City of Richmond | **Report to Committee**

To:	Public Works and Transportation Committee	**Date:**	March 30, 2009
From:	John Irving, P.Eng. MPA Director, Engineering	**File:**	10-6045-01/2009-Vol 01
Re:	**Sea Level Rise**		

Staff Recommendation

That

1. A letter under the Mayor's signature be sent to Premier Gordon Campbell requesting that the Province fund and complete a sea level rise policy specific to the Lower Fraser Delta by December 31, 2009 and identify funding that will allow the City to address any increased risk.

2. A letter under the Mayor's signature be sent to the Fraser Basin Council Executive Director to seek their support that the Province fund and complete a sea level rise policy specific to the Lower Fraser Delta.

For

John Irving, P.Eng. MPA
Director, Engineering
(604-276-4140)

Att. 1

FOR ORIGINATING DEPARTMENT USE ONLY			
ROUTED TO:	**CONCURRENCE**	**CONCURRENCE OF GENERAL MANAGER**	
Policy Planning	Y ☑ N ☐		
REVIEWED BY TAG	YES ☑ NO ☐	**REVIEWED BY CAO**	YES ☑ NO ☐

2594708

Staff Report

Origin

Numerous scientific studies have been completed in an attempt to quantify sea level rise to the Year 2100. The Intergovernmental Panel on Climate Change (IPCC) is considered by most to be the authority in this regard.

In December 2008 the Provincial and Federal governments published their sea level rise summary report entitled "Projected Sea Level Changes for British Columbia" (Attachment 1) based on IPCC projections. This information report provides a range of sea level rise projections to Year 2100 for the Fraser River Delta of 0.35-metre (Low Estimate), 0.5-metre (Mean Estimate) and 1.2 metres (High Estimate).

The Province has not adopted an official policy on sea level rise. Provincial dike height requirements remain at the levels resulting from the 2007 Fraser River hydraulic model flood profile which did not consider sea level rise. While there currently is not a Provincial sea level rise policy in place, the Province has indicated in recent correspondence that current construction around dikes should allow for future dike raising to address a 1.2 metre sea level rise by the year 2100.

Background

The City owns and operates approximately 49 km of dikes on Lulu Island that protect the City from flooding during high tides. The dikes were initially constructed to heights as determined through flooding experiences in the City's earlier history. Today, minimum dike heights are set by the Province based on the 2007 hydraulic model that considers the 1:200 year sea level and the 1894 Fraser River flood of record. A sea level rise allowance for dike heights is currently not an element of the Province's dike height requirements.

The City's first dikes were privately constructed to facilitate farming activities approximately 110 years ago. Since incorporation, the City has experienced floods through dike breaches in 1948 and 1952 which was followed by a concerted effort through senior governments initiatives to complete dike improvements over the period 1968 to 1995 through the Fraser River Flood Control Program.

In 2007, Council adopted Flood Plain Designation and Protection Management Bylaw 8204. This bylaw recognizes that the City is in the Fraser River Floodplain and establishes various mechanisms to protect the City from flooding associated with river and sea water levels. In 2008 Council adopted the 2008 - 2031 Richmond Flood Protection Strategy which contains numerous proactive flood protection related initiatives including a focus on the City's response to sea level rise.

Analysis

The City currently completes dike upgrades through the Capital Program, Public Works Operations and through opportunities that present themselves through Development. Given the fact that sea level rise is taking place and in the absence of a Provincial policy, staff have been proactively proceeding with dike upgrades since 2005 based on an allowance of 0.5-metre over and above the current Provincial requirement.

A recently completed Mid-Island Dike Scoping Study report included cost estimates to raise the City's dikes to various Fraser River and Sea Level flood levels, including an allowance of 0.6-metre for sea level rise. The cost to raise the City's approximately 49 km dikes on Lulu Island to account for a 0.6 metre sea level rise over and above the current Provincial dike height requirements is $28.2 million. Raising the dikes to address a sea level rise of 1.2 metres would increase this cost.

