SEA LEVEL RISE ADAPTATION: CONSIDERING RAPID CLIMATE CHANGE AND LIMITS TO ECONOMIC GROWTH

by

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1 INTRODUCTION AND OVERVIEW

Rising sea levels are threatening to inundate low lying communities, erode beaches, exacerbating existing risk of coastal flooding and creating flood risk in areas that were not considered at risk in the past. In developed areas, governments and landowners have responded to these threats by building dikes, seawalls and other shore protection structures. To date, very little developed land has been given up to the steadily rising sea.

This report begins by describing the problem context, which centres on the phenomenon of sea level rise and coastal management planning. I highlight the fact that planning is operating according to two key misguided assumptions. The first is that sea levels will continue to rise gradually over the next century. This may not be the case. Rather, it is likely that human actions are forcing the climate system and thus the ecosphere into a period of rapid and nonlinear change. The concentration of atmospheric CO_2 in January 2013 at Mauna Loa was 395.55 parts per million (ppm) (NOAA 2013), a new milestone in the rise of greenhouse gases (GHG). These levels have not occurred since the Pliocene era (5.3 – 2.6 million years ago). During that time period, average global temperatures were 2 to 3 degrees Celsius warmer than today and sea levels were 25+/-12 meters higher than in the 18th century (Glikson 2012). The scientific community warns of the possibility of crossing critical thresholds causing abrupt change. Sea levels could rise suddenly as opposed to the gradual rise observed over the past century.

The second assumption underpinning current planning is that the current anomalous era of economic growth will continue. Limits to growth, ‘peak oil’ and 'peak everything' are simply not factored in. At best, climate mitigation and adaptation plans look at strategies to substitute fossil fuels with renewable energy sources. However, as I will explain, this may not be feasible or sufficient to maintain business as usual. In the final analysis, communities must learn to power down and function with much reduced energy and material consumption.

With the above assumptions in mind, the purpose of this report is to establish the 'ecological context' as the backdrop for answering a series of research questions. The first questions is: in this era of rapidly declining energy and natural capital availability, will governments be able to protect development as usual in the face of accelerating sea level rise? In other words, will governments be able to build and maintain highly energy and resource intensive structures to protect urban centres in perpetuity? Second, when energy availability is constrained and costs are prohibitive, what are the alternatives to hard protective structures such as dikes and sea walls? Third, how can adaptation options be evaluated to distinguish the adaptive from the maladaptive?

Given the scope and complexity of these questions, by no means does this report purport to be comprehensive or to give definitive responses to these questions. Rather, it is intended to be but one contribution to this increasingly pressing conversation. That said, I explore answers to the above questions in sequence. The first section describes how global climate change can be understood as a symptom of uneconomic growth. The second discusses peak oil to illustrate the impending reality of limits to growth. Building on this understanding, i.e. the ecological context, I then outline the anticipated constraints for local government operations. The third section highlights the current understanding of sea level rise science at the global scale, at the Fraser Basin region scale, and at the local City of Vancouver scale. I use the City of Vancouver as an example because it is vulnerable to sea level rise, is unprotected by dikes, and is in the early stages of implementing a climate change adaptation plan. This presents a critical opportunity to explore viable and sustainable coastal management response options. The fourth section provides the BC provincial and local City of Vancouver government policy responses to sea level rise projections to date along with selected adaptation options and their estimated costs. The fifth section documents alternatives to hard protective engineering solutions, namely approaches that work with the rising tides. The sixth section evaluates the traditional approach of building structural protection according to criteria for distinguishing *adaptive* from *maladaptive* options.

Adaptation can be defined as "an adjustment in ecological, social or economic systems in response to observed or expected changes in climatic stimuli and their effects and impacts in order to alleviate adverse impacts of change or take advantage of new opportunities" (Adger et al. 2004). Maladaptation can be defined as "an action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors or social groups" (Barnett et al. 2010). This definition can be enhanced by adding that maladaptation also occurs when an action taken to avoid or reduce vulnerability to climate change results in increased vulnerability to the adapted entity itself.

2 CLIMATE CHANGE - A SYMPTOM OF UNECONOMIC GROWTH: KEY CONCEPTS

2.1 Ecological Overshoot

Human-induced sea level rise is one indication that the human enterprise is in a state of ecological overshoot. Ecological overshoot occurs when demand on the biosphere exceeds the available biological capacity of the planet. According to the Global Footprint Network (GFN), humanity has been in a state of global overshoot since the 1980s (GFN 2011). This means that annual demand on bio-resources continuously exceeds the planet's regenerative capacity. As a result, nature's stockpiles are dwindling and planetary waste sinks are full to overflowing. Ecological Footprint analysis, a resource accounting tool that calculates how much nature we have and how much we use, suggests that as the collective human footprint grows, symptoms of exceeding ecological limits, such as sea level rise, will be exacerbated.

Ecological Footprint analysis enables us to measure human demand on biocapacity. This powerful accounting tool illustrates the fact that it now takes the Earth more than a year and a half to regenerate the biocapacity used in a single year (GFN 2011). Moreover, global Ecological Footprint calculations show that our demand on nature since the 1960s has doubled, while the Living Planet Index tracks a fall of 30 percent in the health of species that underpin the integrity of ecosystem services on which we all depend (Living Planet Report 2010). Overshoot is being maintained by liquidating natural capital that accumulated over millions of years. A basic understanding of the second law of thermodynamics makes it clear that degradation of natural resources is often irreversible and cannot be maintained indefinitely. Simply put, there are no substitutes for many ecological goods and services - such as clean air, clean water, nutrient cycling and crop pollination - that create the conditions for all life on this finite and increasingly fragile planet.

2.2 Precursors to Ecological Economics

Concern for the sustainability of nature, society and limits to economic growth are not new. In 1798 Thomas Malthus observed that human populations tend to grow rapidly and will eventually outstrip available resources. This concept has since been referred to as the *Malthusian Trap.* Malthus argued that the human propensity to expand would ultimately be constrained by poverty, famine and disease (Malthus 1798). In 1848 Mill wrote about his understanding of the value of nature in his book *Principles of Political Economy*. Mill wrote a chapter entitled 'Of the Stationary State' where he recognized that there is wealth beyond the material. Mill argued that the inevitable conclusion of unlimited growth was environmental destruction and a reduced quality of life for humans. He stated that a stationary state might be preferable to continuous economic growth. According to Herman Daly, Mill's writing led to a new school of thought carried on by the discipline now known as ecological economics. Daly (2005) states unequivocally that “...the facts are plain and incontestable: the biosphere is finite, non-growing, closed (except for the constant input of solar energy), and constrained by the laws of thermodynamics. Any subsystem, such as the economy, must at some point cease growing and adapt itself to a dynamic equilibrium, something like a steady state" (102).

2.3 Uneconomic Growth

In 1972 a team of MIT scientists created a computer model that analysed global resource consumption and production. The results echoed the concerns and predictions of Thomas Malthus outlined above. The team found that unlimited growth on a finite planet would lead to catastrophe. More specifically, the findings indicated "...that the twin economic burdens of resource depletion and pollution would turn a growth-oriented economy into its own nemesis" (Meadows et al. 1974 as cited by Greer 2008, 5). The model showed that once an economy overshoots the carrying capacity of its environment, the costs of resource depletion and pollution rise faster than the benefits of economic growth. Daly (2005) elaborates on this by explaining, "When the economy's expansion encroaches too much on its surrounding ecosystem, we will begin to sacrifice natural capital...that is worth more than the man-made capital...added by the growth. We will then have...uneconomic growth, producing "bads" faster than goods...making us poorer, not richer. Once we pass the optimal scale, growth becomes stupid in the short run and impossible to maintain in the long run" (100). In the final analysis, dealing with the consequences of growth overwhelms growth itself and brings the economy down. Greer (2008) makes the message clear by saying that "...you can't grow your way out of a crisis if growth is what's causing the crisis in the first place" (6).

In 2004 an updated and expanded version of *Limits to Growth* was released. The authors' findings were in line with the 1972 model outcomes. The take home message was that (in the absence of changes to perspectives, cultural norms, behaviours and institutions that reduce material and energy throughput by a factor of 5-10) consequences of overshoot will lead to systemic ecological, economic and societal collapse in the 21st century (Meadows et al. 2004).

Accelerating sea level rise is but one of the innumerable costs of continuous ecological overshoot and poses a major global socio-economic hazard. There are approximately 200 million people living within coastal floodplains, and about two million square kilometers of land and one trillion dollars worth of assets lying less than 1 m above current sea level (Milne et al. 2009). It is anticipated that sea level rise and exacerbated coastal flooding, in combination with other climate change impacts such as desertification and saline intrusion, will result in significant global population displacement. Estimates of the number of people forced to migrate due to climate change impacts by 2050 range from 200 million to 600 million (McGranahan et al. 2007). How will Canadian communities be affected? Although many climate migrants, often referred to as climate refugees, will relocate within their own countries, there will likely be pressure on Canada's humanitarian immigration program to extend protection to those displaced by the consequences of climate change (Becklumb 2010). Therefore, governments need to begin planning to mitigate flood risk in coastal communities while bearing the possibility of additional population growth due to the influx of climate refugees in mind. Higher immigration translates into increased demand for services, which will be an additional stress for governments struggling to manage the impacts of rapid climate change within the context of limited financial, energy and natural resources availability. The challenges that such constraints will impose on local governments will be discussed further in section 3.6.

2.4 Living Planet Report 2012

This latest World Wildlife Fund report (2012) finds that the ecological footprint of the collective human enterprise now exceeds Earth’s global biocapacity by more than 50 percent. This extent of overshoot reduces the resilience of the ecosphere and its ability to provide for human needs. The symptoms of surpassing ecological limits in pursuit of unlimited material growth range from increasing ocean acidification, runaway climate change, accelerating sea-level rise, rapid desertification, soil loss, ozone depletion and the imminent peak and decline of key non-renewable energy resources (Beddoe et al. 2008).

The focus of this report is on just one symptom of transgressing ecological bounds, namely sea-level rise. However, before the science of climate change and sea level rise projections are explored, the following section looks at peak oil at the macro scale as well as implications for the local scale to highlight the energy and resource constraints that governments will face when evaluating adaptation options for low-lying coastal cities. The far-reaching effects of peak oil coupled with a rapidly changing climate reveal why governments will likely be unable to protect development as usual in the face of accelerating sea level rise.

3 WHAT'S THE DEAL WITH 'PEAK OIL'?

Let me begin with a standard definition of peak oil from Wikipedia: *the point in time when the maximum rate of global extraction is reached, after which the rate of extraction continually declines*. The use of fossil fuels in the 19th century enabled the ongoing explosion of economic and human population growth. Reaching peak oil suggests we are getting close to global limits on further expansion. Ultimately, it may be the pivotal factor that ushers in the end of this historically anomalous period of exponential growth.

At first glance, the peak of global oil withdrawal appears to be a problem of energy resource depletion. However, it is not actually about running out, it is about the end of abundant, accessible cheap oil. The production peak of conventional crude oil exemplifies fast approaching limits to growth because oil is at the leading edge of a larger crisis as all resources will in turn reach their respective 'peaks'. Moreover, as Heinberg (2011) points out, petroleum itself plays a central role in our modern world. Transportation, mechanized food production, and most other industries still depend on uninterrupted access to inexpensive oil. In fact, "the Industrial Revolution was really the Fossil Fuel Revolution, and the entire phenomenon of continuous economic growth...is ultimately based on ever-increasing supplies of cheap energy" (ibid 15).

3.1 Hubbert Analysis and The Discovery of Peak Oil

In 1956 Mr. Marion King Hubbert, a geophysicist working for Shell Oil Company, developed what is now known as the *Hubbert Curve,* an approximation of the production rate of a resource over time. Hubbert initially used his model to accurately predict the peak of US oil extraction and it has become the basis for extrapolating to a global peak (Hubbert 1956).

Hubbert's work led to increasing concern as post peak extraction rates are projected to decline relatively rapidly. Peak oil experts such as Robert Hirsch and Jeff Rubin, among many others, have been sounding the alarm and calling on governments to mitigate the anticipated significant drop in supply relative to demand. The primary issue is that, in the absence of planned transition away from fossil fuel dependence, far-reaching negative economic, social and geo-political impacts are likely to ensue (Hirsch 2005 and Rubin 2009). In the executive summary of a report commissioned by the U.S. Department of Energy Hirsch (2005) wrote, *"...*as peaking is approached, liquid fuel prices and price volatility will increase dramatically, and, without timely mitigation, the economic, social, and political costs will be unprecedented. Viable mitigation options exist on both the supply and demand sides, but to have substantial impact, they must be initiated more than a decade in advance of peaking" (4).

Global dependence on oil and the need to plan for a post peak scenario cannot be overstated. According to the Post Carbon Institute, oil currently accounts for approximately

41% of global fossil fuel consumption, 33% of all global fuel consumption and 95% of global energy used for transportation. Therefore, it is imperative that all governments at all levels plan "...to reduce energy consumption, develop renewable energy sources, and reconfigure our fossil fuel-dependent infrastructure" (Heinberg and Lerch 2008, 2). The urgency becomes clear when two additional concepts are spelled out.

3.2 Energy Return On Energy Invested

Understanding Energy Return On Energy Invested (EROEI) is key to understanding the intractable dilemma that is peak oil. The issue is that remaining energy resources provide less EROEI. At the dawn of the oil age, it seemed that one had only to put a shovel in the ground and oil would begin to flow. At that time EROEI, on average, was 100:1. Today however EROEI averages 10:1 as available liquid crude has become more difficult to access. Extraction often requires deep-water platforms, horizontal drilling, hydraulic fracturing and other complex energy-demanding technologies. According to Orlov (2010) as EROEI decreases from 10:1 toward 1:1 the point will be reached when it is no longer economically or energetically possible to deliver diesel or gasoline to a gas station. Orlov postulates that 3:1 may be the minimum EROEI that the oil industry requires to sustain itself. Greer (2008) explains this phenomenon in simple terms by stating that if it takes the energy of a barrel of oil to extract a barrel of oil, then further extraction is pointless, no matter what the market price. In the end, remaining reserves will be left underground.

