastal Flood Hazard Land Use 2010**
- **Sea Dike Guidelines 2010**

The intent of this Draft Policy Discussion document is to help to bridge the gap between the science and practical application of measures to address climate change factors in British Columbia coastal areas.

The **Guidelines for Management of Coastal Flood Hazard Land Use 2010** document provides guidelines for the management of 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.

The **Sea Dike Guidelines 2010** 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.

Based on the investigations and research summarized in this document, and reflected in the companion reports **Guidelines for Management of Coastal Flood Hazard Land Use 2010** and **Sea Dike Guidelines 2010**, the following conclusions regarding the establishment of policy for climate change adaptation in the coastal waters of British Columbia have been drawn:

1. Sea level rise (SLR) in the future is expected to be both faster and higher than previously anticipated. While there is still scientific uncertainty related to the present understanding of the future rates and magnitudes, it seems reasonable to anticipate higher SLR than summarized in the **"BC Sea Level Report 2008"**. A large degree of the related uncertainty can be eliminated by recognizing that it seems likely that sea level will rise but the rate at which it rises, and therefore the particular sea level rise on a given date, carries the most uncertainty.
2. For planning purposes it is recommended that the rates and trends reflected in Figure 1 and Table 3-2 should be used at present.
3. The choice of appropriate response options or adaptation measures is so site specific that their identification and adoption must be the responsibility of local governments, with guidelines and other support provided by the province. Provincial policy should include updating the basic guidelines for sea dikes, FCLs and Setbacks as spelled out in the companion documents and requiring the establishment of SLR Planning Regions, as described in Section 5.2.

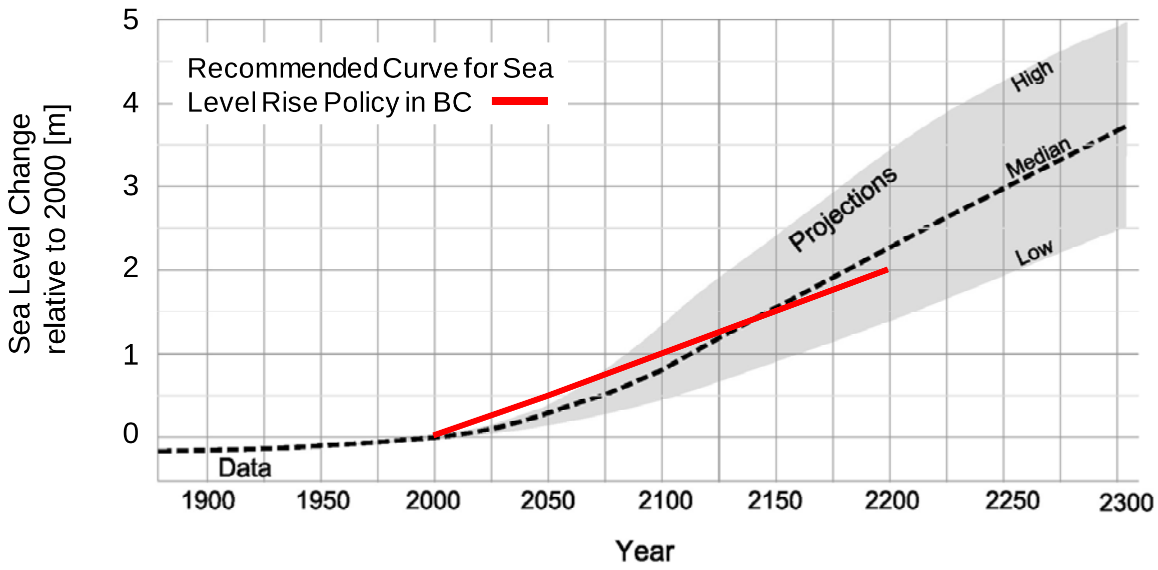

Figure 1: Recommended Global Sea Level Rise Curve for Planning and Design in BC
source: Figure 3-5, this document

Table 1: Sea Level Rise Recommendations and Their Application for BC Sea Dike and Coastal Flooded Land Management Guidelines

Development/ land use timeframe	Global SLR	Regional SLR	Application	Comment
For short to medium term - life of 25 to 50 years	0.5 m	To be developed on a site specific basis. See Appendix B for existing crustal movement rates along coastal BC shorelines.	Evaluation of existing structures (sea dikes)	This estimate is slightly higher than suggested by the present range of SLR estimates and planning curves and anticipates revision in the near future (circa 2014).
For longer term - life of up to 2100	1.0 m		Definition of requirements for permanent structures (sea dikes) that can be expected to be upgraded again in the future as science and knowledge increases	This is consistent with the present "*extreme high*" estimates in **BC Sea Level Report 2008**.
For issues with long life (> 100 years), and as a sensitivity example	2 m		Consideration of long-term land-use and planning issues having very long term implications – especially where decisions may be made that allow or encourage concentration of high value or high population density uses	This value is a balance between the current often stated upper limit of ~ 2 m for updated accounting of ice sheet mass loss by 2100 and potential increases identified by others.

4. At the present time, scientific information on the expected changes in storms approaching British Columbia coastal waters and their characteristics, specifically on the intensity of the storms, their related wave conditions and the associated storm surges in the future, is only starting to emerge. Based on the available information it appears reasonable to conclude that no significant change is expected in coastal BC waters; however, further investigations are warranted to fully assess the regional implications and to further assess future trends.
5. It is clear that the present recommended rates and trends for SLR have significant implications for British Columbia coastal communities. Detailed quantitative risk analysis (QRA) processes may be appropriate for some communities. In the meantime, and in situations where QRA may not be appropriate, the recommendations outlined in this document, and the companion documents, for design standards, design procedures and planning alternatives can provide a basis for initial planning and responses.

Recommendations for the implementation of these updated policies are provided in Section 8 of this document.

Acknowledgements

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 Introduction

1.1 Purpose

Emerging information from scientists and agencies around the world indicates that in the near future and continuing thereafter for some time, anticipated climate change will result in increased rates of sea level rise. Rising sea levels will increase the risk of coastal flooding and the associated consequences.

The purpose of this project is to develop policies and updated guidelines for sea dike design and coastal flood hazard land management to address climate change factors in coastal waters of British Columbia. Specific objectives are to update the sea dike section of the ministry's existing "**Dike Design and Construction Guide**", July 2003, and the coastal section of the current "**Flood Hazard Area Land Use Management Guidelines**" May, 2004. The existing documents are referenced in more detail in Section 2.1 below.

The intent of this Draft Policy Document is to help to bridge the gap between the science and practical application of measures to address climate change factors in British Columbia coastal areas. While scientific studies discuss factors affecting relative sea level in detail, they do not set definitive guidance that can be readily applied to the many practical problems arising from sea level rise and other climate change impacts. For example, determining the appropriate crest elevation of a sea dike or the habitable building floor elevation in a coastal zone, potentially subject to flooding, must be based on policy guidance and engineering analysis in addition to scientific research findings.

1.1.1 The Policy Discussion Paper

Policy decisions are required to help guide the scientific and technical analyses regarding climate change and the implications for coastal sea dikes and flood construction levels. This document discusses the background for potential policies and the supporting rationale for adaption of the updated Provincial guidelines for sea dike design and coastal flood construction levels (FCL).

It specifically addresses:

- Global sea level rise scenarios – which one to use.
- Anticipated climate change effects on storm intensity factors.
- The appropriate project life or time interval to be used for dike and community planning to account for climate change.
- Design "standards": in terms of an annual probability of exceedance for design or planning of coastal flood protection works.
- Implication for long term community planning – e.g., when or where to defend versus retreat.
- Dike right of way – policy planning: specifically acquiring or setting aside the land needed for future dike expansion and upgrade.

1.2 Areas of Interest

The draft policies outlined in this document are intended to apply to all of coastal British Columbia, but the focus is concentrated into the following areas:

- Fraser River delta: Richmond, Delta and Surrey sea dikes.
- Lower Fraser River dikes where sea dike criteria govern.
- Vancouver Harbour: no dikes but extensive foreshore development.
- Squamish River delta: existing and development plans for sea dikes, downtown Squamish.
- East Vancouver Island: extensive existing coastal development and a few sea dikes (i.e. Cowichan River Estuary).
- West Vancouver Island, Central Coast and North Coast: occasional coastal development and few sea dikes (note: design for tsunami effects may govern building location and design).

Tsunami effects are not specifically addressed as these are independent of climate change and are outside of the scope of this document.

1.3 Consultation Workshop

As part of this program, a consultation workshop was held in Vancouver, to present and discuss the initial conclusions and recommendations described in this report and the companion guidelines. The initial conclusions and recommendations were further developed and refined to reflect the feedback received from the attendees and form the content of this report.

2 Reference Documents, Definitions and Terminology

For the purpose of clarity, this draft policy document uses, where possible, definitions and terminology that are either consistent with existing documents or consistent with existing practise worldwide. In some cases existing definitions or terminology may require modification or clarification for application to coastal flooding or sea dike application in a continuing and accelerating climate change driven sea level rise scenario. Existing documents are summarized below followed by a brief summary of the definitions used in this document. Detailed explanation of definitions is provided in Appendix A.

2.1 Existing Documents

"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. An unpublished addendum to this report was also provided by BCMOE for this document and is reproduced in part in Appendix B.

The summary report "Projected Sea Level Changes for British Columbia in the 21st Century (B. Bornhold, 2008, British Columbia and Canada) is also used. Copies of these documents can be downloaded from http://www.dfo-mpo.gc.ca/Library/335209.pdf.

"Dike Design and Construction Guide 2003" means the "Dike Design and Construction Guide – Best Management Practices for British Columbia", July 2003, prepared by Golder Associates Ltd. and Associated Engineering (BC) Ltd. for the Ministry of Water, Land and Air Protection. A copy of the document can be downloaded from: http://www.env.gov.bc.ca/wsd/public_safety/flood/structural.html

"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. A copy of the document can be downloaded from: http://www.env.gov.bc.ca/wsd/public_safety/flood/landuse_mgmt.html

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 such as the **Dike Design and Construction Guide 2003** and **the Land Use Guidelines 2004** are used. However, in some cases existing terminology and definitions need modification, clarification or expansion to be appropriate for coastal conditions. It is recommended that readers of the updated documents familiarize themselves with the updated terminology and definitions in Appendix A as necessary.

3 Climate Change Impacts on Sea Level Rise, Storms and Tides.

3.1 Introduction

In general terms, climate change is expected to result in warmer air and sea temperatures, global, regional and possibly local increases in sea level, changes to ocean storm patterns and characteristics, and changes to precipitation and terrestrial vegetation. The precipitation and vegetation effects will affect rivers and streams that transit coastal areas. While climate change effects may not create new coastal hazards, they will exacerbate existing coastal flooding and erosion problems at many locations, both in areas where coastal flooding is experienced now (2010) or in low lying areas that may become exposed in the future. Commonly quoted impacts include:

- More coastal flooding or inundation, both in areas presently flooded and in areas presently above existing water levels.
- Increased coastal erosion due to exposure of land to higher water levels and wave action.
- Change to coastal ecosystems – potentially leading to coastal erosion and the interaction of storm related effects with the shoreline.
- Saltwater intrusion into coastal wells and aquifers.
- Changes in surface and groundwater quality.
- Changes in coastal sedimentation processes.

Specific changes that will affect shorelines, the land immediately landward of the shoreline and existing coastal defences, through various marine processes, include:

- An increase in mean sea level (MSL), resulting in a rise in the relative elevation of tides, which changes both the frequency of flooding for a given land elevation and exposes new land to a flooding hazard. Depending on the land elevation, flooding may start to occur due to tide alone or due to the combined effects of storms and tide.
- An increase in MSL will lead to a disconnection between the existing correlation between MSL and the vertical reference plane (Canadian Geodetic Datum - CGD) used to define terrestrial elevations[1]. Unless CGD is revised at the same rate as sea level increases a false sense of security may arise.
- Increased water levels will increase the depth of water at existing shorelines and increase the heights of waves that can exist at the present shoreline.
- The frequency and duration of wave action at existing shorelines will increase, leading to more severe design conditions for existing coast defences, or more frequent flooding of low lying unprotected land.
- Wave runup and the volume of water overtopping existing shorelines or coastal structures will increase, which can lead to increased erosion of the area behind the structure, leading to

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[1] 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.

failure of the defence itself, or increased risk and extent of inundation where low lying land exists behind a coastal defence.

- Larger waves, resulting from sea level rise alone, increases the wave loads on a coastal defence structure and the risk of damage or failure. As an example, the weight of a rock required for stability on a sea dike slope is directly proportional to the cube of the wave height at the toe of the structure. Increased wave heights will require an increase in the size of armour required to achieve the same stability. Increased duration of exposure will also likely require an increase in the size or quantity of armour materials on an existing coastal defence structure. Transitions at places along a dike system where other features such as tidal gates or pump outlet structures are present, will also be more vulnerable to damage or breaching.
- Larger waves also means increased wave energy is reflected from coastal defence structures and may lead to higher wave related currents and increased scouring on the seaward side of a coastal defence structure. This will likely increase the risk of undermining the structure and further increasing the depth of water that needs to be considered.

Harford (2008) notes that in BC:

- A 1 metre rise would inundate more than 4600 ha of farmland and more than 15,000 ha of industrial and residential urban areas in the lower mainland of BC.
- Approximately 220,000 people live near or below sea level, currently protected by 127 km of dykes not built to accommodate rising sea levels resulting from climate change.
- Coastal communities and coastal tourism, and their associated infrastructure and services, are vulnerable to erosion, storm surges, extreme high water events and flooding hazards.

Hanak and Moreno (2008) suggest that low-lying coastal communities will face increasing difficulties draining treated wastewater and stormwater via traditional gravity-based systems, as these systems may ‘back up’ due rising sea levels at their outlets. Streams presently flowing through communities or culverts and discharging into tidewater will also be affected. This will be further exacerbated if more extreme precipitation events also occur as part of climate change.

Saltwater intrusion into the groundwater of coastal lands and lands bordering rivers near the coastline will also impact fresh water supply for agriculture, which may, in turn, change the economics and nature of activity, land use and land values. These effects have an influence on decisions relative to management of coastal lands or the design and construction of sea dikes; however, this additional influence of climate change on coastal areas is not addressed specifically in this document.

This chapter examines three aspects of climate change impacts on coastal areas:

- Change in relative sea level – global and regional.
- Storminess and storm surge.
- Impacts on high tides.

3.2 Relative Sea Level Change

Definition of the potential effects of climate changes on sea level requires consideration of two main factors:

- Projected *global* sea level rise associated with climate change (global SLR); and
- *Regional and local* factors that affect the manifestation of global sea level rise in the project area (regional SLR).

An understanding of sea level rise relative to the land also requires an understanding of the ongoing changes in geological related crustal processes along the coastline of BC. These processes are addressed in the **BC Sea Level Report 2008**, and where necessary incorporated or referenced in this document.

3.2.1 Global Sea Level Rise Projections

The degree of change that can be expected in coastal areas is essentially defined by the expected sea level rise, and in turn, by how far into the future the expected changes are considered. Expected global SLR is well described in the scientific and associated literature, and summaries of these projections are provided in various update documents prepared in 2009 (see References, this document). Expansion on and updates to this literature can be expected for some time to come.

Based on present and expected increases in emissions in the near future, sea levels are expected to rise at accelerating rates into the next century and even if drastic measures are affected to slow down or even stop GHG emissions, to persist for several millennia in the future.