Financial Impact

There is no financial impact at this time.

Conclusion

The City's dikes are fundamental for flood protection during high tides and protect billions of dollars of public and private infrastructure. There is a consensus that sea level rise is a fact and the degree of such has been quantified by the Intergovernmental Panel on Climate Change. The City has proceeded with dike upgrades proactively allowing for sea level rise in the absence of a Provincial policy. The establishment of provincial policy and funding to address sea level rise would allow the City to successfully manage this area of future flood risk.

Jim V. Young, P. Eng.
Manager, Engineering Design and Construction
(604-247-4610)

JVY:jvy

Projected Sea Level Changes for British Columbia in the 21st Century

December 2008

BRITISH COLUMBIA

Canada's Pacific Gateway

Government of Canada / Gouvernement du Canada

Canada

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Photo: Doug Hartley, Arrawac Marine Services, Ltd.

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Base map image courtesy of GeoBC and Integrated Land Management Bureau, Province of British Columbia.

Acknowledgements

This document is based on a report by R.E. Thomson, B.D. Bornhold and S. Mazzotti, *An Examination of the Factors Affecting Relative and Absolute Sea Level in British Columbia*, Canadian Technical Report of Hydrography and Ocean Sciences 260, Fisheries and Oceans Canada (2008); both of these reports are a result of a joint project between Fisheries and Oceans Canada, Natural Resources Canada and the Province of British Columbia.

Ben Kangasniemi with the B.C.'s Ministry of Environment was the overall project coordinator. Brian Bornhold of Coastal and Ocean Resources Inc. prepared this summary report.

Assistance in the preparation of this report was provided by Sheri Ward, Coastal and Ocean Resources Inc., Patricia Kimber, Tango Design, and Jennifer Pouliotte of the Ministry of Environment.

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Boundary Bay storm, Feb. 2006. Photo: The Corporation of Delta

Summary

The 21st century is expected to witness a continued rise in global average sea level as a result of the melting of continental glaciers and ice caps, and warming (expansion) of the upper ocean. At the regional scale, sea level will change in response to these global effects, as well as local effects, including ocean and weather conditions and vertical movements of the land due to geological processes. Consequently, the expected changes in sea level for the British Columbia coast will differ from the global projections; they will not be uniform. For instance, estimates of most *probable* sea level rise range from 11 cm at Nanaimo to more than 50 cm in parts of the Fraser River delta. Because of the many uncertainties in measuring past sea level changes and predicting future sea levels, the *possible* range could be much greater. Applying a possible, but extreme, global rise rate, sea level could rise 80 cm for Nanaimo and 120 cm for the Fraser River delta by 2100.

The anticipated changes in sea level could have significant consequences for areas currently protected by dikes (such as the Fraser and Squamish deltas), where coastal erosion is already an issue (eastern Graham Island, Haida Gwaii), or where development and harbour infrastructure is close to present high tide limits.

Of particular concern will be extreme weather events, such as storm surges, occurring at the same time as these high sea levels. These extreme events can add as much as one metre to sea levels, regardless of local shoreline features and waves.

This report summarizes the current scientific knowledge on projected sea level changes as it applies to B.C. during the 21st century to inform decision-making and planning by coastal communities and other authorities. It is a summary of a technical report entitled "An Examination of the Factors Affecting Relative and Absolute Sea Level in Coastal British Columbia" by R.E. Thomson, B.D. Bornhold and S. Mazzotti (2008) in conjunction with Fisheries and Oceans Canada and Natural Resources Canada.

Receding Tigertail Glacier, Prince William Sound, Alaska
Photo: Mandy Lindeberg, Auke Bay Marine Laboratory, Alaska, USA

Introduction

Most scientists and world governments now accept that global climate change is occurring and that it is being driven in part by greenhouse gas emissions related to human activities. This consensus has led to a need to understand the consequences of climate change so that adaptive response strategies can be developed. Climate-induced sea level rise is of particular importance as it threatens large and growing coastal populations around the globe. Although B.C. is dominated by a rocky, high-relief coast, the province is not immune to the impacts of sea level rise. For instance, the Fraser River delta and the east coast of Graham Island (Haida Gwaii) in the Queen Charlotte Islands are particularly vulnerable areas.