3.3 Unparalleled Qualities: Energy Dense, Versatile, Transportable and Easy to Store

Fossil fuels - namely coal, oil and natural gas - are unique in that they have temporarily allowed humans to extend the carrying capacity on Earth that was previously controlled by negative feedback. Before fossil fuels the global population was less than one billion. In a relatively short time, abundant cheap oil has enabled the global human enterprise to reach seven billion people! Kunstler (2005) describes this era as a geologic endowment enabling a one shot bonanza, a one-time deal, a truly anomalous period of human history. Kunstler goes on to use the analogy that "Fossil fuels provide for each person in an industrialized country the equivalent of having hundreds of slaves constantly at his or her disposal" (31).

Oil is a uniquely amazing substance. The energy density of crude oil is unmatched, meaning that it contains an enormous quantity of energy per weight and volume. It is also easy to transport, store, pump and relatively safe to handle. It can be refined into various grades and is used for myriad products from plastics to fertilizers (Kunstler 2005). Our material lives are literally saturated with oil of various permutations. There is really no equivalent. Alternative energy sources simply do not share this distinct set of qualities.

3.4 Why Alternatives will Not Suffice

A recent report by the Post Carbon Institute states that "...there are currently no viable substitutes for oil at current rates of consumption. Although alternatives to oil do exist for many of its uses, they are generally vastly inferior to oil in their energy content and in the ease of which they can be extracted, transported, and turned into a commercially-useable fuel" (Lerch 2010, 2). Conventional energy sources - such as natural gas, hydropower and uranium – also face serious constraints as potential replacements for oil as our dominant fuel (ibid). These constraints entail lower EROEI and energy density compared to crude oil. Greer (2008) explains that aside from issues of EROEI and energy density, generation of renewables are subsidized by cheap oil. For instance, producing a solar cell first requires large quantities of liquid fuel to mine and ship raw materials and then far more energy to power the complex manufacturing process. Often the EROEI or net energy produced is 1:1 or even negative, which means that they ought not be manufactured to begin with (Greer 2008).

As if all these issues were not enough, there is the inconvenient yet crucial fact that gas and coal may have reached or will soon reach their respective peaks as well, a process being hastened by ever increasing demand and the rush to compensate for the declining output of oil. This appetite to consume all available resources is leading to *peak everything* (Heinberg 2007). Needless to say, even if feasible alternatives existed decades would be needed to bring them to scale. As David Price (1995) stated, "to take over for fossil fuels as they run out, an alternative energy source would have to be cheap and abundant, and the technology to exploit it would have to be mature and capable of being operationalized all over the world in what may turn out to be a rather short time. No known energy source meets these requirements" (312).

3.5 So When WILL We Reach Global Peak Oil?

In 2010 the International Energy Agency (IEA) shifted from a position of denial that conventional oil production would peak this century to stating that in fact it already occurred in 2005-2006 (IEA 2010). This message was somewhat glossed over by the assumption that the gap between projected demand and available supply will be filled by undiscovered, undeveloped, low energy density and very expensive to produce oil. The report maintains that despite having past the global peak, growth can be maintained. Perhaps this came across as believable by the average uninformed reader, but to those who truly understand the dynamics of the situation, the report read as incredibly contradictory because it was stated that production will go from the current 70 million barrels per day to 16 in the next 25 years. It is not clear how this is even remotely possible particularly when EROEI and energy density are considered (Whipple 2010).

Officially, then, global peak conventional oil has already passed and extraction rates are in decline. The following revealing excerpt is from an April 2011 video interview of Fatih Birol, IEA's chief economist. Mr. Birol stated the following:

> *"We think that the crude oil production has already peaked in 2006, but we expect oil to come from the natural gas liquids, the type of liquid we have through the production of gas, and also a bit from the oil sands. But in any case it will be very challenging to see an increase in the production to meet the growth in the demand, and as a result of that, one of the major conclusions we have from our recent work in the energy outlook is that the age of cheap oil is over"*

The gravity of this statement given its source can hardly be overstated. It means that the IEA has virtually admitted to the impossibility of continued global economic growth. The question is, will humanity act accordingly by facing biophysical reality and drastically reducing energy and material use? Or will the status quo be maintained to the point where our tightly knit global socio-ecological system crosses critical tipping points and crashes as did the Easter Islanders, the Maya and the Greenland Norse (Diamond 2005)?

Despite the fact that, according to the IEA, the global peak of conventional oil occurred in 2006, there is little evidence that governments are planning for the transition through the end of growth era to a post carbon future. Therefore, it is critical to understand how peak oil will play out at the local level where decision makers are just beginning to grapple with the far reaching implications that sea level rise imposes in addition to planning for the spectrum of local climate consequences such as food and water security. These increasingly challenging responsibilities are being managed with limited budgets as the cost of city operations continues to escalate.

3.6 Peak Oil and Local Government

Kaufmann (2010) articulates two main challenges governments will face once peak oil, meaning energy-supply shortfalls along with high and volatile energy prices, and the necessity of a post-carbon future sinks in:

1. How to maintain order and basic services during a time of economic contraction, when demand for services is rising and revenues are shrinking

2. How to use governmental powers to enable, foster, support, and lead the transition to a more resilient world.

Kaufmann proceeds to explain how transitioning to a post carbon economy will likely affect municipalities. The scenario he paints is as follows:

Although the specific manifestations of peak oil and climate change will vary from one place to another, impacts will undoubtedly manifest in the local economy. This is inevitable because at their root, both peak oil and climate change are a result of unprecedented fossil fuels use. As discussed above, there are no known alternatives that match the unique characteristics of fossil fuels, meaning energy density, transportability and versatility. It is generally understood that on the downward slope of the Hubbert curve, both individuals and governments spend more on energy, which means there is less money left over to purchase other goods and services. The result is that economic activity declines, which may be accompanied by inflation. During economic downturns, citizens struggle to cover basic expenses such as housing, food and transportation. Furthermore, government tax revenues decline just as demand for services increase. There is much that can be done to soften the hardship during such times. There are also things worth noting that will not be effective in addressing the scope and scale of the problem, such as:

- *Preserving the status quo* – this is simply not possible as revenues will be as limited as resources while demand for services will simultaneously increase.
- *Increasing taxes* – this will not generally be feasible during a time of economic contraction, as most people will be challenged to pay for basic necessities such as food and shelter.
- *Focusing solely on reducing energy, operations and service efficiencies* – as much as efficient operations are important, these savings will not be sufficient to offset the combination of rising energy costs and diminishing revenues (Kaufmann, 2010).

Lerch (2007) suggests principles that can help local governments navigate and plan in the face of peak oil and climate change. Chief among them are to incorporate these considerations into all aspects of decision-making for land use and infrastructure investment.

That is precisely what must be done when considering how to adapt to accelerating sea level rise, as will become evident in the following section on the most up to date projections.

4 CLIMATE CHANGE & SEA LEVEL RISE – THE BIG PICTURE

4.1 Crossing thresholds – a small change can make a big difference

The current era is one of rapid climate change (CC) apparently due mainly to emissions of CO_2 and other greenhouse gases (GHGs). These human-induced changes represent an unprecedented threat to the integrity of Earth's ecosystems, and in turn to the socio-economic welfare of humankind.

There is no scientific consensus to distinguish between 'dangerous' and 'acceptable' CC but, despite the lack of scientific grounding, limiting global average temperature rise to 2 ºC above pre-industrial levels (approximately 278 ppm) has become a focal point for policymakers. To achieve this, it is generally accepted that carbon dioxide equivalent (CO_2e) must be stabilized between 450 and 550 ppm. In January 2013, the concentration of the main greenhouse gas CO_2 reached 395.55 ppm (NOAA 2013), with a rate of rise at 1.8 ppm per year (World Bank 2012). Anderson and Bows (2008) state that "the current framing of climate change cannot be reconciled with the rates of mitigation necessary to stabilize at 550 ppmv CO_2e and even an optimistic interpretation suggests stabilization much below 650 ppmv CO_2e is improbable" (6). Therefore, the lack of action to reduce GHG emissions translates into a commitment to 'dangerous climate change' in excess of 2 ºC by the latter half of the 21st century (WWF 2009). Several recent reports, such as the one by the World Bank discussed below, reinforce Anderson and Bows's assessment, acknowledging that limiting warming to two Celsius degrees will now be almost impossible and that we are on track for a catastrophic 4 Celsius degrees of warming. A report issued by the World Bank (2012) finds that we are on track to a 4 ºC warmer world by the end of the century. In the forward the President Dr. Jim Yong Kim writes that "The 4 ºC scenarios are devastating: the inundation of coastal cities; increasing risks for food production potentially leading to higher malnutrition rates; many dry regions becoming dryer, wet regions wetter; unprecedented heat waves in many regions, especially in the tropics; substantially exacerbated water scarcity in many regions; increased frequency of high-intensity tropical cyclones; and irreversible loss of biodiversity, including coral reef systems (ix).

CC modelling and impact assessments tend to present a smoothly incremental increase in scale and severity of impacts as the average global temperature rises. Such assessments do not reflect biophysical reality, as changes are not likely to proceed smoothly. There are thresholds that, once crossed, are likely to result in significant non-linear, large-scale disruptive change. Policy does not account for the fact that “...there could be tipping elements that have not been triggered yet...or have already been triggered, but we have yet to fully realize it because of a lag in response of the relevant system” (WWF 2009, vi). With respect to the focus of this report, crossing tipping points could lead to large and relatively sudden global sea level rise far in excess of the upper bounds of current projections. Even current conservative estimates of a gradual average global rise of 1 metre by the year 2100 increase the value of assets exposed in all 136 port mega-cities worldwide by a total of $US 25,158 billion to $US 28, 213 billion by 2050. This is due to changes such as increased urbanization and exposure of coastal populations to flooding and storm surge events (WWF 2009). Moreover, these numbers are likely gross underestimates as they do not account for cumulative and cascading effects that are not well understood (World Bank 2012).

4.2 Global Sea Level Rise – a brief overview

The phenomenon of sea level rise (SLR) is a direct result of global warming due mainly to: thermal expansion (ocean water expands as it heats up) and melting of glaciers and icecaps (as ice on land melts, additional water flows into the ocean) (Allison 2011). Since 1870, global sea level has risen by approximately 20 cm (IPCC 2007). Prior to 1993, global sea level data was obtained from tide gauges. Since then, measurements are also acquired from satellites. Both types of measurements provide evidence that the SLR has accelerated. Satellite measurements show that sea level is rising at approximately 3.1 mm/year (ibid). This is nearly double the average rate of 1.7 mm/year during the 20th Century. Note that these rates are an order of magnitude faster than the average rate of rise over the previous several thousand years (Convey et al. 2009). Analysis shows that the rate of rise is closely tied to temperature. Essentially, as the average global temperature increases, ocean levels rise faster (Allison 2011).

Projections for average future SLR indicates that a rate of accelerated rise will continue for hundreds of years; even assuming global temperature is stabilized. A combination of scientific modelling and observations indicate that this will translate into 1 to 2 metres of global average SLR by 2100 (ibid). Forecasting and understanding of this complex issue is continually being updated, for which the numbers are generally increasing. As discussed in the above section, it is possible that critical thresholds will be or have already been crossed. This could lead to sudden changes in climate and to “…to large scale changes in ocean circulatory systems or the rapid loss or collapse of the Greenland or West Antarctic Ice Sheets. If such an event occurs, sea level will rise much more than forecast under the most extreme IPCC scenarios”

(International Risk Governance Council, 2010). Such rapid change would likely lead to the loss of many major coastal cities and entire island states (Allison et al. 2009).

4.3 A critique of the last IPCC Report

The last International Panel on Climate Change (IPCC) report published in 2007, referred to as the AR4, put forth sea level projections that quickly became controversial. According to Rahmstorf, the controversy centres on how the AR4 projections are based on models that aim to simulate individual processes like thermal expansion or glacier melt. Many scientists have argued that these process models underestimate both past and future sea level rise (Rahmstorf 2013).

The IPCC Summary for Policy Makers (SPM) (2007) provides the following table entitled 'Projected global average surface warming and sea level rise at the end of the 21st century'. Table 1 presents six different scenarios representing plausible future development of emissions that are potentially radiatively active based on a set of assumptions about driving forces (such as demographic and socio-economic development and the use of technology) and how they are interrelated. For instance, the A1 scenario assumes rapid globalized economic development; global population rising and peaking mid-century and subsequently declining; rapid introduction to new and more efficient technologies.

Temperature Change (°C at 2090-2099 relative to 1980-1999)			Sea Level Rise (m at 2090-2099 relative to 1980-1999)
Case	Best Estimate	Likely range	Model-based range excluding future rapid dynamical changes in ice flow
Constant Year 2000 concentrations	0.6	0.3-0.9	NA
B1 scenario	1.8	1.1-2.9	0.18 – 0.38
A1 scenario	2.4	1.4-3.8	0.20 – 0.45
B2 scenario	2.4	1.4-3.8	0.20 – 0.43
A1B scenario	2.8	1.7-4.4	0.21 – 0.48
A2 scenario	3.4	2.0-5.4	0.23 – 0.51
A1FI scenario	4.0	2.4-6.4	0.26 – 0.59

Table 1: Summary for Policy Makers (IPCC 2007)

The above table estimated a range of 18 to 59 cm of rise by 2100. However, research on the scale and pace of rise as well as on the various contributing factors to SLR has improved significantly since the AR4 was released. For instance, the AR4 reported about 0.41 mm/year as the rate of sea-level rise from ice sheets for the period 1993-2003. In 2011, scientists working on the upcoming climate assessment by the IPCC developed the Ice Sheet Mass

Balance Intercomparison Exercise (IMBIE). Conclusive findings show that the Greenland ice sheet has lost 263±30 billion tons of ice per year from 2005 to 2010. Antarctica lost approximately 81 billions tons per year over the same time period. It is now understood that since 1992, on average, the two ice sheets lost enough ice to raise sea level by about 0.6 mm per year out of the observed 3 mm per year. The majority of the remainder is from melting mountain glaciers and thermal expansion (Kerr 2012).