Figure 3-1 provides a recent summary of global SLR projections extending over the next three hundred years. The grey band spans the range of uncertainty that exists in these predictions, including different estimates of future global SLR resulting from the family of scenarios described by the IPCC in its 2007 Assessment Report 4 (AR4), IPCC (2007). These scenarios consider the overlapping effects of future population growth, global economic trends and emissions trends and strategies. The bands and trends in Figure 3-1 also reflect the effects of what is commonly referred to as post IPCC AR4 science. Projections of very long term persistent changes in SLR are provided in Solomon, et al. (2009), which shows that elevated sea and levels will persist for millennia, even in the most optimistic IPCC scenarios.

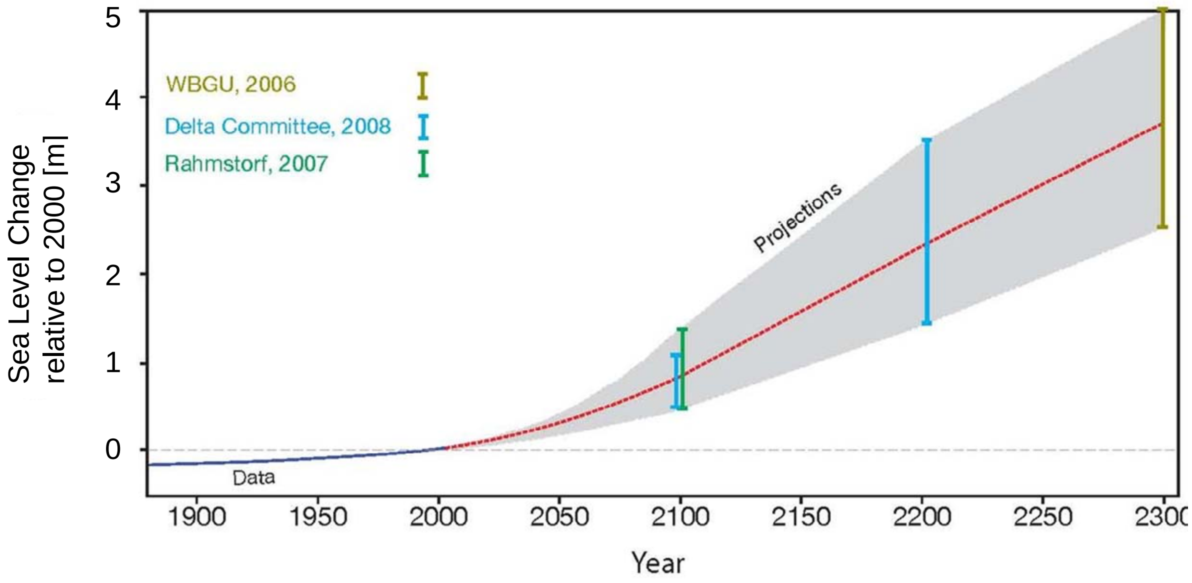
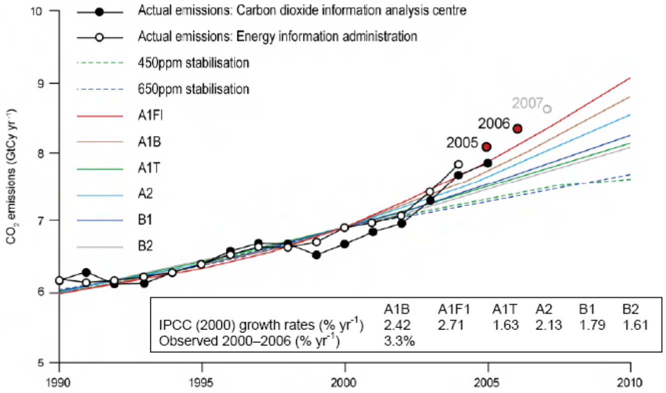


Figure 3-1: Recent Projections of Expected Global Sea Level Rise

Source: Allison *et al.,* 2009

Recent measurements of carbon emissions, Figure 3-2 and sea level rise, Figure 3-3, both suggest that the present trend is close to, or above, the upper envelope of global scenarios. However, the duration of available information, approximately 15 years, may be too short to differentiate between a long term trend versus shorter term fluctuations that exist in the observed data, both in recent times and over the last century. Monitoring and the ongoing assessment of the collected data can be expected to revise these comparisons.

Of the series of greenhouse gas scenarios generated by the IPCC Assessment Report 4 (AR4; IPCC, 2007), the A1FI scenario is often used as the basis for assessing future global SLR. The A1FI scenario predicts a global mean temperature increase of approximately 2° to 6˚C by 2100 to reflect high economic growth with widespread global use of fossil fuels. As actual emissions since 2000 align with or even exceed this IPCC estimate (Figure 3-2) suggests that the A1FI scenario is a realistic basis for assessing potential future effects at this time (Delta Committee, 2008).



	A1B	A1F1	A1T	A2	B1	B2
IPCC (2000) growth rates (% yr^{-1})	2.42	2.71	1.63	2.13	1.79	1.61
Observed 2000–2006 (% yr^{-1})	3.3%					

Figure 2 Projected and observed CO_2 emissions. The envelope of IPCC projections are shown for comparison (*Source*: Steffen 2009, Raupach et al. 2007; with additional data points from Canadell et al. 2007 and Global Carbon Project annual carbon budgets; © National Academy of Sciences, USA)

Figure 3-2: Projected and Observed CO_2 Emissions
Source: NSW Government, 2009

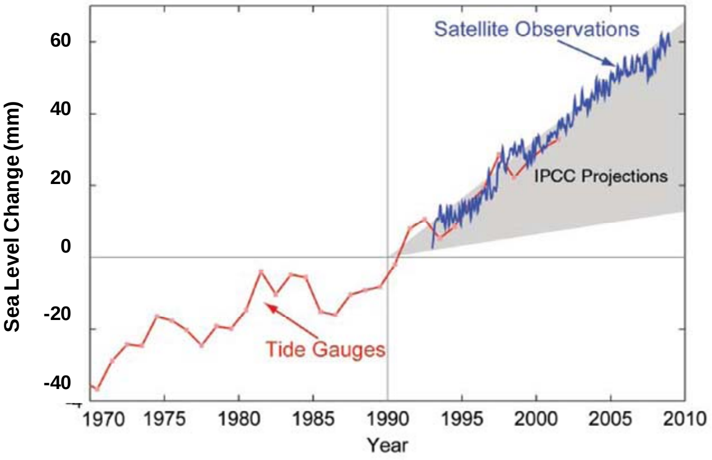


Figure 16. Sea level change during 1970-2010. The tide gauge data are indicated in red (Church and White 2006) and satellite data in blue (Cazenave et al. 2008). The grey band shows the projections of the IPCC Third Assessment report for comparison.

Figure 3-3: Projected and Observed Global Mean Sea Level Changes
Source: Allison *et al.,* 2009

The IPCC A1FI scenario projected a global SLR of 0.25 to 0.76 m by 2100. However, the IPCC estimate does not take into account the effect of melting ice sheets because at the time of the IPCC AR4 report the fate and rate of ice discharge from the ice sheets in Antarctica and Greenland was very uncertain. The occurrence of accelerated ice melt of these ice sheets since IPCC AR4 has led many experts to consider that the IPCC AR4 projections underestimate future global SLR:

- According to Allison *et al*. (2009), satellite and ice measurements now demonstrate that the Greenland and Antarctic ice sheets are losing mass at an increasing rate; glacier melting in other parts of the world has also accelerated since 1990. Satellites also show global average SLR to be 80% above past IPCC predictions; which is consistent with a doubling in contribution from melting of glaciers, ice caps and the Greenland and West-Antarctic ice sheets. Allison *et al.* (2009) predict that by 2100, global sea level is likely to rise at least twice as much as projected by the IPCC AR4; for unmitigated emission it may well exceed 1 meter. The authors note that future sea level rise is still highly uncertain, mainly due to unknowns regarding the rate and extent of response of the big ice sheets to global warming. However, they also note that sea level will continue to rise for centuries after global temperature has been stabilized and several meters of SLR must be expected over the next few centuries.
- In their study for the United Nations Environment Program, McMullen and Jabbour (2009) also indicate that Arctic ice is melting faster than previously assumed, and that plausible values of total global average sea level rise, including all land-ice sources plus thermal expansion, may reach 0.8 to 2 m by 2100.
- Based on their estimates of ice sheet contribution, the Delta Committee (2008) of the Netherlands estimate a global SLR of 0.55 to 1.10 m by 2100, and a *possible* upper limit rise in global SLR of 1.5 to 3.5 m by 2200. This range is indicated in Figure 3-1.
- In December, 2008, the U.S. Climate Change Science Program (USCCSP) released a report to the U.S. President and Congress on expected abrupt climate change. The report specifically addresses the expected effects of an increased contribution to global sea level rise due to dynamic ice mass wasting processes[2] that are not included in the models which underlie the IPCC predictions. The USCCSP report does not predict specific annual rates due to the present lack of detailed predictive tools linking atmosphere – ocean – ice interaction processes. Inclusion of responses from these processes is; however, expected to result in sea-level projections for the 21st century “that substantially exceed the projections in the IPCC Fourth Assessment Report”.
- The selection of the A1FI emissions scenario and its impacts on climate change for 2100 and beyond is also recommended by the Pacific Climate Impacts Consortium[3] and is consistent with other Regional Adaptation Collaborative (RAC) projects in BC, currently planning for a timeline of 2100 and beyond.

3.2.2 Regional Sea Level Rise Projections

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:

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[2] In general terms these processes include an accelerated rate of contribution to sea-level rise due to increased rates of ice movement into the sea or sub-sea melting of portions of the Greenland and Antarctica ice sheets currently grounded below present sea-level.

[3] Pers Comm: T. Murdock, 29 July 2010.

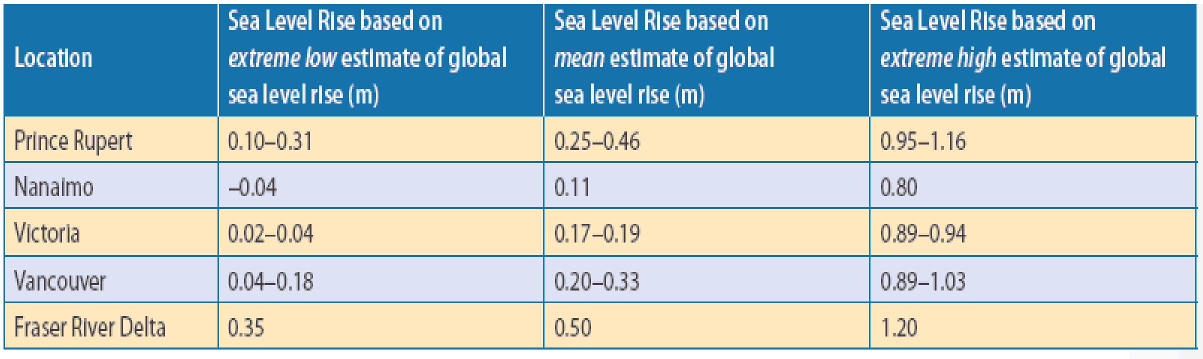
- Variations particular to the Pacific Ocean Basin and to the NW Pacific portion;[4]
- Variations particular to coastal British Columbia waters;
- Local variations caused by crustal movement leading to land uprising or subsidence, which may offset or exacerbate the sea level rise.

The **BC Sea Level Report 2008** provides the most recent definition of expected regional or local sea level rise due to climate change effects. The results of this study are summarized below in Table 3-1. The "*mean*" values in Table 3-1 are based on a global SLR of 0.3 m by 2100, which corresponds to the present rate of rising sea level based on recent satellite observations (Figure 3-3). The "*extreme high*" values are based on a global SLR of 1.0 m by 2100.

The ranges expressed for each region in Table 3-1 are due to variations in the underlying data defining the crustal movement in each region along the BC coast (see Appendix B). There is additional variation – not shown in Table 3-1 – attributable to uncertainties in the crustal movement data. As an example, the "extreme high" estimate for the Fraser River Delta has a range of 0.87 to 1.53 m around the quoted 1.2 m mean value.

Table 3-1: Summary of Regional Sea Level Rise Estimates for 2100 for Selected BC Locations

Source: BC Sea Level Report 2008



Location	Sea Level Rise based on *extreme low* estimate of global sea level rise (m)	Sea Level Rise based on *mean* estimate of global sea level rise (m)	Sea Level Rise based on *extreme high* estimate of global sea level rise (m)
Prince Rupert	0.10–0.31	0.25–0.46	0.95–1.16
Nanaimo	–0.04	0.11	0.80
Victoria	0.02–0.04	0.17–0.19	0.89–0.94
Vancouver	0.04–0.18	0.20–0.33	0.89–1.03
Fraser River Delta	0.35	0.50	1.20

Planning or design of appropriate responses to coastal flooding or of sea dike requirements needs more than an estimated height of sea level rise by a given date. It is also necessary to understand the rate at which sea level will rise to the expected height and how the sea level will rise beyond the specific date.

The planning sea level rise curves being used by other jurisdictions are briefly summarized below.

- the New Zealand Ministry for the Environment (2008) recommends the following parameters for planning and decision timeframes out to the 2090s:
    - a base value of SLR of 0.5 m relative to the 1980-1999 average;
    - an assessment of the potential consequences of SLR of <u>at least</u> 0.8 m relative to 1980-99, where impacts are likely to have high consequence or where additional adaptation options are limited;
    - for longer planning and decision-making timeframes, an allowance for SLR of 10 mm per year beyond 2100. By 2200, this would result in a SLR of approximately 1.8 m.

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[4] Available satellite measurements of recent sea level rise show considerable variation around the globe compared to the often quoted global means. Information on the global variation during upcoming climate change is not as readily available at this time.

- The US Army Corps of Engineers (2009) directs that planning studies and engineering design consider alternatives for the entire range of possible future rates of sea-level change. Alternatives are to be assessed using "low," "intermediate," and "high" rates of future sea-level change. These rates are indicated in Figure 3-4 and have the following basis:
  - The "Low" rate (Modified NRC-I) [5] is based on historic rates of sea-level change from tide gauge records.
  - The "Intermediate" rate (Modified NRC-II) reflects the IPCC 2007 AR4 projections.
  - The "High" rate (Modified NRC Curve-III), which exceeds the upper bounds of IPCC 2007 estimates, anticipates a potential rapid loss of ice mass from Antarctica and Greenland.