The primary mechanisms that determine the level of the sea relative to the land are:

1. *changes in global ocean volume due to melting of ice caps, continental ice sheets and mountain glaciers;*
2. *global and regional changes in ocean volume due to thermal expansion and salinity effects on water density (warmer, fresher water occupies more volume than colder, saltier water);*
3. *regional volume changes due to dynamic atmospheric and ocean processes, such as shifting major wind systems and ocean currents; and,*
4. *local changes due to vertical land motions, associated with recovery from the weight of glaciers during the last Ice Age (rebounding), subsidence (sinking) in river deltas, and tectonic processes in the earth's crustal plates.*

While the general nature of these mechanisms over large geographical areas is well understood, the details at the local scale are not.

Esperanza Inlet. Photo: Doug Hartley, Arrawac Marine Services, Ltd.

Coastal estuary in Kynoch Inlet, Fiordland Conservancy. Photo: B.C. Parks.

Past and Projected Changes in Global Sea Levels

Over the course of geologic time, the earth has undergone sea level changes of several hundred metres, mostly due to the growth and shrinkage of continental glaciers (over many thousands of years) and movement of the earth's crustal plates (tectonics). Very large tectonically-induced sea level changes typically occur over the span of millions of years.

During the last Ice Age, which reached a maximum about 21,000 years ago, global sea levels were approximately 120 m lower than they are today (*Figure 1*). This is because a significant portion of the water in the world's oceans was frozen in continental glaciers. Warming began 18,000 years ago and between 15,000 and 7,000 years ago, sea levels around the world rose rapidly, about 14 mm per year on average. About 2,000 to 3,000 years ago, globally-averaged sea levels stabilized to approximately their present position (*Figure 1*).

Based on worldwide tide gauge records and more recent (since 1993) satellite measurements (*Figures 2 & 3*), we know that global sea level has risen more than 20 cm since the late 19th century. This is equivalent to annual sea level rise rates of about 1 mm per year in the early part of this period to more than 3 mm per year over the past decade or so.

The Intergovernmental Panel on Climate Change (IPCC), an international body of several thousand climate scientists, was charged with presenting a comprehensive status report on climate change and its potential impacts. According to the 2007 IPCC Report, of the 3.2 mm rise per year since 1993 (*figure 3*), more than half of the rise (1.6 mm per year) in global sea level change is the result of volume changes from heating of surface waters (water expands when heated). Most of the remaining increase (about 1.2-1.6 mm per year) is due to melting glaciers in Antarctica, Greenland and mountain areas.