4.4 What does the most up to date science tell us?

As discussed in the above section, the IPCC sea level rise projections were inaccurate, due in large part to the fact that they are based on process models, which produce considerably underestimated past and future SLR projections. Another method to estimate future SLR, the 'semi-empirical approach', suggests that sea level might rise twice as much by 2100 as predicted by the IPCC.

Rahmstorf et al. (2012) note that the fundamental idea underpinning semi-empirical approaches is "...to exploit the link between global sea level and global temperature in past observational data for projecting the future" (1). This method is motivated by the fact that physics-based approaches, i.e. process models, do not adequately capture the complex physics involved. The fact that model outputs have not matched past sea level rise observations or the observed accelerating ice sheet mass loss provides ample evidence of this disconnect (Rignot et al. 2011). Put simply, the semi-empirical approach is based on the idea that the rate of sea level rise will increase as global temperatures increase. The critical issue therefore is how much the rate of rise has accelerated in step with temperature changes.

It must be noted that although overall projections of future SLR based on this method are robust relative to other models, whether or not the empirical link between temperature and sea level will continue to hold into the future is questionable. For instance, modelling does not capture the following: i) loss of glaciers may mean that this source of meltwater will be diminished in future, and ii) a non-linear response of ice sheets may arise which is not captured by data inputs (Rahmstorf 2007). The former phenomena could make semi-empirical projections overestimate SLR while the latter would likely make them an underestimate of future SLR. An additional limitation to this approach may arise if future regional patterns of warming begin to deviate from past observations. So called 'non-linear' phenomena such as the abrupt collapse of the West Antarctic Ice Sheet, the rapid loss of Greenland Ice Sheet or large-scale changes of ocean circulations systems could cause such deviations (Rahmstorf et al. 2012). Limitations aside, these authors conclude that for a global warming scenario of 1.8 °C, 1 metre of SLR results over the period 2000-2100 (ibid). Although this is twice as much as predicted by the IPCC AR4, it is likely an underestimate as 1.8 °C of warming by 2100 is a highly optimistic. Warming will likely be 3-4 °C as noted in section 4.1.

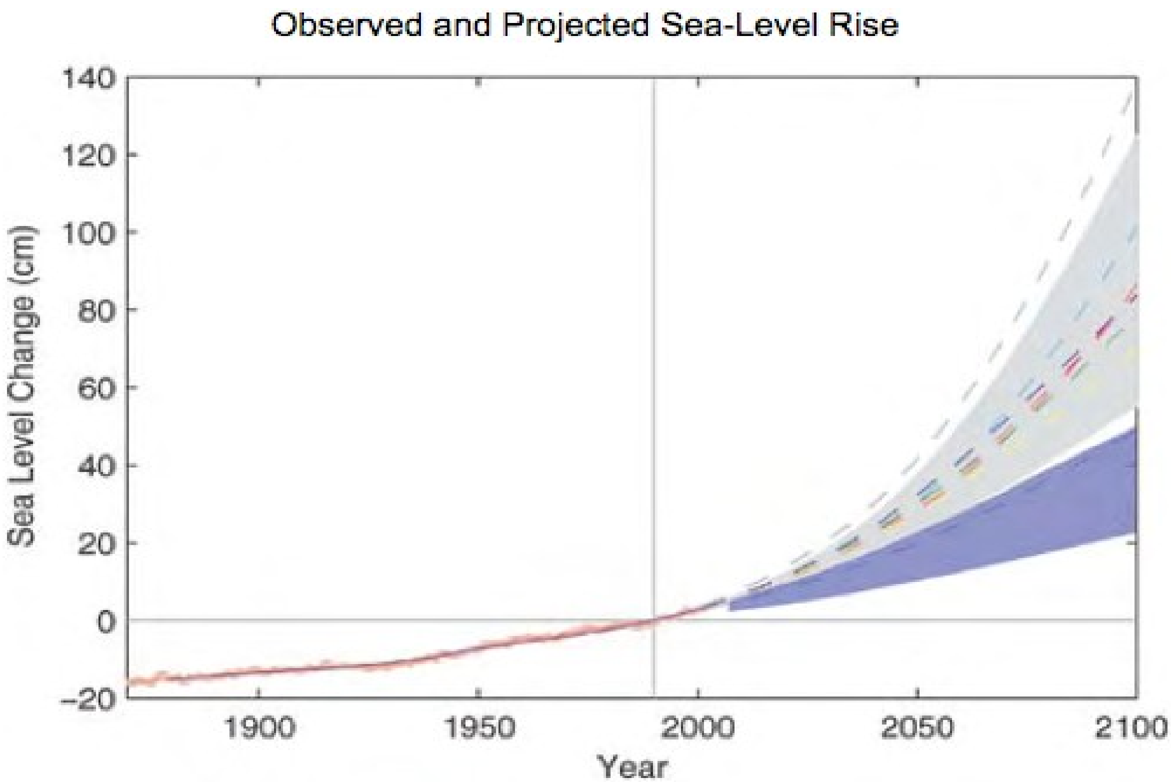

Figure 1: Plot in centimetres rise over time. The blue shaded areas correspond to the IPCC AIB (2007) emissions scenario. The higher grey and dash line projections are from Rahmstorf (2007).

Many assessments published since 2007 put forth similar projections while others suggest that 1 metre could be exceeded. One such study by Pfeffer et al. (2008) takes large contributions resulting from the dynamic instability of ice sheets into account, which leads to an estimated upper bound of 2 m of sea-level rise by 2100. In a similar vein, the Climate Program Office of the US Oceanic and Atmospheric Administration (NOAA) recently published a report (Parris 2012) including new global mean sea-level scenarios as shown in the graph below:

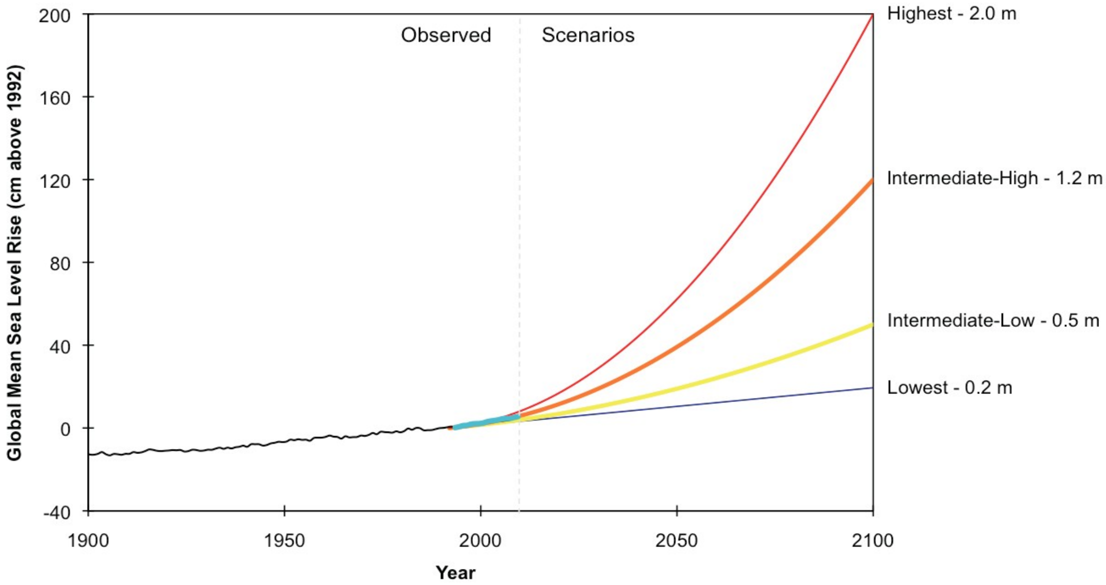

Figure 2: Global SLR Scenarios for the US National Climate Assessment (Parris 2012)

The NOAA report provides a synthesis of the scientific literature on global SLR, and a set of four scenarios of future global SLR. The report concludes that scientists have very high confidence (greater than 90% chance) that global mean sea level will rise at least 8 inches (0.2 metres) and no more than 6.6 feet (2.0 metres) by 2100. The largest source of uncertainty with this range is the contribution of water from melting ice sheets and glaciers in Greenland and West Antarctica. The scenarios shown in the graph are described as follows:

- The lowest sea level change scenario (0.2 m) is based on historic rates of observed sea level change. This scenario should be considered where there is a high tolerance for risk (e.g. projects with a short lifespan or flexibility to adapt within the near-term)
- The intermediate-low scenario (0.5 m) is based on projected ocean warming
- The intermediate-high scenario (1.2 m) is based on projected ocean warming and recent ice sheet loss
- The highest sea level change scenario (2 m) reflects ocean warming and the maximum plausible contribution of ice sheet loss and glacial melting. This highest scenario should be considered in situations where there is little tolerance for risk.

Note that the above scenarios do not assume any abrupt non-linear changes.

4.6 Plus 2-4 °C, the lag effect and implications for long term SLR

Although the rate of rise is dependent on temperature increases over time, there is a substantial lag between rising average global temperature and SLR. To illustrate, hypothetically, assuming a temperatures rise of 4 °C, SLR could reach 2 m by 2100. However, due to the lag effect, after a century or two, the total amount of rise associated with that temperature could be 15-20 m or even more. Point: Coastal cities are likely to be subjected to 1-2 m by the end of the century. However, even the global warming to date means a commitment to continuous SLR for centuries. Glikson (2009) states that "At 460 ppm CO_2-e (a value including the CO_2-equivalent radiative forcing of methane) the energy level of the atmosphere exceeds that of the mid-Pliocene (2.8 million years ago; CO_2 ~400 ppm, +2 to +3 degrees C; sea levels +25±12 meters)."

In summary, despite considerable remaining uncertainties resulting in a wide range of global SLR projections, one point of agreement amongst scientists is that sea levels and greenhouse gas emissions trajectories are interdependent. Furthermore, as discussed, crossing critical thresholds, or tipping points, could lead to non-linear, sudden global sea level rise far in excess of the upper bounds of current projections. Abrupt changes aside, in the coming centuries, both ocean thermal expansion and ice sheets have the potential to result in +25±12 m of rise for higher greenhouse gas emissions scenarios. For the current century, SLR will likely be limited to below 2 meters only if warming remains well below 1.5 ºC (World Bank 2012). As noted in section 4.1, the lack of action to alter current GHG emissions means that limiting warming to below 2 ºC is quickly becoming a remote possibility.

4.5 Regional Variation – the Fraser River Delta

A Canada-wide assessment of the impacts of sea level rise (Shaw et al., 1998 as cited by Walker et al. 2008) found that in terms of SLR impacts, the Roberts Bank–Fraser Delta region ranked amongst Canada's most sensitive coastlines. However, as noted, it is impossible to make accurate predictions about SLR in terms of the where, when and by how much (IRGC 2010). With macro scale unknowns in mind, it is important to highlight significant regional heterogeneity. A study by Thompson et al. (2008) examining the unique factors affecting sea levels on coastal B.C. identifies the Fraser River Delta as being particularly vulnerable. The following processes influencing how global SLR impacts the region are:

- Post glacial rebound
- Plate tectonics
- Impacts of a high magnitude earthquake
- The process of sediment compaction in the Fraser River Delta
- Increased water temperature and salinity
- Short term seasonal and longer term atmospheric conditions

To highlight this last point, during El Niño phases, sea levels off the B.C. coast can rise by 30 to 40 cm due to the warming trend. For B.C. coastal communities "…a worst case scenario is a major winter storm occurring at high tide during a strong El Niño year" (Green Shores 2009, 2-3). A case in point is the 2006 storm surge event in Tsawwassen that damaged over 150 homes. The combination of high tides and high winds sent waves crashing 30-40 feet over the seawall. As a result Boundary Bay was declared a disaster area and the Province provided $3 million in disaster relief (BC MOE draft policy 2011).

Although more research is needed on how climate change and SLR will impact the Fraser River Delta, some location-specific studies have been done. Studies by Thomson et al., (2008) and Bornhold et al. (2009) found that due to sedimentation subsidence, areas in the Fraser River Delta could experience a 0.50 to 1.2 metre relative SLR by 2100. The following table presents location-specific SLR scenarios in BC:

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	0.05	1.20

Table 2: Summary of Regional Sea Level Rise Estimates for 2100 for Selected BC Locations (Thomson, Bornhold and Mazzotti 2008).

As the study by Thompson et al. (2008) highlights, both observed and projected SLR impacts vary significantly from region to region. For instance, during the twentieth century, sea level rose 4 cm in Vancouver, 8 cm in Victoria and 12 cm in Prince Rupert, and dropped by 13 cm in Tofino (BC Ministry of Water, Land and Air Protection, 2002 as cited by Walker et al. 2008). Sea-level rise is a critical planning issue for coastal communities throughout BC as infrastructure such as highways, sewer systems, shipping terminals, and the Vancouver International Airport will all be affected (Green Shores Project 2009). Food security will also be at increased risk. Yin (2001) found that a 1 m rise in sea level would inundate more than 4600 ha of farmland and more than 15 000 ha of industrial and residential urban areas in British Columbia. There are approximately 220 000 people living near or below sea level in Richmond and Delta. It is noteworthy that these areas are protected by an extensive dike system that was not built to accommodate SLR (Walker et al. 2008). Furthermore, First Nations' heritage sites and ecologically sensitive habitat are vulnerable to enhanced erosion and storm-surge flooding associated with SLR. Finally, SLR can result in saltwater intrusion into freshwater aquifers, affecting the quality and quantity of drinking and irrigation water supplies (Green Shore Project 2009).