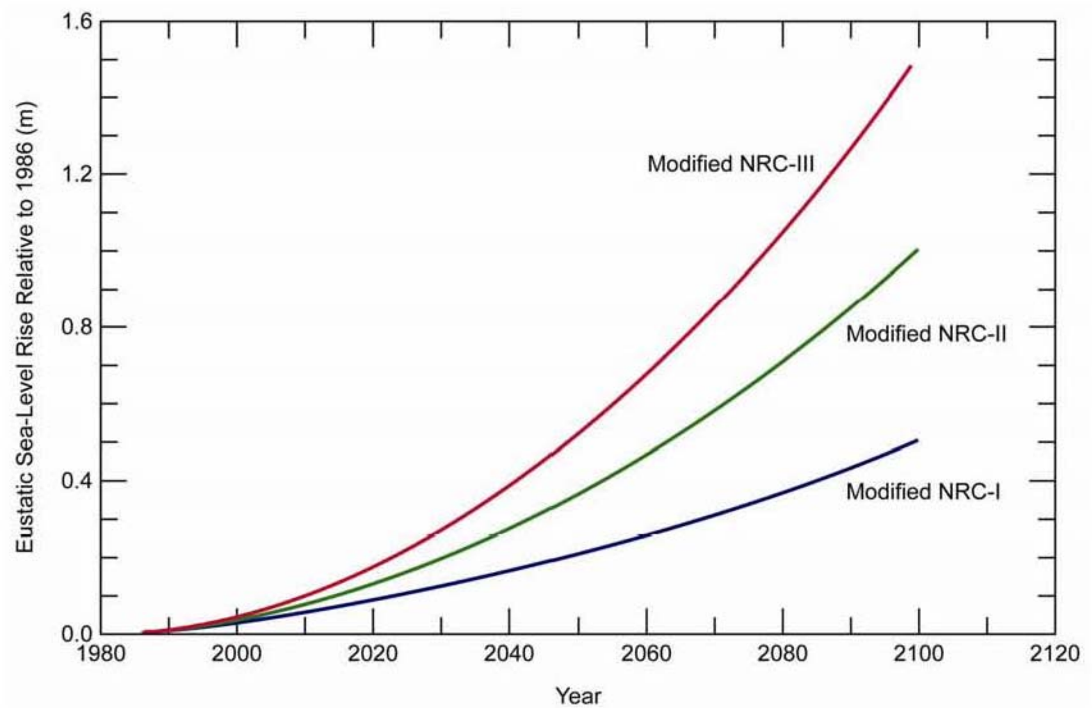

Figure 3-4: US Army Corps of Engineers Planning and Design Curves
Source: (US Army Corp of Engineers, 2009)

- The Delta Committee (2008) of the Netherlands, using the same mean temperature increase of 2 – 6 °C as the IPCC A1FI scenario but including estimates of ice sheet melting, estimates a local sea level rise along the Dutch coast of 0.55 to 1.20 m by 2100, and 2.0 to 4.0 m by 2200.
- In a recent study for the UK, Lowe, et al., 2009, assembled a standalone overview of climate change related marine effects around the UK coastline, showing key findings and detailing the science used. In response to requests for a high end coastal flooding scenario that lay beyond the likely range for the 21st century, but still remained within the physically plausible range, a High plus plus (H++) scenario was developed. This H++ range is an attempt to quantify the emerging understanding of dynamic ice sheet processess described but not fully quantified in the IPCC AR4 reports. An upper limit of +2.5 m sea level rise was adopted for the 21st century

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[5] The NRC curves are from: National Research Council 1987 Responding to Changes in Sea Level: Engineering Implications. National Academy Press: Washington, D.C. http://www.nap.edu/catalog.php?record_id=1006

(from 1990 – 2095). This rise was recognized to be greater than an upper limit of 2 m for the 21st century suggested by Pfeffer, Harper and O'Neel (2008).

It is clear that a range of both planning curves and date specific global SLR estimates are being used worldwide at the present time (2010). These curves and the associated date specific predicted SLR heights can be expected to become similar as more data and analysis becomes available in the future. It also seems clear that the present BC regional SLR estimates for 2100 (Table 3-1) could be low and also that further guidance is warranted for time frames extending beyond 2100.

3.2.3 Recommendation for BC Sea Level Rise Policy and Adaptation Planning

Based on the results summarized above, it is recommended that the sea level rise curve provided below in Figure 3-5 should be used as the basis for defining policy in BC. The envelope of projections shown on Figure 3-5 reflects the ranges described above. The recommended curve is slightly higher than the high projection, for the years from the present, up to approximately 2070, to reflect the present trends of measured CO_2 emissions and sea level rise to be greater than the IPCC projections as discussed above. The recommended curve moves below the current median projection with the recognition that in a planning framework, time remains to revise the recommended curve upwards, if the science or the required response warrants.

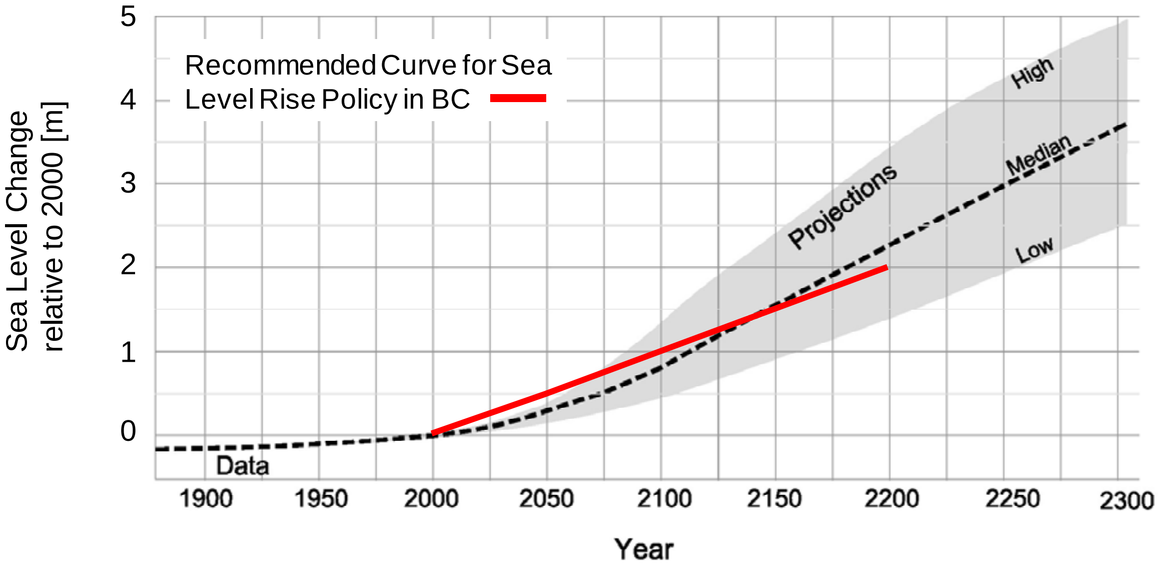

Figure 3-5: Recommended Global Sea Level Rise Curve for Planning and Design in BC

The specific increases for common time frames; their likely application and the underlying rational are summarized in Table 3-2. Specific adjustment of the global SLR defined by Figure 3-5, to account for regional factors along the BC coast, can be made by reference to the **BC Sea Level Report 2008** and Appendix B.

These recommended values represent an initial precautionary approach, given prevailing uncertainties, and will likely undergo review and revision over the near future; as more measurements and observations of related phenomena become available, as the science and the associated modelling assimilate the results, and as the trajectory of global response to climate change issues becomes clearer. It is recognized that considerable social and economic implications may arise; however the early precautionary approach means that implementation of planning measures can be easily adjusted if future data and science confirms a slower rise in global SLR. Based on the envelope curves in Figure 3-5, planning for a global SLR of 0.5 m over the next 25 to 50 years would be appropriate for 2100, if climate change and the related sea level effects follows the low projection curve.

As a further commentary it should be noted that in a 2009 Policy Statement on Sea Level Rise, the New South Wales (NSW) Government of Australia states “The use of the [NSW] benchmarks will be required when undertaking coastal and flood hazard assessments in accordance with the Coastline Management and Floodplain Development Manuals. It is already a statutory requirement that the preparation of local environmental plans gives effect to and be consistent with these Manuals. “ (emphasis added).

The NSW government goes on to state “the benchmarks are not intended to be used to preclude development on land that is projected to be affected by SLR. The goal is to ensure that such development recognizes and can appropriately accommodate the projected impacts of SLR…” (emphasis added).

Table 3-2: Sea Level Rise Recommendations and Their Application for BC Sea Dike and Coastal Flooded Land Management Guidelines

Development/ land use timeframe	Global SLR	Regional SLR	Application	Comment
For short to medium term - life of 25 to 50 years	0.5 m	To be developed on a site specific basis. See Appendix B for existing crustal movement rates along coastal BC shorelines.	Evaluation of existing structures (sea dikes)	This estimate is slightly higher than suggested by the present range of SLR estimates and planning curves and anticipates revision in the near future (circa 2014).
For longer term - life of up to 2100	1.0 m		Definition of requirements for permanent structures (sea dikes) that can be expected to be upgraded again in the future as science and knowledge increases	This is consistent with the present “*extreme high*” estimates in Table 3-1.
For issues with long life (> 100 years), and as a sensitivity example	2 m		Consideration of long-term land-use and planning issues having very long term implications – especially where decisions may be made that allow or encourage concentration of high value or high population density uses	This value is a balance between the current often stated upper limit of ~ 2 m for updated accounting of ice sheet mass loss by 2100, (Allison, et al., 2009; USCCSP, 2008) and the median estimate for the year 2200 developed by the Delta Committee (Delta Committee, 2008).

3.3 Storm Effects

On a global scale, climate change is generally expected to result in increases to the frequency, intensity and to other characteristics of storms, especially for hurricanes or tropical cyclones in low latitude and sub-tropical regions. In the mid-latitude regions, especially in the Pacific Ocean basin between 30 degrees and 60 degrees latitude N, the expected changes that will affect coastal BC waters are not well defined in the climate change literature.

Climate change related influences on the overall storm generation processes in the earth's atmosphere and primarily in the troposphere, where storms are created, may result in increased wind speeds, increased durations of strong winds, larger atmospheric pressures differences and corresponding changes to storm tracks, storm surges and the storm wave climate. However, this is largely conjecture and a potential decrease in some or all of these storm characteristics cannot be discounted at this time.

A review of the scientific literature, as of February 2010, indicates that studies of possible changes are on-going and take two typical forms:

- Review and analysis of long records of recorded winds, water levels or waves.
- Review and assessment of the results of ensembles of Global Climate Models (GCMs) and, in some cases, scaled down results from Regional Climate Models (RCMs). Both model classes generally include coupled oceanic and atmospheric physics in their formulation.

A detailed review of the literature is beyond the scope of this assignment; however, based on an initial review, these investigations tend to suggest the following trends:

- A small increase (generally less than 10 per cent) in the mean or in the extreme values, can be seen in some sets of recorded data from the last 30 to 40 years.
- A similar trend is not clear in recorded data sets that extend as far back as 80 to 100 years.
- Global (GCM) and regional (RCM) atmospheric-oceanographic model results, which have been calibrated against the last 40 years of available data for ocean weather and waves, tend to show only a small increase, sometimes a decrease, for all IPCC scenarios into the future, in the mid-latitudes and especially the latitudes (40 degrees - 50 degrees N) where most storms that affect coastal BC waters are generated.

The difference between the recorded data set based studies and the forward looking coupled models may be because the recorded datasets do not tend to be long enough to separate multi-decadal scale variations from any specific climate change related trends over the decades covered by the recorded data sets.

Regional studies, involving a downscaling of GCM results, specifically to the NE portion of the Pacific Ocean basin, have not reported in the technical literature at the time of this review (February 2010); however, Ulbrich, et al., 2009, in a comprehensive review of climatologies of mid-latitude cylcones for both Northern and Southern Hemispheres, for both the present climate and for possible future anthropogenic climate changes, found a range of mixed results.

For existing climate conditions, Ulbrich, et al., 2009 report the following for the North Pacific basin area:

- An overall northward shift of mid-latitude storm tracks.
- A range of results for frequency or intensity of extreme cyclones that is sensitive to the choice of storm identification algorithms and of the representative dataset.

- A significant change in the intensity of mean winter cyclones over the North Pacific, accompanied by the northward shift in storm track.

For future climate change scenarios, Ulbrich, et al., 2009 found that 16 separate available GCM's, all of which had a reasonable ability to reproduce the general structure of existing climate conditions, tended to show the following trends for the future climate in the North Pacific, over a range of different greenhouse gas scenarios:

- The number of extreme cyclones increases in winter, but the total number of cyclones is reduced.
- An increasing number of extreme cyclones is not a general result and several studies found this is only the case for limited defined areas, such as near Great Britain in the North Atlantic and near the Aleutian Islands in the North Pacific.
- The results are very variable from model to model and appear to be sensitive to how an intense or extreme cyclone is defined.

The Delta Committee (2008), of the Netherlands, concluded, based on IPCC AR4 (2007) scenario results, examined specifically for the Dutch coast, that projected future changes in wind and wave conditions will be small relative to natural variability and the inherent uncertainty associated with the use of relatively short data series. The scenarios used by the Committee showed no clear dependence on future greenhouse gas emissions.

In a recent study for the UK , Lowe, et al., 2009, who examined the results of an ensemble of GCM and RCM model results for IPCC AR4 (2007) scenarios for UK waters, found that the physical significance of any trend in the storminess-driven component of extreme sea level – i.e. surges – by the end of the present century (2100) was small. The related trends in wave climate were also small, with a general decrease of the northern waters of the UK and a small increase over southern waters of the UK. The changes were attributed to expected changes in storm tracks over the North Atlantic.

In a just released study (June, 2010) Mori et al (2010) conclude, on the basis of a 20 km by 20 km high resolution GCM model, for the IPCC A1B scenario, that the mean annual signifcant wave height in the North Pacific, adjacent to British Columbia waters, will decrease by approximately 5 to 10 per cent.

It is clear that further study and analysis is required to define the expected trends over the North Pacific and specifically for the mid-latitiudes occupied by BC coastal waters. For the present assignment we have assumed that the existing storm population is a reasonable model for the expected storm population in the future. It may actually tend to overestimate future trends in southern BC coastal waters.

3.4 Tide Range and High Tide Frequency

Tides around the world are predominately generated by the relative motions and gravitational forces of the earth, moon and sun and their collective effect on the ocean, which covers 70 per cent of the earth's surface. Climate change is not expected to change these interactions directly; however, some high level science papers have postulated that melting of the polar ice caps may eventually change the character of the earth's rotation leading to changes in tidal characteristics. For the purpose of this assignment, no change in tidal characteristics in BC coastal waters is anticipated.

At present there is a close and well defined relationship between tide ranges, mean sea level (MSL) and the vertical reference plane normally used in Canada, i.e. Canadian Geodetic Datum (CGD), to define elevations on land. As sea level rises the relationship between the terrestrial datum CGD and MSL will change, unless CGD is continuously revised. For the purpose of this document we refer to the 2010 version of the CGD terrestrial datum and associated elevations as a constant.

MSL will rise in the foreseeable future due to climate change but the tide ranges, which are related to MSL, are not expected to change. Tide ranges will still be centered about MSL but their absolute elevations will rise in relationship to CGD.

For the purpose of this assignment, existing tidal information is superimposed on a mean water level that reflects the sum of existing mean water level plus the appropriate regional SLR.

4 Community/Land Use Planning and Hazard Management Options

Climate change may not create new coastal hazards but it will almost certainly exacerbate existing coastal flooding and erosion problems. The literature on climate change refers frequently to four main land use "strategies" for adapting to the hazards created or increased by climate change:

- Avoid.
- Protect.
- Accommodate.
- Managed Retreat.

Each of these strategies is briefly discussed in this section, as the need to construct or upgrade sea dikes or to define the exposure to coastal flooding, is closely related to which strategy is being considered or adopted.

4.1 Avoid

In simplest terms, avoidance means not developing in areas considered at moderate to high risk to a hazard. Avoidance measures are typically limited in application to future development or redevelopment. Typical avoidance measures include:

- Zoning or designating lands as undevelopable or only suitable for very low density development or for land uses that have relatively low risk with respect to flooding and inundation. "Risk Zoning" is discussed further in Section 4.7.3 of this document.
- Setbacks to place structures beyond the reach of sea level rise, tides, storm surge or the effects of waves.

4.2 Protect

Protection means building protective structures specifically for protecting private and public assets. Protection approaches and designs may be "hard" (e.g. by armouring the coastline with sea dikes, seawalls or riprap revetments) or "soft" (e.g., by constructing or augmenting berms, dunes, beaches and marshes).