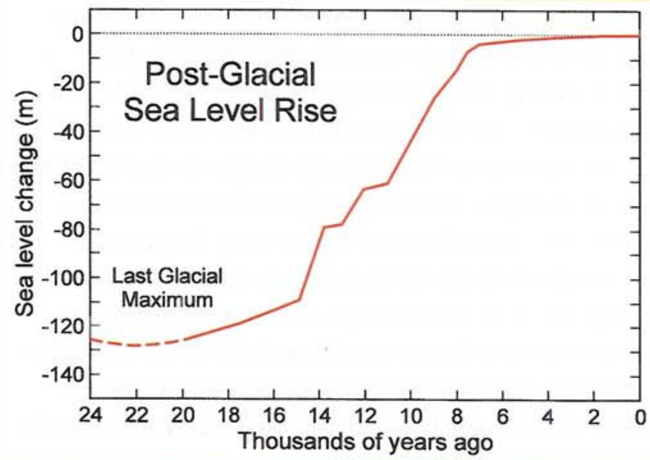

Figure 1: Post-glacial changes in global (eustatic) sea level

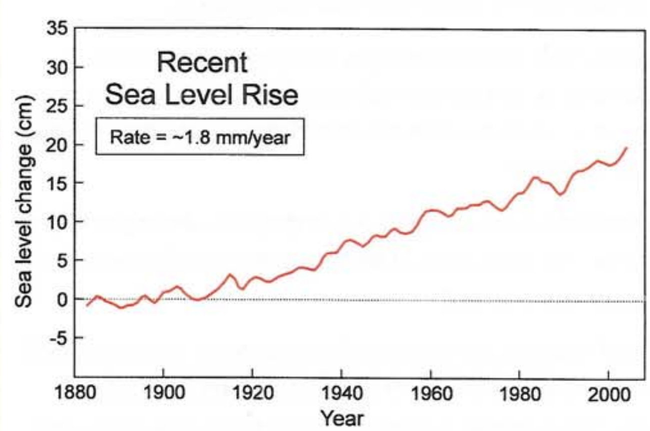

Figure 2: Global mean sea level change since the end of the 19th century based on tide gauge records

Many researchers argue that the IPCC's estimates of glacial melt's contribution to sea level rise are too low and that the rates may increase substantially during the 21st century.

Such changes, caused by many complex– and often interacting – processes, challenge our measurement instruments and techniques. Furthermore, the recent history of rates of sea level change may not necessarily be good predictors of the future; many scientists argue that important processes, such as the melting of glaciers on Antarctica and Greenland, may be accelerating. Thus, projections of future rates of sea level change are uncertain, particularly on more localized scales.

Rapidly eroding bluffs along the east coast of Graham Island, Haida Gwaii (Queen Charlotte Islands)
Photo: Vaughn Barrie, Geological Survey of Canada

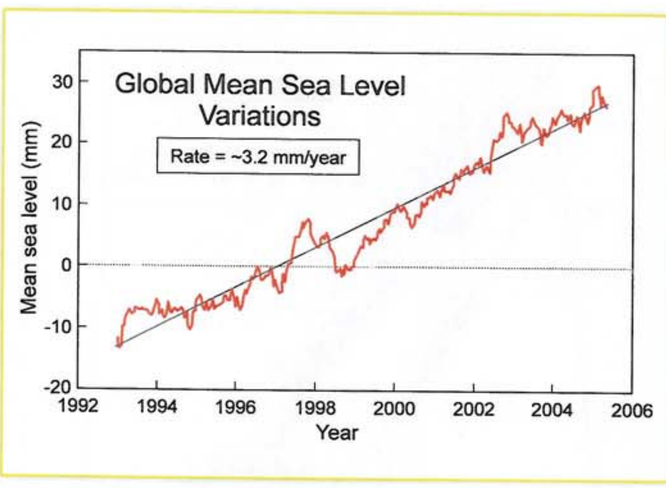

Figure 3: Global mean sea level change since 1993 based on satellite altimetry

Storm surge flooding, Victoria. Photo: B.C. Ministry of Environment

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Past and Projected Changes in British Columbia Sea Levels

Trends in global sea levels are greatly modified by regional and local processes. Thus, while there was a 120 m rise in global (eustatic) sea level over the past 15,000 years or so, parts of the B.C. coast experienced nearly a 200 m fall in sea level, due to local glacial melting and uplift of the land. In some instances, sites as little as 100 km apart, such as Prince Rupert and Haida Gwaii (Queen Charlotte Islands), experienced completely opposite sea level histories (*Figure 4*).