4.6 Sea Level Rise – City of Vancouver

According to an OECD report by Nicholls et al. (2008) that ranks global cities in terms of exposure to climate change risks, the CoV is ranked 15th for vulnerable assets, with USD $55 billion at risk; and 32nd for population at risk, with 320,000 people exposed. The CoV is also exposed to the combined climate-change risks of sea-level rise and storm surges with associated coastal and river flooding (Climate Adaptation Strategy, CoV 2012). Other low lying and highly developed communities such as Richmond, Delta and Surrey are also significantly exposed to these coastal hazards. However, as noted, these municipalities are protected by extensive dike systems. The CoV on the other hand remains un-diked, as historically no floodplains have been designated within city limits. The CoV is also the first municipality in Metro Vancouver to adopt a Climate Adaptation Strategy (2012). As the strategy is currently in the early stages of implementation, there is a unique opportunity to critically examine the most viable and sustainable coastal *adaptive* options, as opposed to those that would ultimately be *maladaptive.*

5 POLICY RESPONSES

5.1 BC Provincial Policy

Legislative Changes and downloaded responsibilities

Until 1975 the joint Federal-Provincial Flood Damage Reduction program was in place to identify urban areas at risk, map and zone them to discourage future development and investigate means of protecting existing development. One of the primary aims of the program was to curtail escalating disaster assistance payments. However, for the most part local governments have resisted limitations to develop in areas designated as flood zones. As a result, authority and responsibility has been transferred to the local government level (Shrubsole 2004).

Legislative changes to the Land Title Act and the Local Government Act in 2003 and 2004 granted local governments the authority to manage land use in flood hazard areas. Key changes to roles and responsibilities include:

- The removal of BC Ministry of Environment approval for subdivisions and floodplain bylaws within flood hazard areas and;
- The granting of greater authority to local governments with the proviso that provincial guidelines are taken into consideration.

The Fraser Basin Council conducted a study (2008) to determine how the above legislative changes have been implemented. One significant finding is that municipalities lack the tools and resources to manage land use in flood prone areas. Specifically, there is a need for updated floodplain mapping, technical flood hazard information and funding for dyke maintenance. Since the 2003 and 2004 legislative changes, local governments have not undertaken any updates to flood construction levels or flood hazard mapping. The authors conclude that the findings point to the need for a renewed provincial role. Furthermore, it is recommended that the province consider new guidelines and regulations to ensure consistency and compliance with provincial standards, to help coordinate decision-making across jurisdictional boundaries and to support regional collaboration (Fraser Basin Council 2008).

Provincial Policy

Although municipal governments are responsible for floodplain management, in January 2011 the Ministry of Environment (MOE) released a draft policy entitled ‘Climate Change Adaption Guidelines for Sea Dikes and Coastal Flood Hazard Land’ (Ausenco Sandwell 2011). Previously, there was no standard for the management of lands exposed to coastal flood hazards. The policy, though still in draft form, is innovative as it accounts for the most up-to date regional climate change and SLR research. The guidance integrates SLR projections into updated guidelines for sea dike design and coastal land management. The policy aims to protect low-lying areas from flooding by encouraging land use in accordance with accelerated SLR scenarios. The policy document highlights that SLR trends have significant implications for BC coastal communities and it is recommended, where appropriate, that local governments conduct locally specific risk assessments. In the absence of such assessments, the recommendation is to plan for 0.2 metre of SLR by 2025, 0.5 metre of SLR by 2050, 1.0 metre by 2100, and 2.0 metres by 2200, which is the median projection. These numbers are intended to serve as guidelines to help local governments, land use managers and approving officers develop and implement land use plans in areas exposed to coastal flooding hazards. The graph below illustrates the projections, which are recommended as the basis for SLR policy in BC.

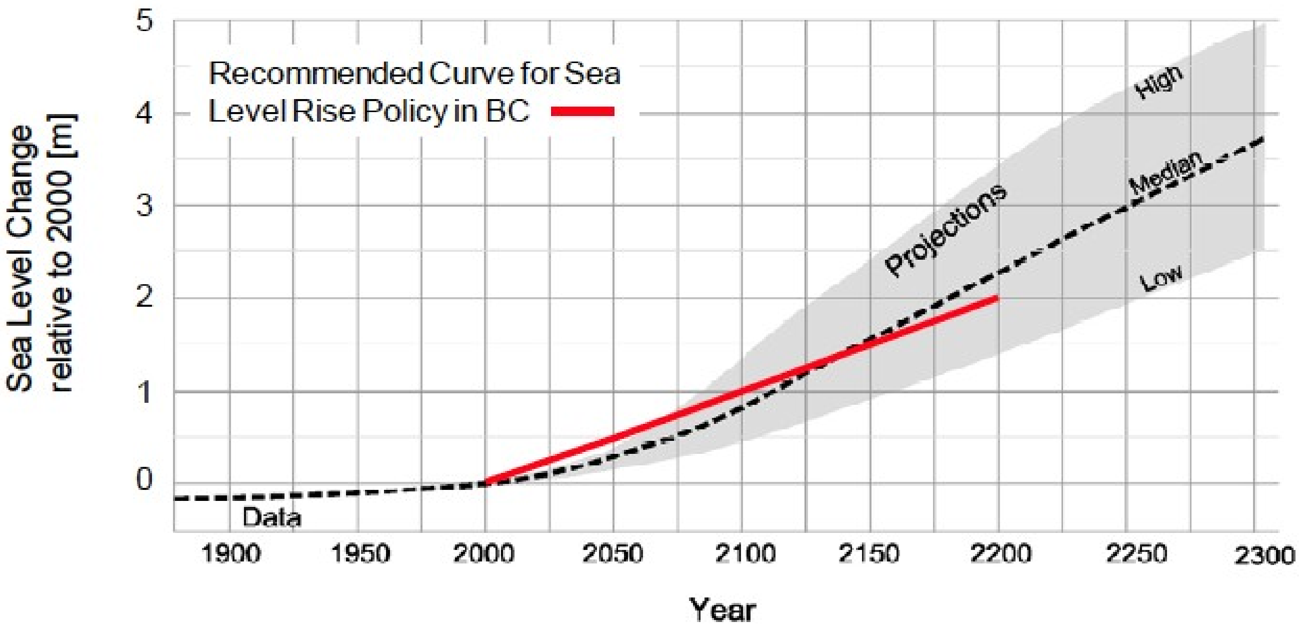

Figure 3: Recent Projections of Expected Global Sea Level Rise and Recommended Global Sea Level Rise Curve for Planning and Design in BC (Allison et al. 2009 as cited by MOE 2011)

As shown in the above graph, SLR is predicted to be moderate until 2025. The rate is then predicted to increase in the time period up to 2100 and then to increase more rapidly thereafter. Uncertainty increases further into the future; therefore as new predictions become available adjustments will be made. Revisions to the policy are scheduled for 2015 and again in 2025. For the time being, all land use and development approvals, as the life cycle of buildings can be 50 years or more, should account for SLR until the year 2100.

Land use planning and hazard management options that consider the above projections are outlined by the policy. The options are:

- **Avoid** – use zoning or setbacks to prevent development
- **Protect** – 'hold the line' using hard floodworks such as dyke systems
- **Accommodate** – adapt land based structures i.e. build above flood construction levels and use liability reduction measures such as statutory covenants
- **Managed retreat** – strategic decision to withdraw, relocate or abandon private and public assets

Ultimately, the viability of a 'protect' strategy depends on the capacity to fund the cost of 'holding the line' in the long term. The policy cautions that the protect approach will likely lead to: reactive planning; a false sense of security; further development; property and ecological damage; and the expectation that defences will be maintained in perpetuity (Ausenco Sandwell 2011). Undoubtedly, alternative planning measures such as avoidance and strategic managed retreat will be unpopular at best. However, inclusive and participatory planning processes may reduce some public opposition if risks and trade-offs are communicated effectively.

Recommended SLR Planning Areas

SLR superimposed on existing flood risk will create serious public health and safety issues in low-lying coastal communities. The provincial policy states “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 risks, SLR Planning Areas should be created throughout coastal BC for settled or new development areas at risk of SLR inundation or related erosion” (33). These 'SLR Planning Areas' are intended to minimize risk and costs for public and private interests by establishing a basis for managing the expected ongoing increases in SLR as it affects land use. The objective is to identify and spatially depict areas vulnerable to coastal hazards and to gradually change land use patterns according to known risks (Ausenco Sandwell 2011).

5.2 City of Vancouver Policy

The City's Climate Adaptation Strategy is the result of participating in the Local Governments for Sustainability (ICLEI) Climate Change Adaptation Initiative pilot. The City worked through ICLEI's five milestone methodology to complete a local CC risk and vulnerability assessment that identifies anticipated impacts and corresponding priority actions. As the strategy is the first of its kind for the City, and for all of Metro Vancouver, many of the proposed actions focus on improving the understanding of anticipated challenges and integrating locally specific climate change information into land use, critical infrastructure upgrades and emergency management (City of Vancouver 2012a).

The strategy identifies SLR as a priority due to the following impacts:

- Increased flooding, erosion and storm surge damage
- Decreased gravity drainage capacity of storm sewer system
- Potential impacts to groundwater

Primary Actions to be taken to address SLR impacts are:

- Complete a coastal flood risk assessment to support strategic sea level rise planning
- Update City flood proofing policies (building elevations/flood construction levels -

FCLs)

The results of the coastal flood risk assessment will provide detailed information about each section of the coastline, which will enable the development of a comprehensive plan to address land use. However, in the mean time, in the absence of downscaled local and site-specific flood data, development proceeds.

In the interim, in January 2012, the city posted a bulletin stating that “As part of its Climate Change Adaptation Planning, the City of Vancouver is planning to revise its Flood-Proofing Policies to address predicted sea level rise following the issuance by the Province of British Columbia of Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use in May, 2011.” This bulletin proceeds to state “The City has undertaken a study to determine the effects of sea level rise on the City’s coastline and the changes that are required to the City’s FCLs. As part of this work the City intends to amend the Flood-Proofing Policies in summer 2012 to implement revised FCLs that reflect the predicted sea level rise. In the interim, the City will encourage applicants with projects in identified flood hazard areas to meet an interim FCL equal to the current applicable FCL plus 1 metre (City of Vancouver 2012b).”

To date the Flood-Proofing policies have not yet been updated, but the above statements indicate that a preliminary study has identified areas that are now known to be prone to flooding. As a first step, the City will encourage or require all development in these areas to be designed to interim FCLs.

5.3 How much will SLR Adaptation Cost?

The state of municipal finances: background context

In 2012 the Federation of Canadian Municipalities (FCM) released a report on the state of municipal finances. Amongst the findings is that federal investment in municipalities increased from $125-million in 2003 to $4.75 billion in 2010. The additional transfers do begin to chip away at Canada's infrastructure deficit, which is the result of over a decade of neglect and underfunding. Federal funding has enabled urgent investment in critical services such as social programs, roads, and water and transportation systems. All the same, local governments still lack access to sufficient revenues, which means that the gap between their responsibilities and their ability to pay persists (FCM 2012).

The FCM report (2012) analyses revenues and expenditures for all three orders of government and reveals the fact that, unlike the provinces and the federal government, municipal expenditures have been increasing faster than revenues. As it stands, municipal governments only collect eight cents of every tax dollar. While federal and provincial governments consume approximately 90% of the national tax base, local governments rely primarily on property taxes. This fiscal imbalance compounded by downloading has result in a "...chronic municipal funding crunch..." (FCM 2006, 7) This imbalance is what drives the ongoing strain on local services and core infrastructure.

In 2006, FCM released a report that examined a range of challenges in cities nation wide. The conclusion was that escalating problems in areas such as housing, infrastructure and transportation are rooted in the out-dated Canadian tax system. The issue structural, where over time municipalities have acquired ever-greater responsibilities without the financial resources to match. This is referred to as 'downloading', which is largely a result of the legislated transfer of responsibilities from one level of government down to another. The outcome is that municipalities are forced to spend money on downloaded work instead of on infrastructure and core services. For instance, in the 1990s federal and provincial governments withdrew social transfer payments that underpinned the Canadian welfare system. Municipalities, already struggling to balance strained budgets, had to make decisions such as whether to fund social services, affordable housing or public transit. The reality of downloading and limited municipal budgets means that continuous trade-offs must be made between maintaining aging roads and water systems and social programs.

The FCM report (2012) concludes that, although recent federal support has addressed some of the infrastructure deficit created by decades of downloading and under-investment, the underlying fiscal imbalance remains, as does a $123-billion deficit. Real solutions require structural tax reform, changes to the funding tools available to municipalities. The renewed investment and cross governmental coordination that began during the 2008-09 recession, along with the federal commitment to a long-term infrastructure plan, indicates that communities can look forward to some stable funding (FCM 2012).

Despite increased federal support, until the underlying structural issues are addressed cities will continue to experience the 'chronic funding crunch' in light of competing priorities. The complex challenges of adapting to climate can be seen as compounding existing financial burdens. Specifically, when it comes to decision making to manage SLR, cost is a pivotal issue. Subsequent to the release of the 'Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use' (Ausenco Sandwell 2011) that recommends planning for 1 m of SLR by the year 2100, the Province commissioned a study to examine the matter of cost. The next section will outline the findings.