There are limits to the extent to which communities can or should rely on structural protection to adapt to climate change effects. On eroding coastlines that have been developed, there is typically high public (and often political) demand for coast protection measures to 'hold the line' and protect private property, infrastructure or utilities. Such measures are often viewed by the public as 'solutions' to coastal erosion problems; however with a rising sea level the distinction between erosion protection and flooding protection may become blurred. The decision to protect tends to:

- Be reactive.
- Lead to a false sense of future security; many constructed coastal defences are not as permanent as the residents behind them assume.
- Often encourage further development behind the structures.
- Lead to other property and environmental damage and impacts on other coastal values including aesthetics and recreational access.

- Rising sea levels will dictate that sea dikes must be raised periodically and considerable land area behind the dikes will need to be acquired for the dike right of way.
- Create an expectation that defences will be maintained in perpetuity, leading to ever increasing financial commitment to maintain and upgrade such defences.

On coastlines that are retreating, the effectiveness of coastal defences is continually reduced while the potential negative impacts caused by them often increase. This process is likely to be accelerated by climate change.

In the aftermath of storm events where retreat or inundation has occurred, there is a temptation to use coastal protection works as a short-term measure to ‘buy some time’ to permit more long-term options to be explored and implemented. However, in reality, once defence works are in place, it is extremely difficult to then remove them.

4.3 Accommodate

Accommodating climate change effects means adapting land-based structures and activities to tolerate flooding and inundation. Typical accommodation measures include (Heap, 2007):

- Building above Flood Construction Levels (FCLs) to avoid flooding.
- Flood resilient construction measures - e.g., waterproof resilient materials; situating electrical devices above projected flood level; one-way valves in drainage pipes; moving building contents out of the flood path.
- Liability reduction measures – e.g., covenants indemnifying governments should a hazard occur; certification by a qualified professional that the design and construction will mitigate risks; more stringent design criteria.
- Warning and evacuation protocols based on thresholds such as rainfall amounts or predicted storm events.
- Innovative institutional and regulatory measures – e.g., rolling easements (see discussion under “Managed Retreat”).

4.4 Managed Retreat

‘Managed retreat’ is defined as any strategic decision to withdraw, relocate or abandon private or public assets that are at risk of being impacted by coastal hazards (New Zealand Ministry of Environment, 2008) . Relocation of properties tends to occur on a case-by-case basis, usually at the discretion of a private property owner.

The various scales of managed retreat include:

- Relocation within a property boundary.
- Relocation to another site.
- Large-scale relocation of settlements and infrastructure.

The most likely methods for implementing managed retreat would be a mix of some or all of the following (New Zealand Ministry of Environment, 2008):

- District and regional plan measures that relate to managing existing use rights and limiting or controlling the construction of protection works.
- Property title covenants, to prevent undesirable activities such as construction of coastal defences. Covenants may also specify where and when retreat and/or relocation is required.

- Financial instruments or assistance measures including:
    - Purchase of property.
    - Subsidies for relocation.
    - Taxation of risk or adverse effects.
    - Pre-paid community relocation fund.
    - Transferable development rights.
    - Relocation of infrastructure out of a hazard area.
    - Insurance incentives or disincentives.

For managed retreat to be implemented, Turbott and Stewart (2006) suggest that regulation must also include two key elements:

1. prohibiting hard protection works in the coastal marine area and adjacent land, and
2. specifying control of land-use rights for both new and existing buildings plus the trigger levels that would require relocation.

Significant barriers exist to managed retreat becoming a strategic and more commonly applied mechanism including public perception, existing land use rights, costs, the infrequent use of decision-making tools, particularly cost–benefit analysis, that incorporate non-market valuations.

4.4.1 Managed Re-alignment – A Variation on Retreat

Managed Re-alignment, a favoured term in Europe, involves setting back the line of actively maintained defences to a new line inland of the original – or preferably to rising ground – and promoting the creation of intertidal habitat between the old and new defences (Rupp and Nicholls, 2002). This is accomplished either by the complete removal or by a breach of the defence. The main objectives are:

- Habitat conservation: intertidal habitat conservation and re-instatement. Intertidal habitat also provides recreation and public enjoyment opportunities and acts as pollution sinks.
- Flood defence: salt marshes can be effective dissipaters of wave energy and the first line of defence against tides and waves, reducing the capital and maintenance costs of fixed flood defences.

In the EU, salt marshes are protected under the EU Habitats Directive and as habitat for species protected under the Birds Directive. The United Kingdom’s biodiversity action plan aims to prevent net loss of salt marsh area, as present in 1992; hence, all losses must be compensated by equivalent replacement habitat. In England, “coastal squeeze” by SLR is recognized as a major threat and targets for creating 140 ha/yr of salt marsh to offset past and present losses have been set.

Managed realignment is most appropriate to low-lying, lightly developed or marginal coastal lands; relocating dikes inland may shorten the length required, increasing the cost effectiveness of this measure. Other factors favouring managed realignment as an adaptation measure include (Rupp and Nicholls, 2002):

- The importance placed on maintaining or re-instating intertidal habitat.
- The traditional use of salt marshes as coastal defence mechanisms.
- The current state of dikes; i.e., whether they are “fit for purpose” or near the end of their life.

- Public perception of the “right” to protection.

4.5 Choice of Options

There are a number of factors that need to be considered when determining which option may be appropriate in any given situation. In general the option to “avoid” only applies in undeveloped lands although it can refer to decisions concerning future development or redevelopment. In this latter case the “avoid” option becomes similar to the option to “retreat” – although perhaps in a managed manner. Factors to be considered when determining whether to “protect” and/or “accommodate” versus “retreat” from coastal flooding hazards, include:

- Number of people affected.
- Development density.
- Property value.
- Capacity to move and the cost of structures and assets to be moved.
- Availability of alternative locations for structures, land use or assets to be moved.
- Liability of public agencies vs. private interests.
- The likelihood or probability of being flooded now or at some time in the future.
- Evaluation of the total implications of each option and identification of the appropriate choice of option.

The key stakeholders in the evaluation of appropriate options include, in no particular order:

- Public bodies and authorities responsible for the area in question.
- Project funders (who may be the same as above).
- Project planners and engineers, largely responsible for the assessment, design and maintenance of the area and works in question.
- The general public.
- Insurers.
- Environmental, heritage and other interested groups.

Ongoing structural protection may be a long-term option in highly developed urban areas with a long history of coastal protection and the funding capacity to pay for the potentially high cost of protection. Coastal planning can strategically identify where “protect” options may be appropriate, and make hard protection works a prohibited activity outside these areas. This would send a clear signal about where such measures are appropriate and, more importantly, where they will not be considered.

Such planning measures can be difficult to implement, particularly with shoreline property owners. Yet the complications that arise from not managing coastal development and protection works can be far more complex and expensive in the long run. Some of the public opposition may be reduced by providing good information and participation processes, but acceptability of these measures will never be universal.

Table 4-1 summarizes some of the options for responding to sea level rise in terms of their approach and environmental effects.

Table 4-1: Example Measures for Responding to Sea Level Rise
(adapted from Titus *et al.,* 2009)

Measure	How It Works	Environmental Effects
Avoid		
Setback	Delay the need for shore protection by keeping development out of the most vulnerable lands	Impacts of shore protection delayed until shore erodes up to the setback line; impacts of development also reduced.
Density or size restriction	Reduce the benefits of shore protection and thereby make it less likely	Depends on whether owners of large lots decide to protect shore; impacts of intense development reduced.
Protect		
Seawall	Shoreline armouring used to define a shoreline- reduces erosion, protects against flood and wave overtopping	Elimination of beach; scour and deepening in front of wall; erosion exacerbated at terminus
Revetment	Shoreline armouring used to define a shoreline - reduces erosion, protects land from storm waves, protects new landfill	Prevents inland migration of wetlands and beaches; traps horseshoe crabs and prevents amphibious movement; may create habitat for oysters and refuge for some species.
Dike	Shoreline armouring used to protect against inundation - prevents flooding and permanent inundation (when combined with a drainage system)	Prevents wetlands from migrating inland; thwarts ecological benefits of floods (e.g., annual sedimentation, higher water tables, habitat during migrations, productivity transfers)
Tide gate	Shoreline armouring used to protect against inundation -reduces tidal range by draining water at low tide and closing at high tide	Restricts fish movement; reduced tidal range reduces intertidal habitat; may convert saline habitat to freshwater habitat.
Storm surge barrier	Shoreline armouring used to protect against inundation -eliminates storm surge flooding; could protect against all floods if operated on a tidal schedule	Necessary storm surge flooding in salt marshes is eliminated
Dune	Elevates land - protects inland areas from storm waves; provides a source of sand during storms to offset erosion	Can provide habitat; can set up habitat for secondary dune colonization behind it.
Beachfill	Elevates land - reverses shore erosion, and provides some protection from storm waves	Short-term loss of shallow marine habitat; could provide beach and dune habitat.
Accommodate		
Elevate land and structures	Avoids flooding and inundation from sea-level rise by elevating everything as much as sea rises	Deepening of estuary unless bay bottoms are elevated as well.
Retreat		
Rolling easement[6]	Prohibit shore protection structures	Impacts of shore protection structures avoided

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[6] Rolling easement : as defined in Titus, James G. 1998. *Rising seas, coastal erosion, and the takings clause : how to save wetlands and beaches without hurting property owners.* Maryland Law Review 57(4), 1281-1399.

4.6 Applying the Strategies in the Areas of Interest

Table 4-2 illustrates how the climate change adaption options could be applied in BC coastal regions. The indicated levels of development and consequences of flooding are a preliminary assessment only and the identification of appropriate Options will require specific attention from site to site.

Table 4-2: Applying Climate Change Adaption Options to the Areas of Interest

Area of Interest	Preliminary Estimate of Area Value	Estimated Consequences of Flooding	Adaptation Options - in potential order of priority
Fraser River delta – Richmond, Surrey and Delta coastal areas	High	High	Protect Accommodate Retreat - no new or redevelopment Avoid – new development
Lower Fraser River diked areas	High	High	Same as above
Vancouver harbour – no dikes but extensive foreshore development	High	High close to shoreline	Protect Accommodate Retreat
Squamish River delta - no dikes but extensive foreshore development in downtown Squamish, industrial development and high ecological values	Moderate to High	High	Accommodate Avoid (new and redevelopment) Retreat – re-establish wetlands Protect
(South) East Vancouver Island – few sea dikes (Cowichan River estuary) but extensive coastal development, mostly low to moderate density (residential, small scale commercial)	Moderate to Low	Moderate - High	Accommodate Retreat Avoid Protect
West Vancouver Island, North East Vancouver Island, Central Coast and North Coast – intermittent coastal development, a few high-medium density nodes (e.g., Tofino, Ucluelet, Sunshine Coast, Powell River, Prince Rupert)	Low to Moderate (at nodes)	Low - Moderate	Avoid - new development Accommodate Retreat

In most situations, especially where development already exists, it is likely that the optimum solution will consist of a mix of options and that the optimum mix will change or evolve with time. In undeveloped areas the choice should be more straightforward.

As an example of an evolving response, say over the next 25 years, local governments may choose to upgrade an existing dike system, while at the same time organizing or altering Development Permit Areas or Bylaws to influence and minimize the consequences of flooding or the overtopping of an upgraded dike in the more distant future. Each area of BC will merit a separate analysis and assessment.

Some tools to manage Climate Change Adaption Options are discussed briefly below.

Identification of appropriate options will nonetheless require guidelines for defining the Designated Flood Level (DFL) and its attendant derivatives; Flood Construction Level (FCL) and Setback or Sea Dike Crest Elevation that will be required to quantify the costs or benefits of any particular

Option. Policy implications for the DFL and its derivatives are described in Section 5 and 6 of this document.

4.7 Land Use Management Tools

Land use management tools that local governments can use to apply one or more of the Climate Change Adaption Options discussed above include:

- Official Community Plans (OCP).
- Development Permit Areas (DPA) – guidelines and requirements for developing in hazard areas.
- Zoning bylaws.
- Restrictive covenants.
- Public education – about the hazards and ways that individuals can address them.[7]
- Early warning and emergency preparedness programs.

These tools are discussed in more detail below.

4.7.1 Official Community Plan Policies and Development Permits

A local government's Official Community Plan (OCP) provides designations for general land use distribution, transportation and utility servicing, as well as general policies on community development and protection. OCPs must contain general land use policy statements and maps showing restrictions on the use of land that is subject to hazardous conditions. Flooding either from rivers or the sea would be a hazardous condition that OCPs must address, with the goals to reduce impacts on people, property and the environment. OCPs may identify Development Permit Areas (DPA) and create Development Permit Guidelines for Protection of Development from Hazardous Conditions, including flooding and some aspects of climate change[8]. These tools can provide different guidelines for different designated areas, different land uses, and different circumstances.

4.7.2 Flood Plain Bylaws

Current BC Provincial Policy encourages the use of Flood Plain Bylaws according to Section 910 of the Local Government Act. These bylaws designate an area as a floodplain, specify the minimum elevation to which development must be constructed, and establish setback requirements and related enforcement provisions.

4.7.3 Zoning and Other Local Government Bylaws

Zoning bylaw provisions can be an added tool in protecting development and the environment from consequences of flooding, by giving preference in flood plains to low risk uses such as agriculture, forestry, day-use recreation or short term industrial uses as opposed to high risk uses such as urban residential of various densities. An example of "risk" zoning is provided in Table 4-3. Note

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[7] under New Zealand's *Building Act*, Land Information Memoranda (LIMs) and Project Information Memoranda (PIMs) provide known site and hazard risk information to help individuals decide for themselves whether to proceed with a purchase of land or development. A LIM is prepared by the local council on request; it is based on all the information a council holds about a piece of land and generally provides a more up-to-date and detailed source of hazard information than may be contained in a district plan. LIM information needs to be periodically updated by district and city councils when new hazard information comes available; the information provided by the LIM may become the basis for liability actions. A PIM is a summary of all the information a council holds in relation to a particular project associated with a piece of land, and outlines all other consents required to complete the project.

[8] *Local Government Act* – Sections 919 and 920.

that zoning on the basis of risk requires that the area in question has been assessed and ranked using a quantitative risk assessment (QRA). A brief background to QRA is provided in Appendix C.

Table 4-3: Zoning for Risk Areas

Source: New Zealand Ministry of Environment, (2008)

Zone	Planning Response
Little or no risk areas	• Flood hazards impose no constraints on planning
Low to medium risk areas	• Not usually necessary to consider flood risk unless local conditions indicate otherwise. Suitable for other than essential services. • A flood risk assessment may be required at upper end of the probability or where the nature of the development or local circumstances indicates heightened risk. • Water-resistant materials and construction may be required. • Generally not suitable for essential civil infrastructure/services such as hospitals, fire stations, emergency depots. • Where such services or infrastructure has to be located in these areas or is being substantially extended - must be capable of remaining operational and accessible during extreme flooding events.
Medium to high risk areas	• Generally not suitable for essential infrastructure such as hospitals, fire stations, emergency depots, schools, ground-based electrical and telecommunications equipment. Land raising may be acceptable. • In areas already built up: May be suitable for residential, institutional, commercial and industrial development, provided flood prevention measures to the appropriate standard already exist, are under construction, or are planned as part of a long-term development strategy. • In allocating sites, preference should be given to those areas already defended to that standard. Water-resistant materials and construction as appropriate. • In undeveloped and sparsely populated areas: Generally not suitable for additional development of any type. • Exceptions may arise if a location is essential for operational reasons; e.g., for navigation or water-based recreation uses, agriculture, transport or some utilities infrastructure, and an alternative lower-risk location is not achievable. Such infrastructure should be designed and constructed to remain operational during floods. • May be suitable for some recreation, sport, amenity and nature conservation uses provided adequate evacuation procedures are in place. Job-related accommodation (e.g., caretakers and operational staff) may be acceptable. • New trailer, mobile home and camping sites should generally not be located in these areas. • If built development is permitted, flood prevention and alleviation measures are required and the loss of storage capacity minimised. • Water-resistant materials and construction as appropriate. • Land should not be developed if it will be needed or have significant potential for coastal managed realignment (retreat) or creation of wetlands as part of an overall flood defence.
Adapted by New Zealand Ministry of Environment, (2008) from Crichton 2005a and Scottish Executive 2004 *Scottish Planning Policy SPP7:* Planning and flooding	

Where other flood regulation tools are not used, building regulations under Section 694 or 698 of the Local Government Act may provide limited mitigation of flood consequences.