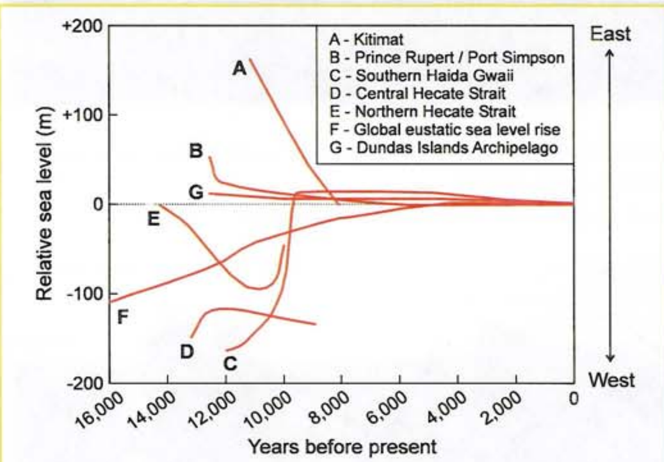

Figure 4: Post-glacial sea level histories from many nearby sites in northern British Columbia reflecting the variable tectonic processes from east to west.

Effects Due to Vertical Land Motions

Post-Glacial Rebound

While these very large post-glacial sea level changes largely stabilized about 8,000 years ago, there appears to be a continuing minor uplift of coastal areas of between 0.20 to 0.25 mm per year along the B.C. coast.

Tectonic Processes

Tectonic processes have a major effect along the outer coast. In areas such as western Vancouver Island, the continued stress of the Juan de Fuca tectonic plate as it moves beneath the North American plate results in an annual uplift (*Figure 5*) of the land (and corresponding fall in sea level) of about 2 to 3 mm per year. This effect diminishes across Vancouver Island and the Strait of Georgia to near zero on bedrock areas near Vancouver. Similar uplift rates of 2 to 3 mm per year have also been measured on Haida Gwaii. The uplift of Vancouver Island is partially reversed during extreme earthquakes (greater than Magnitude 9) along the Cascadia subduction zone with near instantaneous lowering of the land by 0.5 m to 2 m. These events take place approximately every 500 to 600 years with the last occurrence on January 26, 1700.

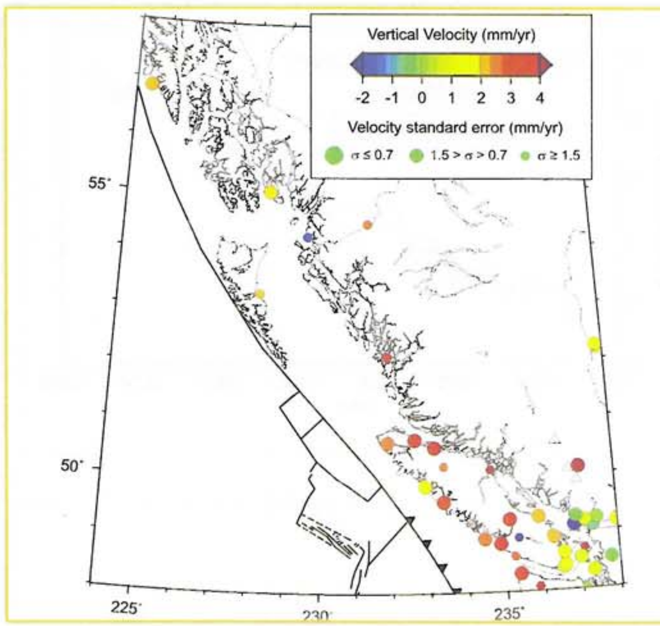

Figure 5: Annual rates of uplift (mm per year) of the land along coastal British Columbia. Note the high rates on southwestern Vancouver Island which diminish rapidly to the east to zero near Vancouver.

Fraser River dike at Richmond. Photo: Colleen Hawkey

Subsidence

On the Fraser River delta, sediment loading is causing the delta to sink at rates of 1 to 2 mm per year (*Figure 6*). While all major deltas in the world are sinking, under natural conditions, new river-borne sediments are added to the surface of the delta, compensating for subsidence. In the case of developed deltaic areas, such as those of the Fraser and Mississippi Rivers, human intervention (dredging, construction of training walls and dikes) results in the diversion of these sediments into deeper water away from the delta, thereby adding to the natural subsidence rate. The rate of sinking for the Fraser Delta is further increased locally (to more than 3 mm per year) by very large construction projects, such as ferry terminals or other port facilities, which further compact the underlying sediments. These rates will slow over time, eventually reaching similar rates of movement to the rest of the region.