Cost of SLR Adaptation

A high level cost estimate of providing flood protection to meet predicted sea level rise by 2100 has been developed (Delcan 2012). The geographical scope includes affected shoreline reaches around Metro Vancouver. One flood protection option was chosen to estimate the cost of protecting each shoreline reach. The study area totals over 250 km. However, for the purpose of this report, only the information that pertains to the City of Vancouver will be cited. The areas identified as exposed to flood risk within the City due to sea level rise by 2100 are South Vancouver, Kitsilano and False Creek. As noted, there are currently no dikes within the City (with the exception of non-standard or 'orphaned' structures in South Vancouver).

Methodology **-** To determine the required protection design level, the methodology developed in the 'Sea Dike Guidelines' (Ausenco Sandwell 2011) was used. These guidelines combine predicted sea level rise with subsidence, maximum high tide level, storm surge, wave effects, local wind set-up and freeboard. The updated approach differs from the previous method used (based on criteria from the 1970s) and results in a much higher level of protection. The new approach was used to determine flood levels, which were then used to estimate the size of a potential flood protection option. For instance, in the case of a structural option such as a dike, the guidelines set the new crest level. Results for the potential new crest level for 2100 for the shoreline reaches in the City of Vancouver are shown in table 3. The table includes existing ground levels based on available GIS data.

Reach Name	Reach length (m)	Standard dike, non-standard dike or undike	Current Land Level (m GSC)	Designated Flood Level (m GSC)	Required crest level (m GSC)	Increased crest level for the year 2100 (m)
South Vancouver	3245	non-standard	4.0	4.5	6.2	2.2
South Vancouver	11325	undike	4.0	4.5	6.2	2.2
Kitsilano and English Bay	1280	undike	5	4.8	7.1	2.1
False Creek	7600	undike	3.5	4.8	6.5	3.0
Vancouver Burrard Inlet	8300	undike	4.0	4.8	6.7	2.7

Table 3: Potential 2100 Crest Levels (Delcan 2012)

Adaptation Options **-** The Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use Draft Policy (Ausenco Sandwell 2011) categorizes options into four groups – one group of structural options termed Protect, and three groups of non-structural options termed Accommodate, Retreat and Avoid. For the costing study however, options for managing flood risk were divided into two broad groups of options – structural and non-structural (Delcan 2012). To estimate the cost of flood protection, measures to achieve either structural or non-structural options were developed and are illustrated in figure 4.

Structural							Non-Structural				
Protect							Accommodate			Retreat	Avoid
Dikes			Floodwalls		Foreshore						
A. Widen footprint to land side	B. Widen footprint to water side	C. Special Structures	D. Permanent	E. Demountable	F. Breakwater / Barrier Islands	G. Coastal wetlands	H. Flood proofing	I. Secondary Dikes	J. Emergency preparedness and response	K. Managed Retreat	L. Planning and Development Controls

Figure 4: Flood Protection Options (Delcan 2012)

The report describes the above options and states that “General practice in flood management discourages the construction of new dikes to enable new development. However, new dike construction is considered for areas where sea level rise will create a new flood hazard in areas where development already exists” (Delcan 2012, 9). An option (see table 4) was selected for each shoreline reach and the associated cost estimate, in 2012 dollars, was calculated.

To meet current provincial safety standards, the cost estimate includes:

- Land acquisition
  - Based on agricultural, residential and commercial land values and property costs
- Engineering
  - Site investigation, geotechnical studies and design
- Geotechnical design

    - Based on new seismic standards
- Environmental design
    - Impact mitigation and compensation
- Relocation of utilities
- Pump station upgrades

It must be noted that the selected options do not necessarily reflect the preferences of the municipal government.

Reach Name	Selected Option	Estimated Cost (millions)
South Vancouver	Dike	68.47
South Vancouver	Dike	239.42
Kitsilano and English Bay	Dike	7.09
False Creek	Storm Surge Barrier	43.13
Vancouver Burrard Inlet	Flood proofing	Costs are incurred site by site by the private land owner
City of Vancouver Total		**358.11**

Table 4: Selected Adaptation Option and Estimated Cost (Delcan 2012)

Costs & Benefits of Protection

The costs estimate of $358.11 million is for the protection of areas at risk of flooding within the City of Vancouver based on selected structural options, namely dikes and a storm surge barrier for False Creek. The total estimated cost for the Metro Vancouver area as a whole is $9, 470 billion. It is noteworthy that the only areas for which non-structural options were selected are Mitchel Island, Tsawwassen Beach, Mud Bay and Vancouver Burrard Inlet (Delcan 2012). The Delcan report (2012) states that the costs should be balanced against the benefits of protecting infrastructure and uninterrupted economic activity. A cost benefit analysis based on USD $55 billion worth of vulnerable assets and 320,000 people exposed to coastal hazards in the CoV (Nicholls et al. 2008) could certainly justify a strategy of protection.

Cost Estimate Limitations

The first major limitation (the end of economic growth and the possibility of abrupt climate change and rapid SLR aside) of Delcan's reported cost estimate is that it is based on current SLR projections. As the rate of rise accelerates along with atmospheric GHG emissions these costs will have to be revised upwards. Additionally, the estimate only includes initial costs of construction and implementation for the selected protective measures. A World Bank report (2010) explores the potential costs for coastal sea dike construction from 2010 – 2050 in response to a range of sea level rise scenarios. The analysis cautions that, depending on the magnitude of SLR, maintenance costs will rise with time as the dike system expands. Despite anticipated escalating costs, when the negative socio-economic impacts associated with increasing coastal hazards are considered, all available analyses suggest that protection is a rational response in highly developed areas (World Bank 2010). Yet, the authors concede that protection is only rational under scenarios of great economic growth, whereas “Protection is much harder to justify if a no-economic growth scenario is considered” (Anthoff and others 2010, as cited by Nicholls et al. 2010, 10).

6 ADAPTATION OPTIONS THAT WORK WITH THE WATER

The first sections of this report described the ecological context of planning by outlining the concepts of ecological overshoot, uneconomic growth, peak oil and the anticipated impacts for local government. Additionally, the municipal chronic funding crunch was discussed along with the estimated cost of pursuing protective measures to address sea level rise for the currently un-diked City of Vancouver and for the Metro Vancouver area as a whole. While opting to protect highly developed coastal zones makes sense in the context of economic growth, this report has painted a picture of the future that will differ drastically from the past. In a scenario of economic contraction, where energy and resource availability is constrained and where prices are high and volatile, local governments will have to focus on maintaining basic services with further reduced revenue. Arguably, development as usual will not be feasible. Therefore, it is within this framing that alternatives to hard protective engineering solutions must be explored and considered.

Coastal Management Trends

Traditionally, developed coastal areas have been protected using hard structures. However, the increased awareness of escalating and unsustainable costs as well as negative effects, such as potential failure, erosion and sedimentation patterns, has led to a shift in focus towards 'soft' protection (e.g. beach nourishment, wetland restoration and creation) and retreat and accommodation strategies. Table 5 expands on adaptation options noted in previous sections and is an overview of available options to reduce hazard vulnerability in coastal zones. The options are not intended to be exhaustive but to illustrate the wide spectrum of possibilities (Nicholls et al., 2001).

Coastal Adaptation Options	
APPLICATION	**OPTIONS**
Protect	
⅄ Hard structural options	-dikes, levees, floodwalls -seawalls, revetments, bulkheads -groynes -detached breakwaters -floodgates and tidal barriers
⅄ Soft structural options	-saltwater intrusion barriers -periodic beach nourishment -dune restoration and creation
⅄ Indigenous options	-wetland restoration and creation -afforestation -wooden and stone walls
Accommodate	
⅄ Emergency planning	-early warning systems -evacuation systems
⅄ Hazard insurance	-limited technology required
⅄ Modification of land use and agricultural practice	-various technologies (e.g. Aquaculture, saline-resistant crops), depending on location and purpose
⅄ Modification of building styles and codes	-various technologies
⅄ Strict regulation of hazard zones	-limited technology required
⅄ Improved drainage	-increased diameter of pipes -increased pump capacity
⅄ Desalination	-desalination plants
Managed Retreat	
⅄ Increasing or establishing setback zones	-limited technology required
⅄ Relocating threatened buildings	-various technologies
⅄ Phased-out or no development in susceptible areas	-limited technology required
⅄ Presumed mobility, rolling easements	-limited technology required
⅄ Managed realignment	-various technologies, depending on location
⅄ Creating upland buffers	-limited technology required

Table 5: Coastal adaptation options (adapted from Nicholls et al. 2001).

This section documents a range of coastal adaptation approaches that embrace the water as it encroaches inland. The following are selected examples of accommodation, restriction of coastal development, and managed retreat strategies.

6.1 Accommodation

This approach allows continued use of coastal areas but does not attempt to prevent tidal inundation, erosion or flooding. The focus is on minimizing risk to people, buildings and infrastructure and developing strategies such as modifying building codes to so that structures are more resilient to flooding and emergency planning and preparedness (Titus 2011). Accommodation measures can also include liability reduction such as special covenants that indemnify governments from the consequences of natural hazards (Arlington 2012).

New Brunswick Coastal Protection Policy

The New Brunswick Department of Environment and Local Government produced a Coastal Areas Protection Policy for New Brunswick in 2002 in response to significant coastal development. Key policy aims are to reduce risks of storm surges and flooding events by adopting a coastal management approach based on sensitivity to impact. The coastal area has been divided into three sensitivity zones:

Zone A - the areas closest to the water known as the coastal lands core area. Due to high risk of damage from storm surges, few development activities are acceptable.

Zone B - this area extends 30 metres landward from the inland edge of Zone A to provide a further buffer. A slightly greater range of activities would be acceptable such as the construction of a new single-family residence and the repair, expansion or replacement of existing structures may be allowed.

Zone C - the areas beyond Zone B that form a transition from coastal to inland areas. The sensitivity to storm damage varies considerably depending primarily on topography, elevation and the erodibility of the land. Activities will be reviewed based on the susceptibility of the development to storm surges, and on impacts to the coastal ecosystem.

The Coastal Areas Protection Policy applies province-wide in both incorporated and unincorporated areas, and to both private and publicly owned land.

Photo 1: Lameque, N.B from the New Brunswick Coastal Areas Protection Policy

Town of Shediac – Sea-level Rise Zone

Shediac has enacted a zoning bylaw (2012) that establishes a 'sea level rise zone'. New buildings in the sea level rise zone must have a minimum elevation of 4.3 metres. The bylaw is intended to:

- Promote sustainable development based on the precautionary principle
- Anticipate, prevent and combat the causes of coastal environmental degradation
- Prevent serious and irreversible damage to the environment, as well as citizens and property
- Only allow developments that will be able to adapt to sea-level rise and storm surges in zones that risk flooding
- Establish minimum requirements to prevent environmental degradation (Town of Shediac, 2012).

Local governments should consider liability for approving building permits in areas subject to flooding and other natural hazards. By implementing a by-law that mandates coastal development setbacks, liability claims from property owners who suffer damage may be minimized (NRCan, 2012).

6.2 Managed Retreat or Relocation

Planned retreat or relocation inland allows the coastline to advance unimpeded. The process supports coastal wetland and intertidal habitat preservation. Over time as the shoreline migrates inland, buildings and other infrastructure are strategically demolished or relocated out of the hazardous zone. This approach is used where coastal protection along with maintenance is viewed as too expensive and potentially ineffective in the long run. The strategy of retreat can be coupled with other regulatory measures such as limiting the type of structures allowed in flood prone areas and relocation and/or property acquisition programs to compensate property owners (NOAA 2007). An official strategy of retreat manages expectations so that people make investments accordingly. Ideally, retreat requires a long lead-time to allow for the investments in buildings and infrastructure to endure for their useful lifetimes (Titus and Craghan 2009).

Anglo Tignish

Storm events have caused considerable shoreline loss in Anglo Tignish, Prince Edward Island. Anglo Tignish is a fishing community in western Prince Edward Island with a population of approximately 800 people (Wikipedia, 2013). For instance, on December 21, 2010, 8 metres of shoreline were lost in one storm event (Arlington 2012).
Due to continuous storm surge events, homes, lighthouses and barns have been moved inland to provide protection from storm damage as the cost of damage outweighs the cost of

relocation (Arlington 2012).

Photo 2: Exposed well due to storm surge erosion December 21, 2010 by D. Jardine.

Pacifica State Beach

The City of Pacifica in in San Mateo County, California and has a history of coastal flooding and erosion. Hard structural measures were used unsuccessfully for decades. In 1982 over 300 homes were damaged in a major flood. In the early 90s, a managed retreat strategy was chosen to improve steelhead habitat, reduce flood risk and preserve the beach. Vulnerable buildings had to be removed. The project cost much less than other proposed protective measures as it required less physical construction. The vulnerable homes and businesses were purchased and demolished. Dunes and four acres of beach along with an estuary were restored. The City partnered with the Pacifica Land Trust and the California Conservancy and worked to achieve public support. The project took a decade to complete. Political viability and success can also be attributed to how the City partnered to access the capital to purchase the vulnerable land outright (NOAA 2007).

New York State Post Sandy Plan

As reported in the New York Times on February 5, 2013, New York State Governor Andrew Cuomo has proposal to spend up to $400 million to purchase and raze damaged homes in the floodplains along the coastline. The plan envisions that the land would be turned into parks, bird sanctuaries, dunes or open beach to serve as buffer zones to future floods. Pending approval of the federal Department of Housing and Urban Development, the plan would minimize damage from rising seas and storms that are projected to occur more frequently and with greater intensity. Although not a new concept, the proposal is novel in its size and scope. Approximately 10,000 homes sit in the flood zone.