4.8 Managing Residual Risk

Risk-avoidance and reduction measures will never completely remove coastal hazard risks. Managing the component of risk that is left over, the residual risk, usually involves transferring that risk. This typically means dealing with any associated consequences via emergency management, insurance, disaster relief or local government liability management. These measures for managing residual risk are briefly discussed below.

4.8.1 Insurance

The insurance industry has an enormous stake in limiting the damage that occurs to insured properties. The approach of insurance companies towards meeting the cost of hazard-induced asset loss has, in the past, been largely reactive. Increased insurance premiums and refusal of reinsurance are based on previous losses incurred. These can provide a disincentive for asset investment within high-risk hazard areas that have previously suffered financial loss.

At the present time insurance against flooding is generally not included in Canadian insurance policies.

Lack of availability of flood insurance can result in extreme pressure on governments to provide ‘protection’ against the hazard. In this situation the usual insurance industry approach may not send a clear signal to property owners, as at-risk areas will not necessarily be affected by insurance premiums unless there have already been hazard events in the past.

However, insurance companies are becoming increasingly proactive in hazard risk management. For example, in 2000, the insurance sector in the United Kingdom threatened to stop providing flood insurance unless the government invested in better protection of 2.2 million properties in flood risk areas. The outcome was that the Association of British Insurers and the British government agreed to the following “standards” (Heap, 2007):

- Provide insurance as a standard feature in areas where the annual probability of flooding is 1.3% or less.
- Maintain flood insurance in areas where improvements to flood protection infrastructure will reduce annual probability of flooding to 1.3% or less.
- Consider providing insurance on a case-by-case basis in other areas.

According to Lloyd’s (2008), if no action is taken, losses in the UK from coastal flooding for high risk properties could double by 2030. The company asserts that adaptation measures combined with flood defences can reduce losses substantially, and that the insurance industry can encourage adaptation through “incentivisation”. “The world cannot insure its way out of climate change”; however, insurance should be viewed as an effective way of managing individual risk that cannot be dealt with by adaptation.

While insurance could be an efficient market-based economic tool to distribute and reflect actual risk for coastal properties, it does not necessarily produce long-term changes in risk. Its efficient application may require intervention and collaboration between governments and insurance companies – and require detailed risk assessment information at the property level, much of which is currently not available.

4.8.2 Disaster Relief

All levels of government may be involved in disaster relief, from the perspectives of emergency preparedness and financial relief. There are limits to the effectiveness of disaster relief for climate change adaption measures. For example:

"The February 2006 winter storm and resulting coastal storm surge damaged over 150 homes in Tsawwassen where the confluence of high tides and high winds sent waves crashing 30-40 feet high over the seawall. Boundary Bay was declared a disaster area, and the Province provided $3 million in disaster relief, covering 80% of residents' damage costs to a maximum of $300,000." (Heap, 2007).

Current limits on disaster relief are unlikely to cover the total cost of recovery or relocation.

"Government is typically more exposed to reconstruction costs of disasters since insured losses usually account for far less than half of total costs. Beyond this, governments are effectively obliged to step in with disaster relief payments whereas insurance companies can choose to discontinue insurance coverage in areas that are judged to be at particular risk..." (Heap, 2007).

It is unlikely that the present umbrella amount in BC would cover the total costs of flooding or inundation due to the expected sea level rise in existing developed areas in BC. In this situation, disaster relief funding can only provide an interim recovery measure.

4.8.3 Local Government Liability

Local governments can be financially liable for the consequences of decisions that are shown to be in breach of statutory or common law duties. Local governments can make use of a range of techniques to reduce the risk of liability, such as (Heap, 2007):

- Certification by a qualified professional that the design and construction will mitigate risks.
- More stringent risk acceptance criteria; e.g., adaptation of a lower AEP for design decision making.
- Warning and evacuation protocols based on thresholds such as rainfall amounts, wind speeds, etc.
- Covenants indemnifying governments should a hazard occur.

However, "care is needed in using these instruments as they may not limit the owner's, or future owners, expectations of further protection, and often have no effect on land value when perhaps they should." (New Zealand Ministry of Environment, 2008)

4.9 General Roles in Defining Suitable Adaptation Options

Virtually everyone has some role to play in addressing the heightened risks of coastal flooding associated with climate change, Table 4-4. A detailed examination of specific policies for components of the matrix in Table 4-4 is beyond the scope of the present document.

Table 4-4: Potential Roles in Managing Risks to Coastal Areas Associated with Climate Change

Role:	Federal government	Provincial government	Local government	Private sector
Research, inventory, assessment of hazards	✓	✓	✓	✓
Information and Education	✓	✓	✓	✓
Land use planning	National protected areas	Flood Protection Guidelines	OCPs, zones, setbacks, DPAs	Influences
Building regulation	Building code	Building code, hazard guidance or regulations	Building requirements	Influences
Land purchase	Grant programs	Grant programs	Purchase programs	Purchase programs
Covenants			✓	
Protective structures	✓ Federal lands	Sea Dike Guidelines, Grant Programs	✓	On private property
Title notice		Require	Implement	Apply
Insurance			Municipal liability insurance	Private property insurance
Emergency response	✓	✓	✓	✓
Disaster Relief	✓	✓	✓	✓

5 Policy Guidelines for Coastal Flood Hazard Areas

5.1 Existing Flood Hazard and Land Use Management Guidelines

The goals of the existing provincial Flood Hazard Area Land Use Management Guidelines: "**Land Use Guidelines 2004**" are:

- To protect against the loss of life; and
- To minimize property damage, injury and trauma associated with flooding events.

The Guidelines were prepared pursuant to Section 5(f)(i) of the Environmental Management Act and must be considered by local governments when making bylaws under section 910 of the Local Government Act. Section 910 authorizes local governments to pass bylaws to designate lands as flood plains and define flood levels and setbacks for development in these floodplains.

Table 5-1 summarizes the main elements of the current Flood Hazard and Land Use Management Guidelines: "**Land Use Guidelines 2004**" that relate to coastal areas. While tsunami hazards are considered in areas outside the Strait of Georgia, there is no specific allowance for global sea level rise or other hazards associated with climate change.

5.2 Updated Guideline Policy Basis

Management of coastal lands that are or may become exposed to coastal flood hazards in a rising sea level scenario requires information on both the expected rise in sea level over time and the present and potential future uses of the exposed lands. The expected rise in sea level over the next several centuries is described in Section 3 of this Policy Document.

In a rising sea level scenario the longevity of the land use, the structures and the buildings on the exposed coastal lands becomes very important. It is necessary to establish management parameters; ie. Flood Construction Levels (FCL) or Setbacks that anticipate the water levels or flood levels and that are applicable up to the end of the lifespan of the land use, structures or buildings in question. In some cases it may also be important to consider the same issues for time frames that extend well beyond the present application.

In general terms, buildings, in particular, have reasonably well defined life spans or renewal cycles. Single Family Residential or Relocatable Manufactured Homes, have a typical lifespan of 50 years. Many other buildings, such as multi-family, commercial or light industrial buildings may have a life span of 75 years. High value concrete or steel buildings for institutional use or for public emergency services may have a life span of 100 years. In each case it is appropriate to consider the FCL or the Setback that is required up to the end of the expected life span.

Figure 5-1 illustrates how planning for the 100 year lifespan of a high value building or land use brings future SLR increases into immediate focus. The graphic illustrates, in 100 year steps, how building elevations will need to be incrementally adjusted (likely higher) to accommodate gradual SLR. The same incremental adjustment will be required, more frequently, for buildings or structures with 25 or 50 year life spans.

Table 5-1: Main Elements of Flood Hazard and Land Use Management Guidelines (2004)

Location	Setback	FCL
Strait of Georgia (SOG) (Sec 3.5.1-p.22)	• 15 m from natural boundary (NB). • 7.5 m from NB where protected from erosion by natural bedrock or protective works designed by professional engineer. • No reduction from 15m in new subdivisions unless each building site is on non-erodible bedrock or local government assumes maintenance responsibility for works designed by a professional engineer. • May be increased (from 15 m) for exposed erodible beaches and areas of known erosion hazard.	• At least 1.5 m above NB • Higher than any FCL established for specific coastal areas
SOG coastal bluffs – new development (p.23)	• Horizontal distance equal to 3 times height of bluff measured from toe, where building site is at top of steep bluff and where toe is subject to erosion and/or is less than 15 m from NB. • May be reduced if supported by a report prepared by a suitably qualified professional.	
SOG coastal bluffs – existing lot (p.23)	• If above setback prevents construction and sufficient protection cannot be provided through engineered works, adopt a modified setback with restrictive covenant stipulating hazard, building requirements and liability disclaimer.	
Outside SOG	• At least 30 m from NB • Established on a site-specific basis taking tsunami hazards into account.	• Established on a site-specific basis, • Take tsunami hazards into account.
Areas protected by standard dikes	• Buildings - minimum 7.5 m from: any flood protection or seepage control structure; or any dike right of way used for protection works. • Fill – not within 7.5 m of inboard toe or side of: any flood protection or seepage control structure; or any dike right of way used for protection works.	• Minimum FCL prescribed for sea adjacent to dike + FCL prescribed for internal drainage (minimum ponding elevation). • Applicable requirements for any secondary sources of flooding within diked areas.

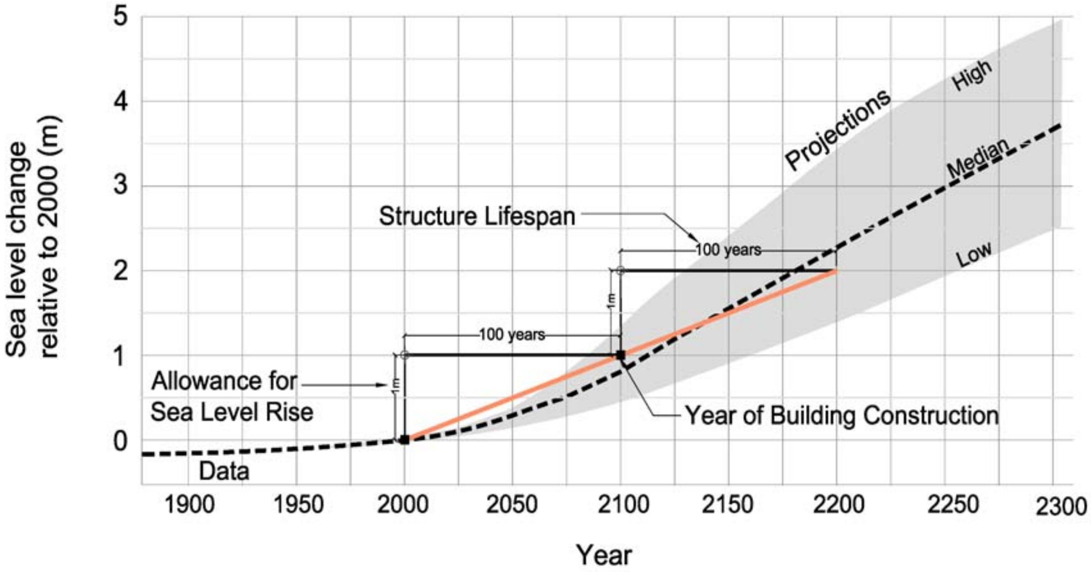

Figure 5-1: Incremental Sea Level Rise Effect on Planning for 100 Year Structures

It is also clear from Figure 5-1 that, initially, anticipation of future sea level rise and the required management parameters, is far more critical for long life span buildings or land use than it is for shorter life span situations. It also illustrates, within the present range of uncertainty, how underestimating future SLR, or the rate of SLR, may require additional measures sooner than anticipated.

To provide an appropriate balance between economic development objectives and a precautionary approach to the uncertainty surrounding future sea level rise, an Adaptive Risk Management approach to Sea Level Rise is warranted. An Adaptive Risk-Management Approach to SLR would plan how short term land uses and structures can be occupied with reasonable risk over their lifespan, but at the same time recognize and allow that future SLR may require the redesign or relocation of the next generation of land uses and structures at a given coastal site. In this approach, the Flood Construction Level and Setback for a given site will have to be increased when a building has reached the end of its planned lifespan. This approach will minimize the initial costs of considering SLR, and the future costs of adaptation.

Guidance on the range of FCLs that may be appropriate on the BC coastline in the future are provided in the updated "**Coastal Land Use Guidelines 2010**" [9] also produced as part of this assignment.

Land use and building approvals based on FCL for 2100 should also include provisions for adaptive management of land uses for SLR to the Year 2200 and beyond. The long term view should also apply when subdivision of new lot parcels or construction of a building implies a change (increase) in the intensity of land use that extends beyond the life of building.

In considering whether to plan for SLR projections of 50, 75, or 100 years out, the complexity of building lifespan is compounded by considerations of underlying land value. Real estate value of

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[9] "Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use in BC. Guidelines for Management of Coastal Flood Hazard Land Use". Prepared by Ausenco Sandwell for the British Columbia Ministry of Environment, October 2010.

land is tied, in part, to the bundle of rights to rebuild on that land. SLR may gradually move the natural boundary, reduce parcel size, increase required building height, and thereby reduce the buildability and value of the land. However SLR change is very slow, and may well be balanced by other factors which tend to increase the real estate value of land over extended periods.

The approach taken, therefore, is to strive to allow continuous beneficial land use of the land affected by SLR, provided; however, that land zoning and permissions anticipate and provide for adapting to SLR as it occurs, and as buildings come to the end of their lifespan and redevelopment is planned.

SLR creates serious risks for public health and property in lowlands on the BC coast. In no cases should new development approvals be provided that will burden future generations of the public with the costs of protecting against known SLR risks. To minimize the future growth of SLR risks, SLR Planning Areas should be created throughout coastal BC for settled or new development areas at risk of SLR inundation or related erosion. These SLR Planning Areas will minimize the risk and costs of SLR to both public and private interests, by proactive planning for future land use.

The SLR Planning Area approach also provides a method to gradually adapt larger scale land use patterns to SLR. The specifics of creating and defining SLR Planning Areas are defined in the updated "**Coastal Land Use Guidelines 2010**" [9] also produced as part of this assignment.

The SLR Planning Areas can also be used specifically to define or include the measures required to preserve future dike right of ways, should a "protect" option be used to adapt land use to climate change.

For land use management guidance in BC, allowances for SLR until the Year 2100 should be used in current planning and building approvals. These approvals should also include provisions for adaptive management of land uses to SLR to the Year 2200 and beyond. This guideline should apply for the period from 2010 until the next SLR review, which should be completed by 2015.

6 Policy Guidelines for Sea Dike Design Options

6.1 Existing Dike Design and Construction Guide

The existing **Dike Design and Construction Guide 2003** provides extensive guidance for the design of dikes, primarily in non-tidewater exposed situations, although flood hazards from the ocean are discussed briefly in Section 1.3.1 and flood design levels for sea dikes are discussed in Section 2.9.8 of the existing document.