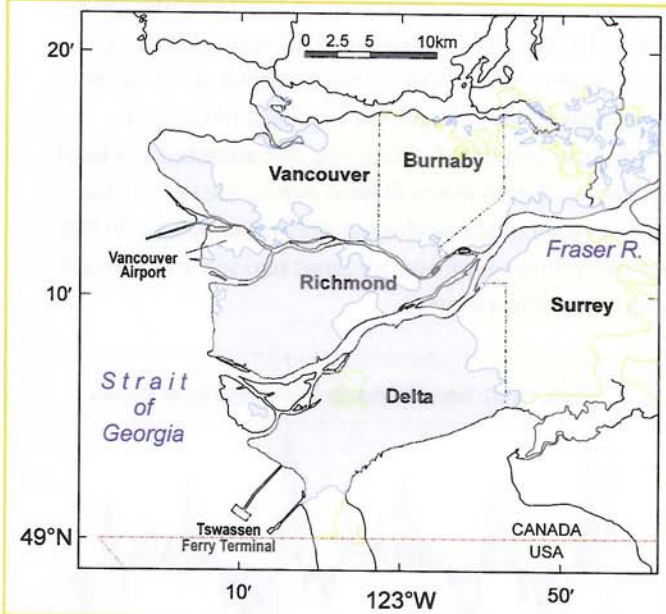

Figure 6: Map of Metro Vancouver and the Fraser Delta showing areas of documented subsidence (blue areas) in the delta region and more stable surrounding areas (yellow areas).

Atmospheric Effects

Atmospheric conditions can also affect sea levels, though on much shorter time scales. Sea level varies between about 0.1 to 0.5 m on one to 30-day time scales due to atmospheric low-pressure systems and associated winds. Strong northwesterly winds and high atmospheric pressure associated with "fair weather" conditions during summer can lead to marked sea level variability on the British Columbia coast. Specifically, prevailing northwesterly (equatorward) alongshore winds in summer combined with high atmospheric pressure and equatorward coastal currents normally lower sea levels by about 0.1 m. Conversely, southeasterly winds in winter combined with low atmospheric pressure and strong poleward coastal currents can increase sea levels by over 0.5 m.

Variability in regional sea level due to currents, water temperature and atmospheric conditions is primarily described by two indices, the El Niño-Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO). ENSO variations are commonly known as El Niño (warm phase of ENSO) or La Niña (cool phase of ENSO). El Niño events occur at a frequency of between two and seven years in the tropical Pacific region and last from six to 18 months. However, only major El Niño events (such as those in 1982/83, 1991/92 and 1997/98) have a pronounced impact on the British Columbia coast. The PDO variability is typically over time scales of 20-30 years. These two cycles interact to intensify or diminish oceanographic effects in coastal areas, such as sea surface temperature, sea levels and storms.


Eroding bluffs, Queen Charlotte Islands. Photo: Vaughn Barrie, Geological Survey of Canada

For much of the 20th century significant ENSO events occurred at intervals of 15 to 25 years (*Figure 7*). Since 1976, El Niño events have become more intense and frequent, with longer lasting effects. Off the coast of Oregon, Washington and British Columbia, documented sea level changes related to major El Niño events are in the range of 0.30 to 0.40 m above the monthly mean values. In the 1997-98 El Niño event, Hecate Strait had sea levels about 0.4 m higher than normal.