The proposal derives from recommendations of the NYS 2100 Commission, one of many panels formed after Hurricane Sandy to shore up resiliency of coastal communities in light of the tough lessons that have been learned. According to the New York Times, the proposal includes the following conditions:

- Participation is voluntary
- Participants would receive the pre-storm value of the house with a 5% bonus to relocate within the home county.
- Owners could receive up to $300,000 per home
- For those who opt to stay grants would be available to help with flood-proofing, which involves building at least 2 feet above the projected flood level, which will mean building 15 feet or higher above ground level.

San Francisco Ocean Beach Master Plan

The plan aims to proactively adapt San Francisco's Ocean Beach, 3.5 miles of rugged coast from Cliff House to Fort Funston, to climate-change according to a sustainable long-term vision. The beach is a national park, a popular urban public space and the site of a major infrastructure complex. Neighbourhoods, roads, parks and infrastructure have been built up along the coast. 10, 000 feet (3048 m) of seawalls and other protective structures have been installed but dramatic erosion during storms renders the protection insufficient (King 2012). Climate models indicated that the coast will be subjected to increasingly frequent and severe storm surges, which will be exacerbated by approximately 1.3 m of projected sea level rise by 2100 (State of California 2010). To address the complex challenges posed by severe erosion, jurisdictional issues, diverse stakeholders and accelerating sea level rise, the plan includes six key moves, organized by geographical shoreline reach, to be implemented incrementally over decades (King 2012).

South Reach

1. Reroute the Great Highway behind the zoo via Sloat and Skyline Boulevards
    - A section of the highway will be replaced by a coastal trail
2. Introduce a multipurpose coastal protection/restoration/access system
    - The highway and parking lots will be dismantled incrementally to allow erosion to proceed inland
    - The existing wastewater tunnel will be protected by a low hard structure, a berm or revetment and sand

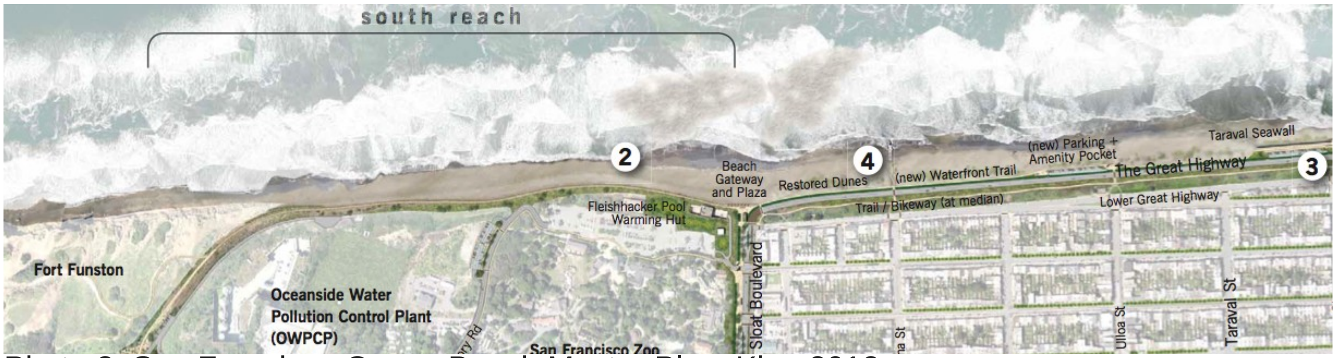

Photo 3: San Francisco Ocean Beach Master Plan, King 2012

Middle Reach

3. Reduce the width of the Great Highway to provide amenities and facilitate managed retreat
    - Narrow the highway
    - Introduce a promenade and amenities
    - Allow dunes to migrate inland over the road

4. Restore the dunes along the middle reach
    - Nourish the beach with sand
    - Restore native dunes

North Reach

5. Create a better connection between Golden gate Park and Ocean Beach
    - Improve pedestrian and bike access
    - Introduce permeable paving, amenities and vegetation
    - Retain events capacity and historic character

6. Introduce bicycle and pedestrian improvements north of Balboa Street
    - Narrow the highway
    - Introduce a separated bikeway with connections to Lands End and beyond

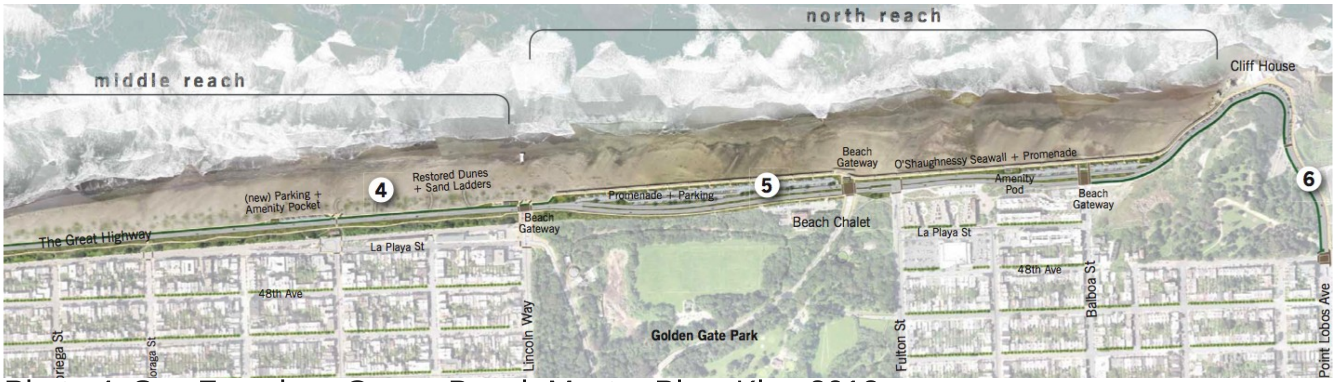

Photo 4: San Francisco Ocean Beach Master Plan, King 2012

The estimated cost of implementation is $353, 623, 794 spread over the next forty years. These costs are measured against the considerable benefits of avoiding emergency coastal protection, maintaining recreational uses and improving ecological and habitat functions. The plan will undergo a revision by 2030 and currently does not include private property. However, it is noted that the gradual acquisition of private property through rolling easements or other means needs to be considered (King 2012).

6.2.1 Rolling Easements

Rolling easements are regulatory mechanisms or interests in land that do not limit land use but prohibit protection measures. They can be placed along an entire shoreline so that as the ocean rises, the easement 'rolls' landward (NOAA 2012). Land title remains with owners of inland lots until the land is encroached upon by the sea, which may take decades. All the while, public access to the shoreline is maintained (Strack 2011, Titus and Craghan 2009). Unlike setbacks, there is no restriction on land use. A landowner can build with the understanding that protective works are prohibited and that at some point structures will have to be relocated (NOAA 2012). Rolling easements "...merely warn the owner that someday, environmental conditions may render the property useless, and that if this occurs, the state will not allow the owner to protect her investment at the expense of the public" (Titus 1998, 1389). As owners have decades of lead-time, property values are reduced by one percent or less (Titus 1998). For more information on cost advantages of rolling easements see Titus (1998).

Rolling easements provide an alternative to prohibiting all development in a hazardous area. Therefore, this strategy is appropriate for areas where preventing development is not feasible and where coastal protection is deemed unsustainable (Titus and Craghan 2009). All in all, rolling easements are an effective way to implement managed retreat policies and can be combined with other approaches such as setbacks and building restrictions. Needless to say, implementing and enforcing easements in highly developed communities would require changes to legislation to establish the process, the rights and the decision making authority (Strack 2011, NOAA 2012).

South Carolina's Rolling Easements

In 1988 the South Carolina legislature passed piece of legislation to manage coastal erosion and sea level rise by establishing a setback of 40 times the annual rate of erosion. The increased setback rendered some properties undevelopable and the case of Lucas vs. South Carolina Coastal Council went to trial. The state had to compensate Lucas for the lost use of his property (NOAA 2012).

The decision led to a legislative amendment in 1990 to establish a rolling easement on any lot seaward of the setback line to avoid further legal action. Effectively, lots on the ocean site of the setback line can be developed but no hard structures can be used. If buildings are damaged during a storm they can be repaired but if the lot is submerged during high tide rebuilding or repair is no longer permitted (Titus 1998 as cited by NOAA 2012).

7 ADAPTATION EVALUATION CRITERIA

Traditionally, policies to preserve existing development patterns using structural protection have by and large been based on a calculation of the benefits of avoiding damages and loss of land compared to the costs of protection***.*** Cost benefit analyses have many limitations and cannot capture the implications of a rapidly changing climate where the risk landscape is constantly evolving. All things considered, it is important that coastal communities ensure that adaptation choices do not exacerbate existing vulnerability. The final question that this report seeks to answer is: how can adaptation options be evaluated to distinguish the adaptive from the maladaptive? The IPCC Third Assessment Report defined maladaptation as “an adaptation that does not succeed in reducing vulnerability but increases it instead (IPCC 2001, 990). Barnett and O'Neill (2010) build on this definition and describe maladaptation as:

> *action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors or social groups*[1]

The authors assert that strategies to address climate changes such as sea level rise, are

[1] As stated in the introductory section, further to this definition, maladaptation also occurs when an action taken to avoid or reduce vulnerability to climate change results in increased vulnerability to the adapted entity itself.

maladaptive relative to alternatives if they:

- Increase emissions of greenhouse gases (GHGs)
- Disproportionately burden the most vulnerable
- Have high opportunity costs
- Reduce incentives to adapt
- Set paths that limit the choices available to future generations

In this section, these criteria, or pathways to maladaptation, will be used to evaluate the hard engineering protection option as opposed to alternatives that work with natural processes such as accommodation and retreat.

Increasing GHG emissions

This first type of maladaptation describes cases in which hard protective works result in increased energy use. According to Barnett and O'Neill (2010), the problem with energy-intensive adaptation actions is that, while they address one aspect of climate change, they contribute to positive feedback by increasing GHG emissions, "thereby increasing the likelihood that further adaptation to climate change will be required in the future" (2). For instance, should the City of Vancouver proceed with constructing dikes and a storm surge barrier, the initial construction, along with maintenance and upgrades over time, will require large energy inputs. A study of energy requirements and GHG emissions associated with proposed protective measures would enable evaluation against this criterion and would complement the previously discussed Delcan study (2012) estimating monetary costs of protection.

Among the components included in estimating the cost of dike construction, the Delcan report documents the volume of earth fill required for a typical section of dike. An example for the construction of a section of dike in South Vancouver is provided, which would require 16.78m^3/m of earth fill too protect the area from a 1 m rise in sea level. The dike would be 6.16m high and 14.6m wide. Additionally, 0.5m of rip rap (rock or concrete to prevent erosion) would be required along the water edge of the dike at 2.35m^3/m.

The energy requirements and associated emissions should be analysed for excavating, processing, transporting and installing all necessary materials, as well as for site preparation and surface restoration. Removing the current ground cover and repaving bicycle and pedestrian pathways, along with possible realignment of existing roads, will undoubtedly demand large amounts of energy and produce significant GHG emissions. For instance, cement production is a highly energy-intensive process where each tonne produced releases approximately 1 tonne of CO_2 (Worrell et al. 2001 as cited by Rehan and Mehdi 2005). Moreover, these CO_2 emissions will conflict with the City's Greenest City 2020 Action Plan, which aims to eliminate dependence of fossil fuels and reduce community-based GHG emissions by 33% from 2007 levels (City of Vancouver 2012c).

Disproportionately burdening the most vulnerable

If an adaptation action meets the needs of one sector or population and simultaneously increases the vulnerability of other socio-economically marginalized groups, that action is deemed maladaptive (Barnett and O'Neill 2010). This begs the question of whether or not the protect approach will adversely impact some social groups more than others. Socially just adaptation requires a local understanding of which groups are most vulnerable, involving affected communities in planning, and developing responses that build adaptive capacity (Brisley et al. 2012). For instance, in the event that a dike system fails or is overtopped, some people have less capacity to manage during and after a flood event. Vulnerability and impacts depend not only on physical hazards but also on human factors such as socio-economic status and health. Nixon (2008) conducted a study of human vulnerability to sea level rise in the Metro Vancouver area for the year 2100. The study looked at indicators of vulnerability such as low income, recent immigration and English as a second language. Five areas received high scores for both socio-economic vulnerability and exposure to coastal hazards, being northeast Vancouver, downtown Vancouver, southeast Vancouver, downtown Richmond and the City of North Vancouver. In light of this research, cities need locally tailored socio-economic vulnerability studies and strategies that identify people who may need more help when it comes to preparing for, coping with and recovering from a major flood event.

Socio-economic implications of dikes also include loss of housing due to land acquisition and loss of community amenities along the foreshore (Arlington 2012). Additionally, the escalating costs of upgrading and maintaining protection over time could translate into a tax burden that disproportionately impacts low-income households. Opting for protection may be less socially disruptive in the short term. In the long term however, a system of coastal protection may be more disruptive – particularly if it fails or cannot be sustained (Titus 2009).

High Opportunity Costs

An approach can be maladaptive if the social, economic or ecological costs are high compared to mutually exclusive viable alternatives (Barnett and O'Neill 2010). Regarding social costs, an assessment of how building dikes will affect socio-economically marginalized populations is beyond the scope of this report. However, with the common public good in mind, BTAworks (2011) analysed what types of land uses will be affected by various SLR scenarios within the City of Vancouver. The authors found that historic areas, public spaces, agricultural and industrial lands become disproportionately affected. This finding highlights the need for long term planning to ensure that areas outside of the floodplain are set aside for these uses, as they will be integral to the resilience of future localized economies. The report alludes to this by stating “the importance of these types of land may indeed increase as increasing fuel costs stimulate local manufacturing, distribution, and repair industries as well as food production and processing” (BTAworks 2011, 15).