In the existing document, sea dike crest height is estimated based on the following:

- Tidal fluctuations: the maximum high tide is indicated as the appropriate tidal water level.
- Storm Surge: the 1:200 year average return period storm surge plus a freeboard (normally 0.6 m) is specified.
- Wave Runup: additional considerations for definition of a sea dike crest height “may include wave runup and setup”.

The structure of the existing document suggests that the freeboard allowance of 0.6 m is intended to cover uncertainty associated with definition of the 1:200 year average return period storm surge.

The existing document also indicates elsewhere that additional freeboard may be required to allow for long-term dike settlement due to geotechnical foundation conditions. For the purpose of this Draft Policy Document the additional freeboard required for long-term dike settlement is not specifically addressed but it still must be considered. Crustal subsidence or uplift is; however, considered in the definition of the regional SLR

No guidance for dike location, on or near the shoreline, or for the stability design of outer slopes, crest elevations and widths or for the stability of landside slopes, where wave related overtopping may create instability issues, is provided or directed.[10] Coastal erosion hazards, either during a design event or regular ongoing processes are only indirectly addressed in Section 1.3.4 of the existing document.

In most cases, sea dikes in BC were initially constructed landward of the Natural Boundary, but as sea level rises in response to climate change the present location of the Natural Boundary will become submerged and many new considerations, taking into account all aspects of wave-coastline-structure interaction will eventually need to be addressed. The **Dike Design and Construction Guide 2003** also does not specifically refer to vertical or near-vertical seawall type structures that exist or may become necessary in urban settings.

An updated Sea Dike Guideline document needs to address:

- Appropriate designated flood levels, within the context of open water exposure and climate change related effects
- Consideration of acceptable amounts of wave overtopping that must be accommodated on the landside of the sea dike
- Consideration of the implications to the functional geometry of a sea dike located within a space constrained urban setting, i.e. Vancouver Harbour, compared to more common and less developed locations, i.e. the Fraser River Delta or the Squamish River Delta.

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[10] Reference is made to a complementary document “Riprap Design and Construction Guide”, which deals mainly with river dikes.

- Consideration, at the conceptual level of design, of the implications to wave exposed locations i.e. the Fraser River Delta shoreline, compared to less wave exposed locations, i.e. inside Vancouver Harbour or to river flow dominated settings, i.e. the Squamish River Delta.

6.2 Evolution of Dike Design

Historically, sea dike (and river dike) design and construction practice, worldwide, has evolved through several stages:

- Initially, the location and design of dikes were based on the observations and experience of local inhabitants, where the dike elevation was set based on the highest water levels either experienced directly onsite or suggested by the available history for the area. Where dikes were exposed to open water, the elevation of the dike was increased to allow for exposure to storm related wind and wave setup and wave runup, again based on local experience.
- In the 1950's, following severe flooding in storms experienced around the North Sea, statistical methods began to be used to define expected storm surge levels and associated wind and wave related set-up. These methods evolved, particularly in the Netherlands, due to the early work of a national agency known then as the Delta Committee (Vrijling, 2001). The methodology led to a specification of a total water level, including astronomical tide and storm surge with a defined return period, or annual probability of being exceeded (AEP), and an additional freeboard for wave effects. It was explicitly recognized that some risk of flooding or inundation must be accepted and that it was not economically practical to build defence structures large or safe enough to prevent all flooding. As some overtopping of the sea dike was therefore expected, the dike was designed, constructed and maintained so as to prevent breaching as a result of the expected overtopping.
- The change from experience based criteria to statistically based criteria was also accompanied by the recognition that all potential modes of failure, not just overtopping of water, had to be considered and therefore the components of the dike system had to be designed to an even higher standard to ensure that breaching did not occur at the design total water level.
- In the Netherlands, the early versions of this approach led to the adoption of an annual exceedance probability (AEP) of $1x10^{-4}$, or an average return period of 10,000 years for the design total water level. An additional allowance (freeboard) was also added to account for expected effects of other processes occurring at the same time as the design total water level.
- During the 1980s, the development and application of reliability theory and risk assessment began to be applied in practical terms to the design of coastal structures, and in particular, to the design of storm surge barrier systems in the Netherlands and the UK. Research also began on the application of these techniques to the design of sea defences in general and practical guidelines began to emerge by the 1990s (Technical Advisory Committee on Water Defenses, 1990).
- The evolution of the design approach outlined above is leading to requirements in the Netherlands for dike design to be assessed so that the probability of actually being flooded or inundated, is, in principle, a probability less than what is referred to as the threshold probability of the total design water level. The safety norm for every dike ring in the Netherlands has been defined as the average yearly probability of exceedance of the total design water level.
- This post 1980's risk based process has also led to a range of threshold probabilities for the design total water level that varies for different regions of the Netherlands, depending on the value(s) of the area being protected, the nature of the flooding hazard, and the consequences of the inundation. A summary of the threshold probabilities for the design total water level is provided in Figure 6-1.

- The Delta Committee (2008) has since recommended that the overall flood probability for all diked areas should be further reduced by a factor of 10 to 100 to reduce the possibility of sudden large breaches and the possibility of large numbers of casualties. This recommendation partially recognizes that a breach may remain open for some time before it can be closed and flood water removed.
- It should be noted; however, that a reduction in the overall flood probability does not mean that the AEP (or the threshold probability) of the Designated Flood Level, to use the BC definition, should be decreased. The recommendation is tied to a proposed switch, from defining the threshold probability of total water level, to defining a target safety level associated with the total risk of actual flooding or inundation (if a dike actually breaches).

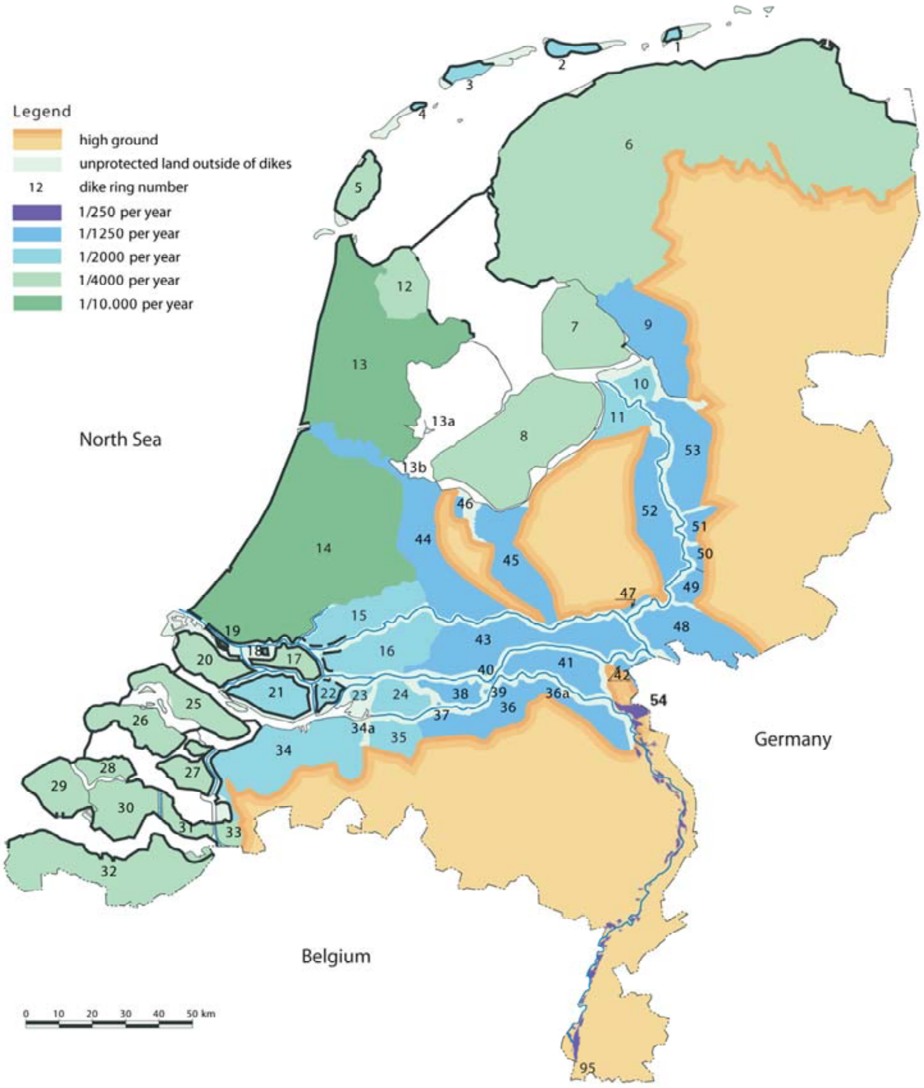

Figure 6-1: Example of the Threshold Probability of Total Design Water Level
source: translated from Rijkswaterstaat (2008)

The present BC guidelines for sea dike design follow the early models for dike design and are based on the specification of a 1:200 year average return period storm surge, coupled with high tide, plus freeboard, regardless of the implications of a more severe storm or of expected overtopping. A sea dike will also very likely be exposed to more than one storm and tide combination in a season.

The basis for the specified 1:200 year return period is understood[11] to be the 1:200 year return period historically assigned to the 1894 Fraser River flood that forms the basis for river dike design in BC[12]. It should be noted; however, that the present 1:200 year return period storm surge event cited in the existing BC guideline document is not directly comparable to the threshold return period events summarized in Figure 6-1, as they represent a total water level, which in the case of the BC guidelines is the summation of the tide level and the storm surge level.

The methodology for estimating the AEP of a combination of tide and storm surge is discussed in more detail in Appendix D of the companion update report "**Sea Dike Guidelines 2010**"[13], also prepared for this project.

Definition of an appropriate design event for a specific sea dike in BC that reflects a quantitative risk analysis approach such as evolved elsewhere is beyond the scope of the present assignment; however, it is reasonable to expect that if a quantitative risk analysis was undertaken, a similar range of annual exceedance probabilities for the total design water level, which depend on the value of the land use and the implications of flooding or inundation in a given area, would emerge that are similar to those summarized in Figure 6-1.

A brief description of a quantitative risk assessment (QRA) process that could be undertaken is provided in Appendix C.

A summary of an interim recommendation for BC sea dike and flooded land management is provided in Section 6.3.

6.3 Policy Implications for Sea Dike Design in BC

There are three related but separate issues regarding the development of policies for sea dikes and coastal flooded land management in BC:

- What future sea level should be accounted for?
- What project life or time interval should be used for planning purposes?
- What design standard for the probability of exceedance should be used for flood protection works?

A brief discussion of each issue is provided below.

6.3.1 Future Sea Level Rise for Sea Dike Design

Recommendations for the future sea level rise that should be accounted for in sea dike design are summarized in Section 3.2.3 of this document.

The appropriate choice of a design SLR value is directly related to the anticipated design life of the sea dike and indirectly to the planning measures undertaken to accommodate the actions required at the end of the expected service life of the sea dike.

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[11] Pers comm. J. Shah, P. Eng. BCMOE

[12] The estimated return period for the 1894 Flood is now understood to have been increased to 1:500 years based on recent investigations by others.

[13] "Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use in BC. Sea Dike Guidelines". Prepared by Ausenco Sandwell for the British Columbia Ministry of Environment, October 2010.

6.3.2 Project Life

It is clear that, in almost all cases, once the decision is made to maintain an existing sea dike or to construct a new sea dike, this decision has important implications well into the future that affect the health and safety of life and property in the protected area. It is clear that a single policy on a recommended project life is impossible to define without extensive discussion among the affected stakeholders. Once a sea dike is in place it represents a commitment in perpetuity unless it is part of a planned program of Adaption Options that anticipates retreat or risk management in some form or another. Issues that must be considered in setting a Project Life include:

- The condition of any existing sea dikes
- Planned phasing of design and construction
- Financing
- Implementation of other Adaptation Options.

6.3.3 Design Standard

The existing guidelines for dike design and construction in BC are essentially based on flooding experience on the Fraser River, translated to the coastline as outlined in Section 6.2. These guidelines suggest that a storm surge level equivalent to a 1:200 year return period plus high tide, should define the design total water level or the Designated Flood Level.

The AEP of this Designated Flood Level can be estimated to be approximately 1/4000 year as discussed in more detail in Appendix D of the companion update report "**Sea Dike Guidelines 2010**" also prepared for this project.

An additional site specific allowance for wave runup and setup should be added to the Designated Flood Level to define the design crest elevation of the sea dike[14].

In contrast, the Flood Protection Act (1996) in the Netherlands defines the following levels of protection for the equivalent of the Designated Flood Level:

- Central Netherlands (exposed to the sea): threshold probability (AEP) of 1/10,000 per year.
- Rest of coast and lower reaches of rivers: threshold probabilities (AEP) of 1/4000 per year.
- Upper reaches of rivers: threshold probability (AEP) of 1/1250 per year.

The corresponding safety target with regard to the probability of actual inundation (i.e. flooding due to expected overtopping or a local dike breach) are one or two orders of magnitude higher – in other words the safety targets, expressed as AEPs, are 10 or 100 times smaller than the values indicated above and shown in Figure 6-1. The variation across regions results from a risk optimization process: zones having a lower population density and a smaller expected loss of assets are assigned lower safety target level than heavily populated and built-up zones. But the net resulting consequences to individuals and to individual assets are similar across all zones and are deemed to be acceptable.

In the absence of detailed risk assessments and cost-benefit analyses for individual sea dikes in BC, Table 6-1 suggests general risk categorizations (as described in Appendix C) and design AEPs for the Designated Flood Level for the areas of interest in this project.

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[14] Settlement of the as-constructed dike, including the dike materials and the underlying foundation soils, is factored into the geotechnical design provisions for the dike and the maintenance plan.

As the AEP of the Designated Flood Level is for the total water level, the associated AEP for the storm surge component is also provided in Table 6-1 to allow comparison with the existing guidelines.

Table 6-1: Preliminary Risk Categorization and Design AEPs for areas of interest.

Area of Interest	Suggested Time Line for Risk Assessment	General Risk category	Suggested Design AEP for	
			Designated Flood [a]	Storm Surge [b]
Fraser River delta *– Richmond, Surrey and Delta sea dikes*	100 yr	High	1/10000 yr	1/500 yr
Lower Fraser River dikes	100 yr	High	1/10000 yr	1/500 yr
Vancouver harbour *– no dikes but extensive foreshore development*	100 yr	High	1/10000 yr	1/500 yr
Squamish River delta *- no dikes but extensive foreshore development in downtown Squamish, industrial development and high ecological values*	100 yr	High	1/10000 yr	1/500 yr
(South) East Vancouver Island *– few sea dikes (Cowichan River estuary) but extensive coastal development, mostly low to moderate density (residential, small scale commercial)*	50 yr	Moderate - High	1/4000 yr	1/200 yr
West Vancouver Island, North East Vancouver Island, Central Coast and North Coast *– intermittent coastal development, a few high-medium density nodes (e.g., Tofino, Ucluelet, Sunshine Coast, Powell River, Prince Rupert)*	50 yr	Low - Moderate	1/4000 yr	1/200 yr

Notes:

a: Suggested Design AEP for Designated Flood are for the Designated Flood Level being equalled or exceeded. The probability of dike failure will likely be different, depending on details of the dike system.

b: Follows from the indicated AEP for the Designated Flood Level, based on the probability of a high tide occurring simultaneously as the storm surge being approximately 1/20, as described in Appendix D of the companion update report "**Sea Dike Guidelines 2010"**[13]**.**

7 Uncertainty and Freeboard Allowance

The existing documents for the management of flooded land and for sea dike construction implicitly or explicitly include a freeboard allowance of approximately 0.6 m[15].