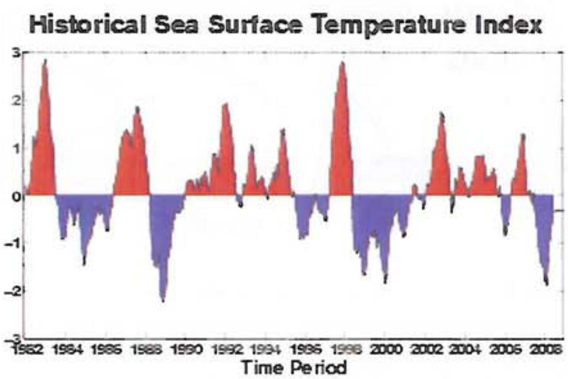

Figure 7: Record of El Niño (warm phase in red) and La Niña (cool phase in blue) events over the past 25 years. The index of sea surface temperature anomalies is in °C.
Source: NOAA found at: www.cdc.noaa.gov/people/klaus.wolter/MEI

Effects Due to Temperature and Salinity

Annual changes in the temperature and salinity of ocean waters off the B.C. coast give rise to sea level fluctuations of about 0.2 m (warmer, fresher water occupies more volume than colder, saltier water). Studies of river flow in British Columbia have shown a trend to earlier snowmelt and higher discharges in the spring for most rivers. Also, with increasing warming due to climate change, as future run-off patterns from coastal rivers change and the temperature of the upper ocean warms, the magnitude and timing of these sea level cycles will also change. These cycles are set against a broader regional sea level rise driven by warming and salinity changes. In the northeast Pacific, sea level rise due to temperature and salinity has been estimated at about 1.1 mm per year. About half of the rise can be attributed to temperature increases, and the other half to salinity decreases in the upper ocean. These trends are not uniform throughout the northeast Pacific, however. For example, in the Strait of Georgia, salinity effects account for about 63 percent of the observed sea level change and temperature accounts for about 37 percent, as a result of coastal run-off.

Table 1: Relative Sea Level Rise by 2100 for Selected Locations

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

Conclusions

Storm Effects

Extreme sea level events, related to intense storms, can result in sea levels reaching one metre above the predicted high tide level. These elevations do not take into account any wave run-up effects, which are controlled by local coastal and seafloor morphology. Run-up effects can therefore add significantly to the actual sea level heights experienced at a particular location. Since extreme events add to the sea level conditions at the time, the most hazardous situation would be a major storm system at high tide during an El Niño year when sea levels are elevated due to temperature effects.

Projections for the Year 2100

Table 1 (facing page) presents the projected sea level changes for various locations along the B.C. coast for the end of the 21st century using extreme low, mean and extreme high estimates of global sea level rise. The extreme high estimates exceed the IPCC 2007 sea level rise projections, but are considered possible.

There are 13 tide gauges in B.C. Each of these provides a historical sea level trend and can provide estimates of future projections for these locations. Only projections from five gauged locations are presented in Table 1.

Conclusions

Projected sea level rise rates vary significantly along the B.C. coast. Decisions regarding land-use, economic development and major long-term infrastructure projects must consider local sea level change to effectively manage risks and reduce vulnerabilities.

Estimates of sea level rise at the global scale will remain highly uncertain as the rate of melting of the polar ice caps is difficult to predict. However, scientists are confident in the general projections. A review of sea level rise prepared for Washington State came to conclusions similar to those presented here. Estimates of sea level rise rates at the regional scale can be improved by investigating vertical land movement, the effect of changes in coastal runoff and projected changes in climate patterns. Further collaboration between federal and provincial experts and between experts in B.C. and Washington State will advance our understanding of the complex processes affecting sea level along the Pacific coast.

Suggested Further Reading

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. 49 p.

Mote, P., Petersen, A., Reeder, S., Shipman, H. and Whitely Binder, L., 2008, *Sea Level Rise in the Coastal Waters of Washington State*. Report of the University of Washington Climate Impacts Group and the Washington Department of Ecology. 11 p.

IPCC. 2007. *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L. (Eds). Cambridge University Press, Cambridge. 989 p.

Sea wall damage in Stanley Park from wind storm, 2006
Photo: Vancouver Board of Parks and Recreation

For further information on climate change and access to an online copy of this report visit:

www.env.gov.bc.ca/epd/climate

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