The economic cost of hard coastal protection estimated by Delcan (2012) can be seen as a high opportunity cost in that funding and resources are diverted away from alternatives. While one approach is taken, the window of opportunity to effectively plan and implement alternative strategies may be lost. For instance, in the interim, the opportunity to set land aside for colonization by coastal ecosystems, or for short term uses with the condition that structures will be removed when the sea level reaches a certain height, is lost (Abel et al. 2011). As development continues, the value of assets at risk increases, as does the pressure to build structural defences. According to Strack (2011) hard defences have been well tested and have proven, at best, to be temporary and expensive measures. If storm conditions exceed the design profile of a dike system, the outcome can be devastating. Hurricane Katrina resulted in more than 1000 deaths in 2005 (Knabb et al., 2005 as cited by Titus 2009). Post Katrina, approximately $10 billion has been spent to upgrade the defences only to achieve the design standard that existed before the disaster. It is estimated that an additional $50 billion is required to achieve a higher level of protection. Moreover, as risks continually increase with a changing climate, protective measures must be constantly monitored and reinforced to maintain an acceptable level of risk (Nicholls et al. 2010).

The ecological costs of structural defences include coastal habitat ‘squeeze’ where intertidal zones and beaches are eventually eliminated as the eroding shore reaches the dike (Titus 2011). Without shoreline armouring, sediment transport remains undisturbed and tidal habitat can migrate naturally. Additionally, as tidal ecosystems are degraded, ecosystem functions such as providing flood control, acting as a storm surge buffer, protecting water quality and providing habitat for numerous aquatic plants and animals is threatened (Titus 2009).

Reduce Incentive to Adapt

Adaptation actions that reduce future incentives to adapt are considered maladaptive (Barnett and O’Neill 2010). Coastal development and protective measures are mutually reinforcing in part because the cost of protection is less than the value of land and structures and also because an unsafe area is perceived as safe (Titus 2011). Franck (2009) discusses how the implementation of protective measures changes the economic dynamics of a community. In effect, defences lead to a false sense of safety, increasing economic development in the short term, but causing larger economic losses in the long term. Residents and investors often perceive risk to be eliminated by dikes when in reality risk cannot be reduced to zero. The result is that the risk of flooding is not factored into land use development decisions and continuous investments are made. A reassessment of the protection approach may only occur once a large storm surge causes the system to fail and a large amount of capital is lost. Therefore, protecting low-lying communities may increase long-term exposure where a major flood event results in greater losses than would have occurred in the absence of protection (Kydland and Prescott as cited by Franck 2009).

As both urbanization and climate change accelerate, it may be necessary to move away from hard-engineering solutions towards preventing new development, incremental retreat and non-structural solutions such as flood warning systems and evacuation planning (Jha et al. 2012).

Path Dependency

According to Barnett and O'Neill (2010) "a major issue with large infrastructure developments is the way they commit capital and institutions to trajectories that are difficult to change in the future" (212). Due to the increasing uncertainty of future socio-economic and climatic conditions, effective adaptation requires flexible responses. Large expensive engineering projects can reduce flexibility to respond to unexpected changes. Put another way, investing heavily in one option decreases the future diversity of available adaptation possibilities (ibid). If protection is chosen over alternatives, the flexibility to later adopt an avoidance or retreat strategy is impaired. On the other hand, planning for retreat or avoidance does not limit the ability to establish structural measures in the future (Titus 2009). Nevertheless, the political pressure to ensure assets are safeguarded will likely preclude deviating from traditional strategies of structural protection. That said, establishing a rolling easement policy could facilitate retreat and preserve the right of future generations to choose whichever strategy they see fit (Titus 2011). Given irreducible uncertainty with regards to future circumstances, it seems clear that the decision to sink enormous resources into 'holding the line' today will surely limit the options available in the future.

In summary, adaptation strategies may serve to increase overall vulnerability if they increase emissions of GHGs, disproportionately burden the most vulnerable, have high opportunity coasts, reduce incentives to adapt or establish paths that reduce the range of choices available to generations. These criteria provide a way to evaluate projects that are intended to be adaptive in the long run (Barnett and O'Neill 2010).

8 CONCLUSIONS

This report attempts to respond to three questions, the first of which is, in this era of rapidly declining energy and natural capital availability, will governments be able to protect development as usual in the face of accelerating sea level rise? Answering this question begins with recognizing that humanity has been in a state of ecological overshoot since the 80s (GFN 2011). Nature's budget and regenerative capacity are quickly being drawn down, and waste sinks are overflowing. Ecological economists explain that once an economy overshoots the carrying capacity of the ecosphere that contains it, we have reached the point where the long-term costs of additional growth outweigh (usually) short-term benefits. A growth oriented economy results in uneconomic growth that is "stupid in the short run and impossible to maintain in the long run" (Daly 2005, 100). The consequences of growth, such as accelerating sea level rise, will overwhelm any gains of further growth and inevitably the economy will contract.

The entire phenomenon of continuous economic growth is based on abundant and cheap supplies of energy. Peak oil, being the point of maximum extraction followed by continual decline, illustrates fast approaching limits to growth in the absence of sustainable substitutes. Despite debate about precisely how declining supplies of fossil fuel relative to demand will play out over time, it is generally understood that prices will continue to increase. Higher oil prices trickle throughout the economy causing havoc such as supply chain disruptions and escalating food costs. Furthermore, there are no viable substitutes for conventional oil at current rates of consumption. Evidently, the age of cheap oil and global economic growth is drawing to a close. Foresight dictates that planning for a post peak scenario is imperative.

As global markets are highly interconnected, the end of growth at the macro level means that economies will be disrupted across all scales. Although some areas may continue to experience continued growth, the global economy as a whole will contract. For local governments, consequences will take the form of energy supply shortages, high and volatile energy prices and higher prices for everything. In a shrinking economy, revenues will decline and a larger percentage of smaller budgets will be spent on energy, which will strain the ability to maintain basic services and critical infrastructure. Simultaneously, citizens will be struggling to make ends meet and the demand for services and social supports will increase. By this scenario, governments will not likely have the capacity to fund or operate highly resource and energy intensive engineering projects such as dike systems.

It follows that, with the end of economic growth, governments will not be able to protect development as usual in the face of accelerating sea level rise. Moreover, the evolving scientific understanding of the pace and scale of climate change adds another layer of complexity to the predicament. The challenge of maintaining core city operations amidst considerably reduced revenue, high energy prices and energy scarcity will be compounded by the complex problems associated with a 2-4 ºC warmer world by the end of the century. As atmospheric GHG concentrations rise unabated, critical tipping points may be crossed, which could result in rapid sea level rise over and above the upper bounds of current projections. Currently, the BC provincial government recommendation is to plan for 1m of sea level rise by 2100. As new global and regional projections become available, these numbers will likely be adjusted upwards. The high level cost estimate for the City of Vancouver to adapt by building dikes and installing a storm surge barrier is over $358 million. This does not include maintenance or how much the costs will increase as sea levels exceed 1m. Depending on the magnitude of SLR, costs of construction, continual upgrades and maintenance could very well be unsustainable in the long term even if economic growth were to continue. A protection strategy is not a well-reasoned plan of action if a no growth scenario is considered.

The second question addressed in this report is, given projected constraints on energy availability and prohibitive costs, what are the alternatives to hard protective structures? Arguably, in a scenario of economic contraction, local governments, as well as higher levels of government, will have to cut any and all projects deemed non-essential to maintain necessary services. Escalating and unsustainable costs, negative ecological effects and potential failure of structural protection will likely result in more cities turning away from traditional engineering solutions in search of alternatives. Examples of accommodation and managed retreat strategies, along with rolling easements that can facilitate retreat, were presented. To date these cases are few and far between. For the most part they have only been implemented in small communities or rural areas where the protection approach has failed. The proposed post Hurricane Sandy New York State Plan may be the one example, should it proceed, of planned retreat in a highly developed area. In light of the difficult lessons learned from the recent hurricane, it will be interesting to see if and how the plan moves forward. The legislative changes made in South Carolina and the establishment of a rolling easement also provide a model for other cities to follow. There is no doubt that land use changes of such a magnitude in any city with an extensively built up coast will be highly contentious and difficult to achieve.

The final section of this report offers criteria by which to evaluate adaptation options to determine if they will actually be adaptive in the long run. The criteria were used to assess the hard engineering protection option. Although further research is required to determine GHG emissions and socio-economic impacts on vulnerable populations, it can be argued that the such a strategy is maladaptive on all five criteria, and would therefore serve to increase overall vulnerability. These five 'pathways to maladaptation' provide a basis for evaluation that should be thoroughly examined before committing resources to any major adaptation project.

In light of these findings, it is clear that decision-making at all levels of government should consider reviewing and updating current coastal land use planning to include plausible scenarios that reflect the upper bounds of sea level rise projections. Sound planning in this era of peak oil and potential non-linear, rapid climate change should proceed according to the precautionary principle. This approach applies to sea level rise and exacerbated flood risk where, in the absence of scientific consensus, if an action or policy is associated with a risk of causing harm, authorities have a responsibility to protect the public. This report argues that current planning underestimates the likely pace and scale of global climate change and sea level rise. Plans also assume economic growth along with energy and resource availability. Adaptation that will be sustained in the long term necessitates creating public awareness of rapid climate change and limits to economic growth along with the impossibility of maintaining development as usual.

References

Abel, Nick, Russell Gorddard, Ben Harman, Anne Leitch, Jennifer Langridge, Anthony Ryan, and Sonja Heyenga. 2011. Sea level rise, coastal development and planned retreat: Analytical framework, governance principles and an Australian case study. *Environmental Science and Policy* 14 (3): 279-88.

Allison, I., N.L. Bindoff, R.A. Bindschadler, P.M. Cox, N. de Noblet, M.H. England, J.E. Francis, N. Gruber, A.M. Haywood, D.J. Karoly, G. Kaser, C. Le Quéré, T.M. Lenton, M.E. Mann, B.I. McNeil, A.J. Pitman, S. Rahmstorf, E. Rignot, H.J. Schellnhuber, S.H. Schneider, S.C. Sherwood, R.C.J. Somerville, K. Steffen, E.J. Steig, M. Visbeck, A.J. Weaver. 2009. The Copenhagen Diagnosis. Updating the World on the Latest Climate Science. The University of New South Wales Climate Change Research Centre (CCRC), Sydney, Australia: 60.

Allison, Ian. 2011. The copenhagen diagnosis: Updating the world on the latest climate science. Burlington, MA: Elsevier

Anderson, Kevin, and Alice Bows. 2008. Reframing the climate change challenge in light of post- 2000 emission trends. *Philosophical Transactions. Series A, Mathematical, Physical, and Engineering Sciences* 366 (1882): 3863-82.

Anthoff, David, Robert J. Nicholls, and Richard S. J. Tol. 2010. The economic impact of substantial sea-level rise. *Mitigation and Adaptation Strategies for Global Change* 15 (4): 321-35

Arlington Group Planning + Architecture Inc. 2012. Draft Sea level rise Adaptation Primer. BC Ministry of Environment.

Barnett, Jon, and Saffron O'Neill. 2010. Maladaptation. *Global Environmental Change* 20 (2): 211-3.

B.C. Ministry of Environment. January 2011. Climate Change Adaption Guidelines for Sea Dikes and Coastal Flood Hazard Land Use. Accessed January 1, 2013. www.env.gov.bc.ca/wsd/public_safety/flood/pdfs_word/draft_policy_rev.pdf

Becklumb, Penny. 2010. Climate Change and Forced Migration: Canada's Role. Library of Parliment, Industry, Infrastructure and Resource Division: 1-9.

Bornhold, Brian D., British Columbia. Climate Change Branch, and British Columbia Government EBook Collection. 2008. Projected sea level changes for British Columbia in the 21st century. Victoria, B.C: Climate Change Branch.

Brisley, R., Welstead, J., Hindle, R., & Paavola, J. 2012. Socially just adaptation to climate change. York, United Kingdom: Joseph Rowntree Foundation. Retrieved from CAKE:

Burton, Ian. 1996. The growth of adaptation capacity: practice and policy. In: Smith, J.B.; Bhatti, N.; Nenzhulin, GV.; Benioff, R.; Campos, M.; Jallow, B.; Rijsberman, F.; Bydyko, M.I., and Dixon, R.K. (eds.), *Adapting to Climate Change: An International Perspective*. Springer-Verlag, New Yor, NY, pp. 55-67.

Burton, Ian. 1997. Vulnerability and adaptive response in the context of climate and climate change. *Climatic Change* 36 (1): 185-96.

Church, J. A., White, N. J., Konikow, L. F., Domingues, C.M., Cogley, J. G., Rignot, E., Gregory, J. M., et al. 2011.Revisiting the Earth's sea-level and energy budgets from1961 to 2008. Geophysical Research Letters, 38(18), L18601.

City of Vancouver. 2012a. Climate Adaptation Strategy.

City of Vancouver. 2012b. Flood-proofing Policy Review and Interim Measures.

City of Vancouver. 2012c. Greenest City 2020 Action Plan 2011-2012 Implementation Update.

Cities Climate Leadership Group and Connecting Delta Cities. 2010. Connecting Delta Cities: sharing knowledge and working on adaptation to climate change.

Convey, P., ACCE Consortium (incl Bentley M.J.), R. Bindschadler, G. di Prisco, E. Fahrbach, J. Gutt, D. A. Hodgson, P. A. Mayewski, C. P. Summerhayes, and J. Turner. 2009. *Antarctic climate change and the environment*. UK: Cambridge University Press.

Delta Commission. 2008. Working together with water: summary and conclusions. Accessed February 10, 2013. www.deltacommissie.com/en/advies

Franck, Travis. 2009. Coastal adaptation and economic tipping points. *Management of Environmental Quality* 20 (4): 434.