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, ie., the appropriate wave theory for the depth of water or the estimate of wave crest elevation, say for the defining the design loads on the underside of a jetty or platform deck.

In the specific case of a climate change related assessment, whether it is for the purpose of defining the Flood Construction Level or a Sea Dike Crest Elevation, 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.

Using a QRA approach, as summarized in Appendix C, all of these uncertainties can be included in the risk assessment process. Freeboard can then treated as a specific parameter that controls the resulting risk. Freeboard can then be calibrated and/or optimized to reflect specific uncertainties in a risk-consistent and economic manner.

Uncertainties related to coastal flooding and sea dike design can be identified as follows:

Climate Change:

- Future GHG emissions
- The rate at which sea levels will change in response to climate change.
- The effect of climate change on storminess, wave setup and runup, and other factors that may affect global and regional sea levels.

Site Conditions

- The actual relationship between MSL and the datum used to define terrestrial elevations
- The bathymetry offshore of the dike or land area
- The presence of and future plans for maintenance or upgrading of any structures that may provide protection to the area in question
- Local micro-climate or oceanographic effects that may result in stronger winds or higher waves (or vice versa) than defined by available data sources for winds, waves, or water levels
- Surface and subsurface soil conditions that may result in variable rates of coastal erosion or sedimentation or of scouring or settlement along the dike or shoreline in question

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[15] A summary of the basis for the 0.6 m freeboard allowance in the 1.5 m vertical offset for FCL (see Table 5-1, this document) is provided in the companion document **Coastal Land Use Guidelines 2010** [9].

Design Methodology

- Although coastal engineering is a reasonably developed area of engineering practice, specification of engineering parameters such as wave heights or wave height distributions in shallow water, wave runup, wave overtopping and structural stability of sea dike armour elements generally rely on empirical science and the predictive tools carry forward underlying uncertainty.
- Existing coastal engineering practice guidelines also do not provide all necessary details on stability or overtopping characteristics of all types of potential sea dike structures.

The amount of freeboard applied at any stage of design should follow a precautionary principle, by addressing, separately, any uncertainties that are not included and/or considered, either directly in design or in the QRA. This may include the possible combination of any uncertainty related directly to inundation related hazards with one or more uncertainties related to environmental or other technical issues. Human/operational/organizational considerations should also be considered as uncertainties, and an allowance can be added on top of the above to cover “unknowable unknowns”.

As a minimum, it is recommended that the present freeboard allowance of 0.6 m should be included in both sea dike design and coastal flood land assessment, above and beyond any specific allowances adopted to deal with the known uncertainties identified above. These known uncertainties should be explicitly stated during design. It is reasonable to assume that the existing 0.6 m allowance represents an optimal experienced based allowance for freeboard to accommodate unknowable unknowns. QRA may show that more or less freeboard is needed but without undertaking an analysis it is impossible to know for certain.

8 Policy Conclusions and Recommendations

8.1 Policy Conclusions

Based on the investigations and research summarized in this report, and reflected in the companion reports "**Coastal Land Use Guidelines 2010**" [9] and "**Sea Dike Guidelines 2010**"[13], and the comments from stakeholders in the Consultation Workshop, the following conclusions regarding the establishment of policy for climate change adaptation in the coastal waters of British Columbia have been drawn:

1. Sea level rise (SLR) in the future is expected to be both faster and higher than previously anticipated. While there is still scientific uncertainty related to the present understanding of the future rates and magnitudes, it seems reasonable to anticipate higher SLR than summarized in the **"BC Sea Level Report 2008"**. A large degree of the related uncertainty can be avoided by separating the fact that sea level will rise from the actual rate of SLR. The most uncertainty lies in the prediction of the sea level rise on a given date.
2. For planning purposes it is recommended that the rates and trends reflected in Figure 3-5 and Table 3-2 should be used at present.
3. The choice of appropriate response options or adaptation measures is so site specific that their identification and adoption must be the responsibility of local governments, with guidelines and other support provided by the province. Provincial policy should include updating the basic guidelines for sea dikes, FCLs and Setbacks as defined in the companion documents and requiring the establishment of SLR Planning Regions, as described in Section 5.2.
4. At the present time, scientific information on the expected changes in storms approaching British Columbia coastal waters and their characteristics, specifically on the intensity of the storms, their related wave conditions and the associated storm surges in the future, is only starting to emerge. Based on the available information it appears reasonable to conclude that no significant change is expected in coastal BC waters; however, further investigations are warranted to fully assess the regional implications and to further assess future trends.
5. It is clear that the present recommended rates and trends for SLR have significant implications for British Columbia coastal communities. Detailed quantitative risk analysis (QRA) processes may be appropriate for some communities. In the meantime, and in situations where QRA may not be appropriate, the recommendations outlined in this document, and the companion documents, for design standards, design procedures and planning alternatives can provide a basis for initial planning and responses.

8.2 Next Steps and Recommendations

8.2.1 General Implementation:

1. Because the recommended SLR policies outlined above will have a significant impact on BC coastal communities, it is recommended that an extensive outreach program be undertaken to outline and discuss the implications and steps forward and to initiate the necessary community discussions and planning.
2. The outreach program should include:
    a. Preparation of formal SLR policies in the form of a short policy statement document referencing this document and its companion guideline documents,

    b. A provincial government public communications plan and program,
    c. Preparation of a schedule for implementation and anticipated updating,
    d. Workshops and seminars for local government, professional technical bodies and public consultation.

8.2.2 SLR Planning Area Implementation – Recommendations

1. A key element for the management of future Coastal Flood Hazard is the implementation of the creation of SLR Planning Areas, as described in Section 5.2. The need for and requirements of should be identified in the formal SLR policies discussed above.
2. The Province should initiate a coastal flood plain mapping program throughout coastal British Columbia to acquire detailed topography, including the intertidal regions, to provide sufficient resolution and base mapping to identify the boundaries of SLR Planning Areas. This mapping program will increase local government awareness of SLR issues, encourage SLR planning and provide required information necessary to complete area specific coastal engineering studies.
3. The Province should initiate a provincial program to support SLR Planning, providing both grants and technical assistance to local governments.

8.2.3 Coastal Flood Protection Implementation – Recommendations

1. The Province should initiate an overview engineering study to determine the costs of upgrading coastal flood protection in BC to meet the new standards defined in this document and the companion guideline documents.
2. For the existing Flood Protection Program, sea dike projects should only be approved as sea dike projects that appropriately consider the new guidelines.
3. The new guidelines should be applied as a condition of Dike Maintenance Act approvals.

8.2.4 Coastal Flood Protection Technical Issues - Recommendations

1. The definition of the new Flood Construction Reference Plane includes a simplified estimate of the effect of waves on the shoreline response. The recommended factor is based on calibration against one survey along the exposed coast line of Victoria. A review of the appropriate factor over more regions of coastal British Columbia should be undertaken to validate or refine the recommended factor.
2. The expected future magnitude of storm surges and their properties for SLR planning purposes are based on preliminary analysis of long-term tidal records. A more detailed review of storm surges and their attendant properties should be undertaken to provide necessary technical information throughout coastal British Columbia.
3. Definition of many of the coastal engineering features of the methodology defined in this document and the companion guidelines needs reliable and accepted definitions of wind and wave climate throughout the coastal waters of BC. A detailed program to define the wind and wave climate should be undertaken by the Province to provide a uniform and consistent body of technical information throughout coastal British Columbia waters.

9 References

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Appendix A – Definitions, Terminology and Acronyms

Contents

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 runup 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

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Appendix B – Uplift and Subsidence Rates

Ausenco
Sandwell

Contents

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	**°N**	**°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	**°N**	**°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 – Quantitative Risk Analysis

Ausenco Sandwell

Contents

1 Quantitative Risk Analysis and Risk Management Approach

1.1 Quantitative Risk Analysis (QRA)

Risk is generally understood to include elements of both the likelihood of occurrence of a hazardous event, the consequences of the event, and the manner in which the hazard is perceived by individuals and/or stakeholders. Risk can be expressed, qualitatively, as:

Risk = Probability x Perceived Consequences

A risk-based approach to a hazard such as flooding therefore requires an understanding of the likelihood of a flooding event, the consequences of the flooding, and their perception by stakeholders and their proxies. By necessity, evaluation of the risk and a determination of its acceptability require a broadly based evaluation that involves all stakeholders involved in the particular situation.

In the next sections an appropriate QRA framework for a spatially distributed system subject to a natural hazard is detailed. Risk acceptance is discussed followed by risk-based optimization and calibration which results in optimal risk-based design specifications and risk control/mitigation measures.

1.2 QRA Framework

Quantitative risk analysis (QRA) focuses on what can go wrong with systems and on the likelihood that any undesirable outcomes may occur. In a QRA, systems must be well-defined and may include engineering systems such as infrastructure, environmental systems, and human systems affecting health, welfare, and quality of life. Typically, the systems being assessed are subject to considerable uncertainties which can be intrinsic or external to the system. In addition, QRA usually involves spatially distributed systems such as urban areas, or multi-unit systems such as process plants or aircraft, while the systems are themselves subject to uncertain temporal variations, such as deterioration, climate change, or socio-economic growth/decline.

Various modern standards exist worldwide as well as nationally, which provide detailed protocols and guidelines for performing QRA. The benefits of QRA are numerous and well documented (JCSS, 2008a). QRA provides a basis for both operational and strategic decision making. Operational risk-based decision making includes for instance: the selection of optimal design solutions, reliability based design, performance-based design, and development of optimal risk mitigation measures for a specific system/hazard. Examples of strategic risk-based decisions are: risk-based maintenance/repair planning, optimal resource allocation, optimal spreading of risk between lifecycle phases, optimal hazard response planning, and hazard policy development.

QRA is normally concerned with the risks associated with not just one asset, e.g. a single structure, or an infra-structure network, or a single hazardous activity, but with a portfolio of assets. If risk assessments are not performed consistently for the individual components of the asset, then it is not possible to assess the overall portfolio risk. Furthermore, and more importantly, it is then also impossible to develop consistent strategies in terms of resource allocation and actions affecting risk control and mitigation.

As in the case of the present project, QRA often focuses on risk resulting (directly or indirectly) from one principal hazard. In that case, it provides the basis for the management of risks before, during and after the occurrence of such hazards:

- before the hazard occurs the issue of concern is to optimize investments into preventive measures such as protecting assets, optimizing adequate design specifications, and developing preparedness and emergency strategies.

- during the occurrence of the hazard the issue is to limit consequences by containing damages and by means of rescue and evacuation.
- after the hazard, the situation is to some degree comparable to the situation before the event, however, the issue here is to decide on the rehabilitation of the losses, the repair of functionalities and the re-consideration of future preventive measures.

The basic QRA framework in the case of one principal hazard (such as a flood) and a spatially distributed system (such as a coastal zone) is shown in Figure 1-1. The left-hand side shows the "inductive" part of the QRA which addresses the question how the hazard can occur. Typically, fault tree analysis and logical Bayesian net analysis is used to analyse the various causal sequences that lead from a root cause such as an extreme event or a failure to the occurrence of the central hazard. The right-hand side chiefly involves a "deductive" type of analysis (event trees, Bayesian nets, etc.) to determine and aggregate the different consequences caused by the hazard (JCSS, 2008b)

It is important to realize that all the "boxes" in the original, intermediate and final steps of the analysis shown in Figure 1-1 are stochastic, i.e. they need to be treated probabilistically. The QRA must therefore account for all uncertainties associated with the system, the characterization of the hazard, the hazard models, and the consequence models.

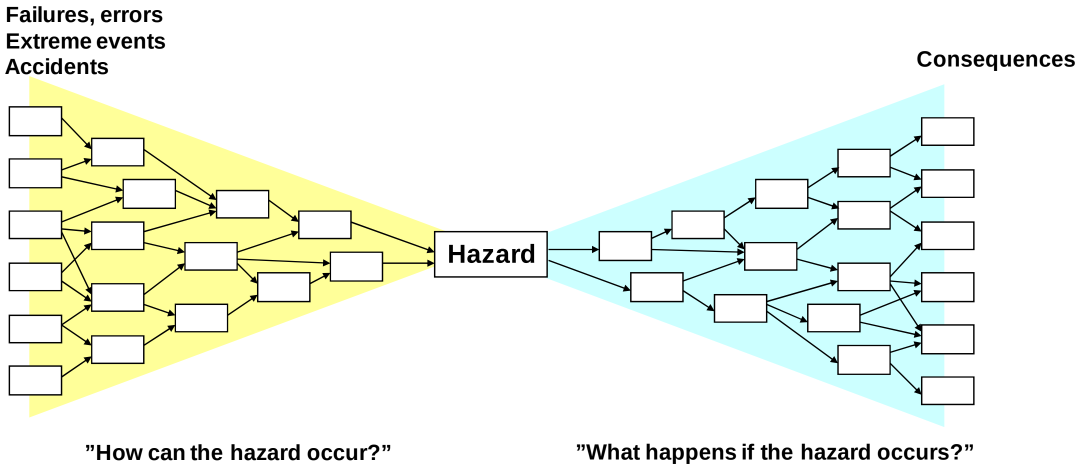

Figure 1-1: Quantitative Risk Analysis (QRA) for a system exposed to a hazard (general framework).

In the specific case where the hazard is a flood/inundation, the framework for the QRA is shown in Figure 1-2. Some of the boxes in the failure sequences (LHS) and the consequence chains (RHS) are labelled to illustrate the analysis. A special "climate change" box is also included as it affects several "starting" variables such as storm frequency, storm intensity, sea level, etc. This allows the QRA to cover a long-term period such as the planning horizon or the specified design life.

It is important to realize that in Figure 1-2, all the "boxes" in the LHS yellow triangle are affected by design specifications and policy measures. In other words, the probabilities associated with the various sequences leading to the central "hazard" event are "controlled" by these specifications and measures. Similarly, all of the boxes in the RHS blue triangle can be affected and "controlled' by various risk mitigation measures which affect the extent and the magnitude of the consequences.

Essentially then, QRA amounts to the analysis of a well-defined sequential probabilistic network that can be externally controlled by the design/policy measures on both sides of the "flood/inundation hazard". In the format depicted in Figure 1-2, the QRA amounts to a 'forward" analysis – this means that it provides us with the aggregated risks associated with flooding for a defined coastal area during a specified long term period of time.

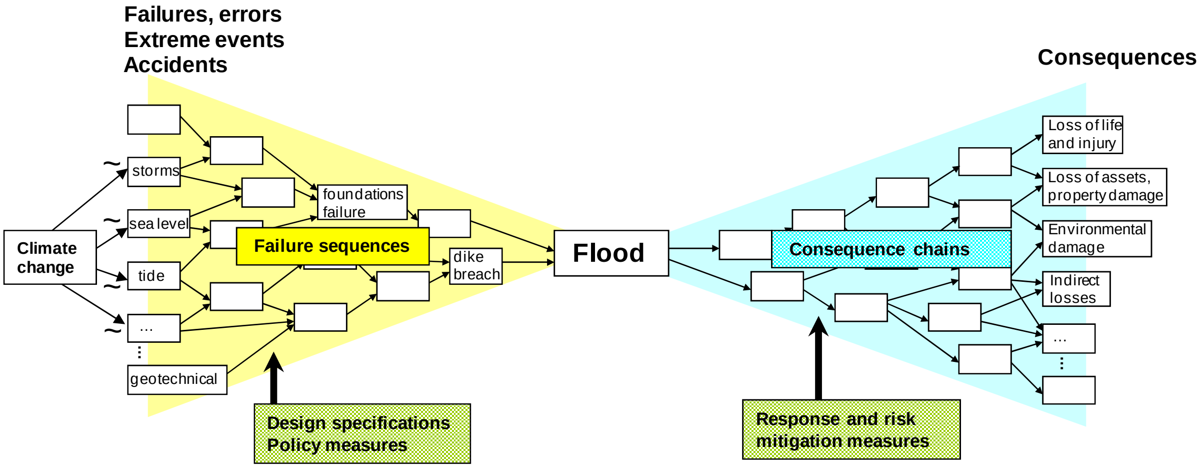

Figure 1-2: QRA for a specific coastal zone subject to a flooding or inundation hazard.

1.3 Risk Comparison and Risk Acceptability

The assessment of the risk and evaluation of its acceptability involves quantification of the consequences of possible scenarios in terms of safety, economics and the environment, and the likelihood of these consequences. These consequences can be evaluated in two ways: qualitatively, or quantitatively. The former applies when a more or less informal risk assessment is performed, while the latter is called for when a full hazard QRA is performed as described in the previous section.

In a qualitative risk assessment, the acceptability of risk can be subdivided into three classes:

- Low or broadly acceptable risk –where the likelihood of occurrence is insignificant and the resources or effort required to further reduce the consequences is disproportionate to the achieved risk reduction
- Medium or tolerable risk – where the measures to further reduce the consequences are either impractical or actions can be defined and implemented (including warning systems, evacuation, monitoring or compensation) to further minimize or manage the consequences
- High or unacceptable risk – where the risk is high and cannot be justified except in extraordinary circumstances.

The evaluation of a risk in terms of safety is generally resolved in terms of the protection of human life and the related probability of being death, which in the context of an individual is generally assessed in terms of accident statistics and which sets the probability of death by accident or natural illness, on an annual basis as approximately 1:10,000 or 10^{-4}. In the context of society in general, elements of voluntariness, the numbers of people exposed to the hazard and the nature of the activity become involved. The more involuntary the situation, or the more people involved, the lower the acceptable probability of occurrence becomes.

The evaluation of a risk in terms of economics is generally resolved in terms of the benefit – cost ratio of the proposed works, with appropriate ratios being defined by the concerned stakeholders. The evaluation of risk in terms of the environment is not well defined in quantitative terms although in many cases an evaluation of the economic consequences of a lost or depleted environment resource and the cost of recovery or restoration of the resources may be undertaken.

A qualitative risk evaluation/management process will eventually lead to a Risk Evaluation Matrix along the lines illustrated in Table 1-1.

Table 1-1: Risk Evaluation Matrix

Likelihood	Decreasing likelihood	Virtually certain	🟥	🟥	🟥	🟥	🟥
		Very likely	🟨	🟥	🟥	🟥	🟥
		Likely	🟨	🟨	🟥	🟥	🟥
		About as likely as not	🟨	🟨	🟨	🟥	🟥
		Unlikely	🟨	🟨	🟨	🟨	🟥
		Very unlikely	🟩	🟩	🟨	🟨	🟨
		Exceptionally unlikely	🟩	🟩	🟩	🟩	🟨
			Insignificant	Minor	Moderate	Significant	Major
			Consequence				

🟩 *Low risk* 🟨 *Moderate risk* 🟥 *High risk*

A specific example of a qualitative risk evaluation matrix for flooding showing the factors considered for climate change adaption planning (from New Zealand), is provided in Table 1-2.

Similarly, when consequences and their probabilities have been fully quantified using a formal QRA, the question is how to compare and interpret risks, how to evaluate if they are acceptable, and if they need to be managed or reduced. Risk acceptance must be meaningful for individuals, stakeholders and for the public at large. In the case of flood risks, past and current practice is considerable, and practice normally sets the tone for risk acceptance. Moreover, risk evaluation for floods is quite similar to risk evaluation for other natural hazards (subject to a similar QRA framework). In the case of BC, for instance, experience with seismic risk acceptance is quite relevant.

Table 1-2: An Example of Consequence Evaluation

Source: New Zealand Ministry for the Environment (2008)

Receptor	Consequence				
	Insignificant	**Minor**	**Moderate**	**Significant**	**Major**
People displaced (no. or permanency)	< 10 Short-term inconvenience	10–50 Disruption for several days	50–100 Disruption for weeks – months	100–200 Permanent loss of some homes	> 200 Permanent loss of many homes
People (no. of injuries)	< 5	1–10	10–25	25–50	> 50
People (no. of fatalities)	0	0	1	< 5	> 5
Economic impact	Minimal financial losses	Moderate financial loss for a small number of owners	High financial losses probably for multiple owners	Major financial losses for many individuals and/or companies	Huge financial losses involving many people and/or corporations and/or local government
Essential services	Short-term inconvenience	Disruption for a day or two	Disruption for several days to weeks	Some long-term impacts	Large long-term loss of services
Infrastructure	Short-term inconvenience	Disruption for a day or two	Disruption for several days to weeks	Loss requiring reinstatement of parts of infrastructure network	Loss of significant parts of infrastructure network requiring reinstatement or relocation
Commercial services	Short-term inconvenience	Disruption for a day or two	Disruption for several days to weeks	Some long-term impacts	Extensive long-term loss of services
Cultural assets	Some minor impacts	Some impacts on significant cultural assets	Moderate impacts on significant cultural assets	Some irreversible damage to cultural assets	Complete loss of significant cultural assets
Ecosystems	Short-term impact	Some impacts on valued natural environment	Moderate impacts on valued natural environment	Major impacts on valued natural environment	Complete loss of important natural environment

Regulatory criteria concerning risk acceptance are typically specified in terms of the As Low As Reasonably Possible/Practicable (ALARP) format. The idea is that risks, depending on their magnitude, can be evaluated to be negligible, tolerable or non-acceptable, as shown in Figure 1-3 in the specific case of life safety (similar representations can be made for other type of consequences). Figure 1-3 shows the relationship between consequences (C) – the number of fatalities and their frequency (F), and is commonly referred to as a FC diagram.

In Figure 1-3 the ALARP region is shown together with a scrutiny line which aims to indicate in which case measures for risk reduction must be developed.

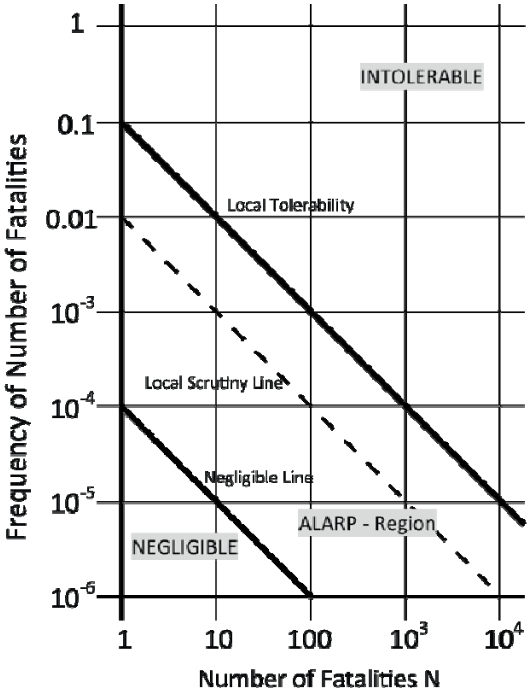

Figure 1-3: Illustration of Typical Implementation of ALARP in Life Safety Risk Regulation.

The acceptance lines in Figure 1-3 show a linear dependency between the logarithms of the consequences and their exceedance probabilities. Typically, except for the UK, a non-linear dependency is introduced such that events associated with severe consequences are weighed more heavily in the evaluation of acceptance. Such non-linear criteria are adjusted to represent what is commonly referred to as risk aversion or disaster averseness.

Risk acceptance and risk management must be also be viewed in relation to the problem of rational allocation of available economical resources for risk reduction (JCSS, 2008c). The willingness to pay for risk reduction (WPRR) is fundamental to risk acceptance, and it is closely related to the life quality index method (LQI) for risk comparison or the so-called LQI principle (JCSS, 2008d). The use of the WPRR and the LQI principle allows risks to be evaluated for specific engineered facilities and/or hazards.

Under normal conditions no individual person would willingly accept life and property risks without some prospect of benefits or direct compensation; the LQI principle is an assessment of the marginal life saving cost associated with a given policy decision such as specifying dike heights.

Following the LQI principle, acceptability is an issue which has to be viewed in relation to a decision. The decision must satisfy the requirement that a certain limiting amount of economical resources are invested into saving human lives and protecting assets. The LQI principle helps in assessing risk independent of societal sectors, industry, field of engineering, etc. Both societal risks as well as risks to individuals are covered by the use of the principle in the sense that the criteria derived from the LQI hold irrespectively for all persons.

1.4 Risk-based Optimization and Calibration of Design Specifications and AEPs

The “forward” QRA analysis framework shown in Figure 1-1 and Figure 1-2 can be reversed in order to perform a “backward” optimization. This is shown schematically in Figure 1-4. In this type of analysis, the consequences and their likelihoods in the boxes on the RHS of the diagram are assumed to be given or constrained. What this means in practice, is that their F-C characteristics in a typical FC diagram as shown in Figure 1-3, are satisfactorily located within an acceptable risk zone, or, providing appropriate risk mitigation/management are in place, within an ALARP zone.

The unknown elements in Figure 1-4 are now the set of design parameters, specifications, or measures in the two rectangular boxes below the two sequence triangles. These can be obtained on the basis of a 'stochastic optimization" which typically amounts to a minimization of the overall cost subject to the constraint that all risks are acceptable. If there is just one single or a very small number of design parameters that need to be optimized, then the backward analysis is referred to as a risk-based calibration of these design parameters. Essentially, this type of analysis allows us to develop risk-based measures that exert acceptable and affordable control of the hazard.

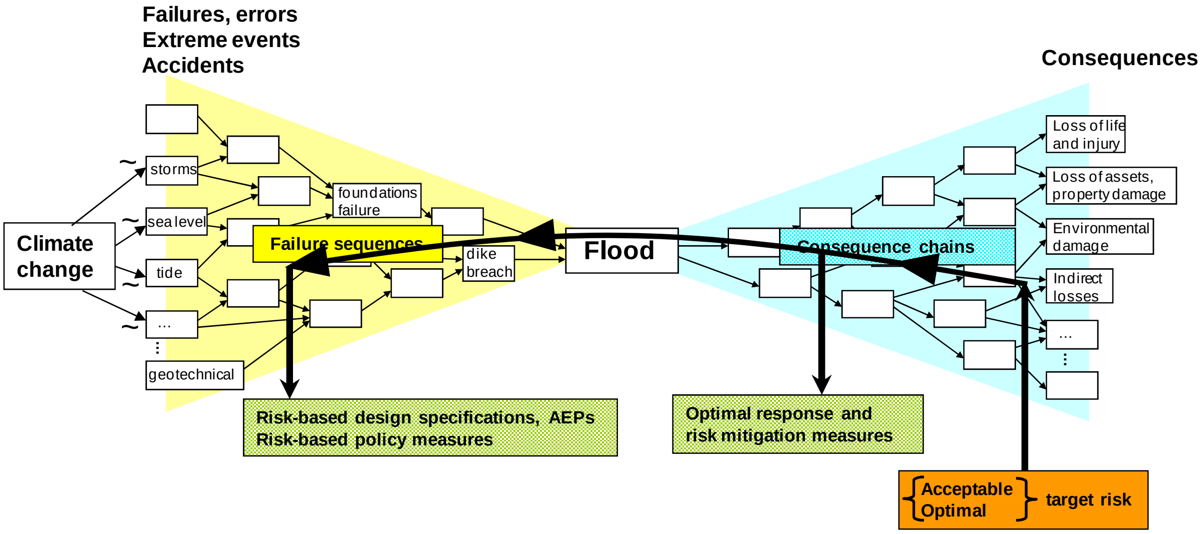

Figure 1-4: Developing and Calibrating Consistent Risk-based Measures and Criteria.

In the case of inundation, one overall risk-based optimization would not be effective as the spatial distribution of flood consequences would be too extensive to result in site-specific specifications.

For instance, the use of one overall AEP would not be economically effective. Therefore, a practice called "risk-zonation" is used to create geographic subsets of zones having more or less similar consequences, e.g. in terms of affected population/assets. For each zone, a separate set of design parameters such as AEPs can then be calibrated which accounts for the likely flooding consequences specific to a given zone. This approach would allow an effective calibration and fine-tuning of the appropriate AEPs throughout coastal BC.

1.5 Annual Risk versus Design Lifetime Risk

The probability *P*(*t*) of a hazard event occurring during a design life *T* (or, a project life *T*; or a planning horizon *T*; or an exposure of duration *T*) is related to the annual exceedance probability (AEP) of the hazard event or to its return period 1/AEP as follows (Borgman 1963):

$$p(T) = (1 - e^{-AEP * T}) \times 100$$

where:

$p(T)$ = probability (in percent) of the hazard event occurring during T

T = planning timeline or the design life (in years)

AEP = annual exceedance probability of this hazard event (in 1/years).

The relationship between the design lifetime probability, the planning or design life time *T* and the AEP, over typical time lines that are relevant to planning or design of sea dikes or the administration of coastal flood risks, is illustrated in Table 1-3.

Table 1-3: Relationship between Lifetime Probability (%), Design Life (years) and AEP
- for clarity AEP is expressed as 1/Return Period, as shown – with rounding

Lifetime Probability *p*(*T*) in %	**Design Life or Planning Time Line - *T* - (in years)**					
	1	10	25	50	100	200
64%	AEP=1/1	AEP=1/10	AEP=1/25	AEP=1/50	AEP=1/100	AEP=1/200
50%	1/2	1/15	1/40	1/75	1/145	1/300
25%	1/4	1/35	1/90	1/175	1/350	1/700
10%	1/10	1/95	1/240	1/475	1/1000	1/2000
1%	1/100	1/1000	1/2500	1/5000	1/10000	1/20000

Note that the above equation and table assume a stationary long-term situation with each year being independent from, and identically distributed as, any other year.

1.6 Risk Reduction and Risk Management

The results of a QRA approach may identify risks that are found to be unacceptable or need to be reduced (ALARP). In such a case, a risk management process would aim to move a given system, subject to hazards from a high, or perhaps a medium risk, to a low risk expected outcome. The options available include:

- Reducing or minimizing the consequences as quantified in a form similar to Table 1-2
- Increasing the design related parameters to a lower AEP (a longer average return period)
- Decreasing the time line over which the particular scenario is exposed to the risk

Risk can be managed by a combination of measures that reduce or limit the probability (i.e., preventive measures) or limit the consequences (proactive, preparatory and response measures). Preventive measures include dike building and reinforcement. Proactive measures aim to avoid hazard situations, such as zoning and building regulations.; preparatory measures includes disaster planning and practice; and response measures include emergency response programs and insurance.

The optimum combination of measures "depends on the nature of the disaster, the properties of a dike system and the cost effectiveness of the various types of measures", Delta Committee (2008).

To compare approaches to risk management taken by different nations: in the Netherlands, with its extensive system of dikes and flood structures, the primary emphasis is on prevention; there, flood protection is seen as a “paramount collective good” (Delta Committee, 2008). In the USA and the UK, the focus is on dealing with consequences with organized damage control, disaster management and insurance programs. According to the Delta Committee (2008), “Japan has the best coverage of the entire safety chain, from spatial planning and prevention (flood defences) to disaster management and recovery”.

In the case of British Columbia, the desired approach still needs to be defined.

1.7 References

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