Fraser Basin Council and Arlington Group Planning & Architecture Inc. 2008. Flood Hazard Area Land Use Management: Review of Flood Hazard Area Land Use Management in B.C. http://www.fraserbasin.bc.ca/publications/documents/08_Flood.pdf

Glikson, Andrew. The Atmosphere Is Not Waiting For Human Decision. *Counter Currents*, November 30, 2009. Accessed March 6, 2013. http://www.countercurrents.org/glikson301109.htm

Glikson, Andrew. On tree rings, CO2 levels and the Pliocene. *The Conversation*, July 12, 2012. Accessed February 5, 2013. http://theconversation.edu.au/on-tree-rings-co2-levels-and-the-pliocene-8474

Green Shores Project. 2009. Climate Change and Coastal Shores in British Columbia. Accessed December 15, 2012. www.greenshores.ca/sites/greenshores/documents/media/142.pdf.

Goldberg, Edward D., Intergovernmental Oceanographic Commission, and Unesco. 1994. *Coastal zone space: Prelude to conflict?* Paris: Unesco Pub.

Greer, John Michael. 2008. *The long descent: A user's guide to the end of the industrial age*. Gabriola Island, B.C: New Society Publishers.

Gregory J. and Huybrechts, P. 2006. Ice-sheet contributions to future sea level change, Philosophical Transactions of the Royal Society A, 1709-1731.

Heinberg, R., and Lerch, D. 2008. "The Real New Deal: Energy Scarcity and the Path to Energy, Economic, and Environmental Recovery." *Post Carbon Institute*. Accessed December 7, 2011. www.postcarbon.org/files/real-new-deal.pdf

Hirsch, Robert. 2005. "Peaking of World Oil Production: Impacts, Mitigation, & Risk Management." Accessed February 1, 2013. www.netl.doe.gov/energy-analyses/pubs/Oil_Peaking_NETL.pdf

Hubbert, M. 1956. “Nuclear Energy and Fossil Fuels.” *Drilling and Production Practice*. Accessed January 29, 2013. www.hubbertpeak.com/hubbert/1956/1956.pdf

International Energy Agency. 2010. “World Energy Outlook 2010: Executive Summary.” *OECD*. Accessed February 1, 2013. http://www.iea.org/Textbase/npsum/weo2010sum.pdf

International Risk Governance Council. 2010. Sea Level Rise and its Implications. Accessed February 13, 2013. www.irgc.org/IMG/pdf/Emerging_risks_Sea_Level_Rise.pdf

IPCC, 2007: Summary for Policymakers. In: 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., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC. 2013. Frequently Asked Question 10.2: How Likely are Major or Abrupt Climate Changes such as Loss of Ice Sheets or Changes in Global Ocean Circulation? Accessed February 1, 2013. https://www.ipcc.unibe.ch/publications/wg1-ar4/faq/wg1_faq-10.2.html

Jha, Abhas Kumar, Robin Bloch, Jessica Lamond, and Open Knowledge Repository. 2012. *Cities and flooding: A guide to integrated urban flood risk management for the 21st century*. Washington, D.C: World Bank.

Kaufmann, John. Local Government in a Time of Peak Oil and Climate Change, in *The post carbon reader: Managing the 21st century's sustainability crises,* Heinberg, Richard, and Daniel Lerch. 2010. Berkeley, Calif: Univ. of California Pr. [distributor].

Kerr, R. A. 2012. Experts agree global warming is melting the world rapidly. *Science* 338 (6111): 1138-.

King, P. G. May 2012 San Francisco Ocean Beach Master Plan. Accessed February 10, 2012. http://www.spur.org/ocean-beach

Klein, Richard J. T., Robert J. Nicholls, and Nobuo Mimura. 1999. Coastal adaptation to climate change: Can the IPCC technical guidelines be applied? *Mitigation and Adaptation Strategies for Global Change* 4 (3): 239-52.

Knabb, R.D., J.R. Rhome, and D.P. Brown, 2005: Tropical Cyclone Report: Hurricane Katrina, 23-30 August 2005. National Hurricane Center, Miami, FL, 43 pp. http://www.nhc.noaa.gov/pdf/TCR-AL122005_Katrina.pdf

Kunstler, James Howard. 2005. *The long emergency: Surviving the converging catastrophes of the twenty-first century*. New York: Atlantic Monthly Press.
Kydland, Finn E., and Edward C. Prescott. 1977. Rules rather than discretion: The inconsistency of optimal plans. *The Journal of Political Economy* 85 (3): 473-91.

Lerch, Daniel. 2007. *Post carbon cities: Planning for energy and climate uncertainty : A guidebook on peak oil and global warming for local governments*. Sebastopol, Calif: Post Carbon Press.

Lerch, D. 2010. “Making Sense of Peak Oil and Energy Uncertainty”. This publication is an excerpted chapter from *The Post Carbon Reader: Managing the 21st Century’s Sustainability Crises,* Richard Heinberg and Daniel Lerch, eds. Healdsburg, CA: Watershed Media.

Malthus, T. R. 2001. *An essay on the principle of population*. London: Electric Book Co.

McGranahan, G., Balk, D., and Anderson B. 2007. The rising tide: Assessing the risks of climate change and human settlements in low elevation coastal zones. *Environment & Urbanization* 19 (1): 17-37.

Meadows, Donella H., and Club of Rome. 1974. *The limits to growth: A report for the club of rome's project on the predicament of mankind*. New York: Universe Books.

Meadows, Donella H., Jørgen Randers, and Dennis L. Meadows. 2004. *Limits to growth: The 30-year update*. White River Junction, Vt: Chelsea Green Pub. Co.

Mill, John Stuart. 2001. *The principles of political economy*. Kitchener, Ont: Batoche.

Milne, Glenn A., W. Roland Gehrels, Chris W. Hughes, and Mark E. Tamisiea. 2009. *Identifying the causes of sea-level change*. UK: Macmillan.

Neil Adger, W., Nigel W. Arnell, and Emma L. Tompkins. 2005. Successful adaptation to climate change across scales. *Global Environmental Change* 15 (2): 77-86.

National Oceanic & Atmospheric Administration. Trends in Atmospheric Carbon Dioxide. Accessed February 15, 2013. http://www.esrl.noaa.gov/gmd/ccgg/trends/

Natural Resources Canada's Regional Adaptation Collaborative. 2012. Climate Change Vulnerability Assessment: Souris and Souris West Prince Edward Island. Accessed February 5. 2-13. www.atlanticadaptation.ca/erosion

Nicholls, Robert J., and Earle N. Buckley. 2001. Technological options for adaptation to climate change in coastal zones. *Journal of Coastal Research* 17 (3): 531-43

Nicholls, R. J., et al. 2008. Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes: Exposure Estimates, *OECD Environment Working Papers*, No. 1, OECD Publishing.

Nicholls, R.; Brown, S.; Hinkel, J. Economics of Coastal Zone Adaptation. October 2010. The World Bank, Washington DC, USA. Discussion Paper 10, 62 pp.

Nixon, E. 2008. Human Vulnerability and Climate Change: An Assessment of Greater Vancouver's Human Vulnerability to Sea Level Rise in 2100, in Proceedings of the Canadian Hydrographic Conference and national Surveyors Conference, 2008.

NOAA. 2007. Managed Retreat Strategies: Case studies. US Department of Commerce. Accessed February 05, 2013. http://coastalmanagement.noaa.gov/initiatives/shoreline_ppr_retreat.html

NOAA. 2012. Erosion Control Easements: Case studies. US Department of Commerce. Accessed February 05, 2013. http://coastalmanagement.noaa.gov/initiatives/shoreline_ppr_easements.html#1

Orlov, Dmitry. September 2010. "Peak Oil is History." Accessed December 1, 2012. http://www.culturechange.org/cms/content/view/674/66/

Price, D. 1995. Energy and Human Evolution. *Population and environment: A Journal of Interdisciplinary Studies* 16(4): 301-319.

Rahmstorf, Stefan. 2007. A semi-empirical approach to projecting future sea-level rise. *Science (New York, N.Y.)* 315 (5810): 368-70.

Rahmstorf, M. Perrette, and M. Vermeer, "Testing the robustness of semi-empirical sea level projections", *Climate Dynamics*, vol. 39, pp. 861-875, 2012.

Rehan, R., and M. Nehdi. 2005. Carbon dioxide emissions and climate change: Policy implications for the cement industry. *Environmental Science and Policy* 8 (2): 105-14.

Rignot, I. Velicogna, M. R. van den Broeke, A. Monaghan, and J. T. M. Lenaerts. 2011. Acceleration of the contribution of the greenland and antarctic ice sheets to sea level rise. *Geophysical Research Letters* 38 (5).

Rubin, Jeff. 2009. *Why your world is about to get a whole lot smaller: Oil and the end of globalizaiton*. USA: Random House Canada.

Shaw, J., and Geological Survey of Canada. 1998. Sensitivity of the coasts of Canada to sea-level rise. Ottawa: Natural Resources Canada, Geological Survey of Canada.

Shrubsole, Dan, and Canadian Water Resources Association. 2004. Canadian perspectives on integrated water resources management. Cambridge, Ont: Canadian Water Resources Association.

State of California. 2010. Sea-Level Rise Interim Guidance Document. Developed by the Sea-Level Rise Task Force of the Coastal and Ocean Working Group of the California Climate Action Team.

Strack, Mick. 2011. Preparing for the Invasion: Retreat from the Coast. Proceedings of the Surveying & Spatial Sciences Biennial Conference, Wellington, New Zealand, 21-25 November 2011

The Essex Wildlife Trusts. 2010. Abbotts Hall Farm. Accessed. February 3, 2013. www.essexwt.org.uk/visitor_centres__nature_reserves/abbotts_hall_farm/

Titus, James. 1998. Rising Seas, Coastal Erosion, and the Takings Clause: How to Save Wetlands and Beaches Without Hurting Property Owners. *Maryland Law Review*. 57: 1279-1399.

Titus, G., James. 2009. *Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region*. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [James G. Titus (Coordinating Lead Author), K. Eric Anderson, Donald R. Cahoon, Dean B. Gesch, Stephen K. Gill, Benjamin T. Gutierrez, E. Robert Thieler, and S. Jeffress Williams (Lead Authors)]. U.S. Environmental Protection Agency, Washington D.C., USA, 320 pp.

Titus, J.G. and M. Craghan, 2009: Shore protection and retreat. In: *Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region*. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [J.G. Titus (coordinating lead author), K.E. Anderson, D.R. Cahoon, D.B. Gesch, S.K. Gill, B.T. Gutierrez, E.R. Thieler, and S.J. Williams (lead authors)]. U.S. Environmental Protection Agency, Washington DC, pp. 87-104.

Town of Shediac Beaubassin Planning Commission. January 30, 2012. Zoning By-law # Z-11-44.
Parris, A., P. Bromirski, V. Burkett, D. Cayan, M. Culver, J. Hall, R. Horton, K. Knuuti, R. Moss,

J. Obeysekera, A. Sallenger, and J. Weiss. 2012. Global Sea Level Rise Scenarios for the US National Climate Assessment. NOAA Tech Memo OAR CPO-1. 37 pp.

Pfeffer, W. T., J. T. Harper, and S. O'Neel. 2008. Kinematic constraints on glacier contributions to 21st-century sea-level rise. *Science* 321 (5894): 1340-3.

Rees, W.E. 2010. Resilience Thinking. In Heinberg, R and D. Lerch, eds. 2010. *The Post Carbon Reader: Managing the 21st Century's Sustainability Crises* (Published by Watershed Media for the Post Carbon Institute, Santa Rosa, CA).

Thomson, Richard E., Brian D. Bornhold, Stéphane Mazzotti, Institute of Ocean Sciences, Patricia Bay, British Columbia. Ministry of Environment, Canada. Dept. of Fisheries and Oceans, and British Columbia Government EBook Collection. 2008. An examination of the factors affecting relative and absolute sea level in coastal british columbia. Vol. 260. Sidney, B.C: Institute of Ocean Sciences, Fisheries and Oceans Canada.

UK Environment Agency. 2009. Flooding in England: A National Assessment of Flood Risk.

UK Environment Agency. 2013. National Flood and Coastal Erosion Risk Management Strategy for England: Dunwich Heath and Minsmere case study. Accessed February 8, 2013. http://www.environment-agency.gov.uk/research/policy/130073.aspx

Viles, Heather A., and T. Spencer. 1995. *Coastal problems: Geomorphology, ecology, and society at the coast*. London: E. Arnold.

Walker, I.J. and Sydneysmith, R. 2008. British Columbia; in From Impacts to Adaptation: Canada in a Changing Climate 2007, edited by D.S. Lemmen, F.J. Warren, J. Lacroix and E. Bush; Government of Canada, Ottawa, ON: 329-386.

Whipple, Tom. "The IEA's New Peak." *Post Carbon Institute,* November 24, 2010. Accesed November 10, 2011. www.postcarbon.org/blog-post/188071-the-iea-s-new-peak

Wikipedia. "Peak Oil". Accessed November 11, 2011. www.en.wikipedia.org/wiki/Peak_oil

World Bank. 2012. *Turn Down the Heat: Why a 4°C Warmer World Must Be Avoided*. © Washington, DC: World Bank.

World Wildlife Fund. 2012. *Living Planet Report* 2012. WWF International, Gland, Switzerland.

World Wildlife Fund and The Wildlife Trusts Joint Marine Programme. May 2002. Marine update 52: Abbotts Hall Farm coastal wetland restoration.

Worrell, E., Price, L., Martin, N., Hendriks, C., Meida, L.O., 2001. Carbon dioxide emissions from the global cement industry. Annu. Rev. Energy Environ. 26, 303–329.

Yin, Y. 2001: Designing an integrated approach for evaluating adaptation options to reduce climate change vulnerability in the Georgia Basin; report submitted to Climate Change Impacts and Adaptation Program, Natural Resources Canada: 50. Accessed December 12, 2011 http://adaptation.nrcan.gc.ca/projdb/pdf/80_e.pdf