Climate Induced Sea Level Rise; an investigation of adaptation strategies and erosion mitigation in coastal regions

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Executive Summary

Climate induced sea level rise has become a growing concern through the twentieth century and ongoing research speculate an unprecedented increase in recent years (Nicholls & Cazenave, 2010). As sea levels continue to rise, coastal cities are at increasing risk of coastal flooding from the encroaching shorelines.

The purpose of this paper is thus to look at methods separate from the traditional methods of technological and engineered defensive infrastructure. The specific objective is to illustrate and discuss – through the use of case studies – the implementation of innovative approaches to flood defence and erosion mitigation.

In looking at adaptation strategies, the case studies were separated into four categories: (1) Elevated Development, (2) Floatable Development, (3) Floodable Development, and (4) Living Shorelines; evaluating each on the basis of costs, benefits, and disadvantages.

While the research is limited to strategies structural in origin, this research found a specific need to seek methods that accommodate the changes of sea level rise as opposed to protective strategies. As a result this investigation of alternative adaptations to sea level rise is not representative of all available options. Besides being more cost efficient and having low impact, we find that accommodation provides longer term solutions. Although managed retreat seems to be a logical response, often the displacement of populations becomes an issue technically, socially, politically and economically. Thus instead of managed retreat at a city wide level, strategic retreat might be a better option as it gradually abandons dwellings, and promotes rebuilding in areas at low risk of flooding. However, the most economical option would be climate-wise development planning that limit and prevent new developments in areas at risk. Mixed/Integrated strategies are also considered a valuable option, especially in situations where development already exists. Research for the future however, should not be limited to infrastructure both accommodating and protective, but instead focus on solutions for other impacts of sea level rise in aspects of agriculture, such as increasing salinity and its effects of grown crops, and transportation.

Introduction

Through the twentieth century is the growing concern of human induced climate change supported by emerging information from scientists and agencies around the world (MOE, 2011). As the global climate continues to change as a result of increasing amounts of carbon dioxide in the atmosphere, the world struggles to understand and address its implications. At a more local level, municipalities may be impacted with new pressures to integrate and adapt, but exposed to obstacles such as broad adaptation policies that lack specific guidance.

In recent studies, while an increase in sea level rise is expected, Nicholls et al has suggested an unprecedented increase in the rate of sea level rise from the years 1993-2009 with a mean rate of .3 ± 0.4 mm/year (Nicholls & Cazenave, 2010). This could lead to further implications, as current recommendations for planning and design in BC only project a 1 meter increase by the year 2100 (MOE, 2011), thus highlighting the growing vulnerabilities of coastal and delta regions. While human development impacts reduce the resilience of delta plains, this further exacerbates the effects of sea level rise. In addition, as sea levels continue to rise, traditional methods of technological and engineered defensive structures will become increasingly expensive and difficult to maintain, on a year to year basis (City of Port Coquitlam, 2010). It is for these reasons that we seek other methods of adaptation and mitigation.

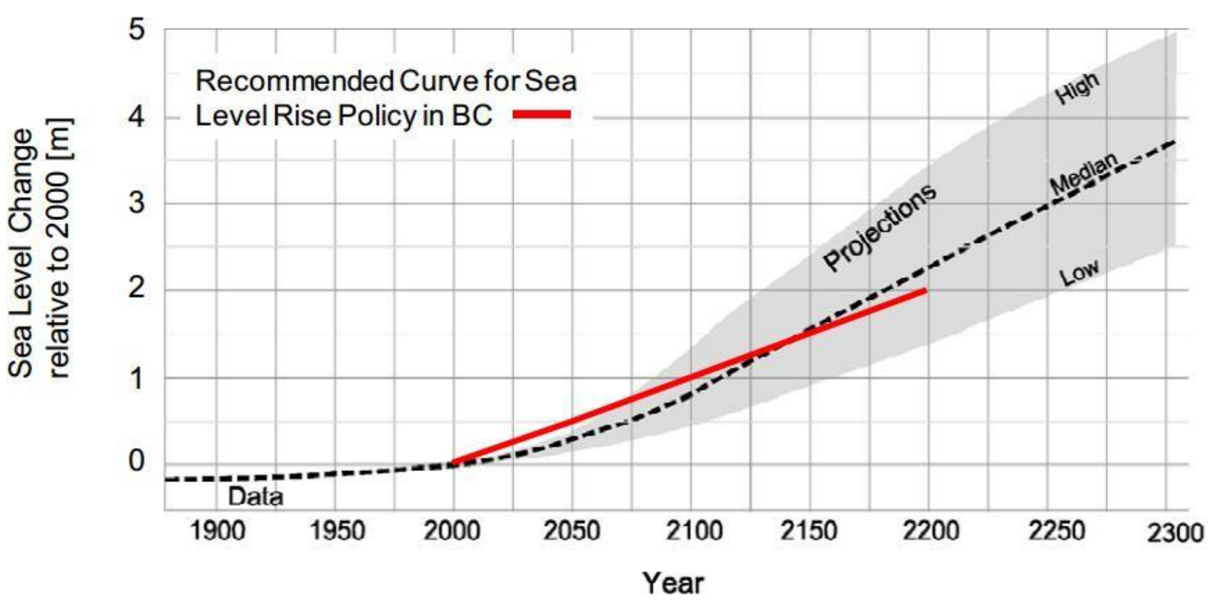

Figure 1. Recommended Global Sea Level Rise Curve for Planning and Design in BC (MOE, 2011).

The purpose of this paper is to investigate innovative approaches to flood defence and erosion mitigation through the use of case studies to address the rising sea level in coastal British Columbia. By looking at methods of adaptation separate from technological and human engineered structures, we find a potential for low impact, cost effective strategies. We will thus separate these case studies into four categories: (1) Elevated Development, (2) Floatable Development, (3) Floodable Development, and (4) Living Shorelines; evaluating each on the basis of costs, benefits, and disadvantages.

While this study may not set definitive guidance for coastal mitigation and adaptation to BC, by careful evaluation of each of the four methods, I hope to conclude with recommendations of adaptation and erosion mitigation strategies.

Methodology

To separate the sea level rise adaptation strategies, we looked at the case studies individually to fit the categories: (1) Elevated development would include structures that are constructed at a fixed and predetermined height; (2) Floatable development includes structures not with fixated heights, but instead heights are varied in the onset of floodwater; (3) Floodable development is determined by its capacity of holding or storing water temporarily; and (4) Living shorelines being structures designed to use living organisms to reduce shoreline erosion.

Many technological and structurally engineered strategies were eliminated because of both cost and purpose. While the case studies we looked at are adaptation strategies, their purpose included multi-functional options, whereas engineered structures - such as dykes, barriers and levees - are built for the sole purpose to withstand rising sea levels.

The Thames Barrier, for example, was built in London as a movable flood barrier completed in 1982 (Environment Agency, 2012) and built to protect 125 square kilometres of central London from flooding by tidal surges. When the project opened in 1982, the total construction estimated at £534 million. In today's standards the estimated cost would be £1.3 billion and thus a structural solution out of reach financially to most coastal regions.

Elevated Development

Elevated Development is the raising of the height of land or existing development that usually accompanies coastal armouring and is considered to be a relatively low cost infrastructure. In the aftermath of Hurricanes Katrina and Rita, during the rebuilding of many private properties, homeowners found that they were required to comply with new regulations for eligibility of flood insurance (English E., 2009). The infrastructure was thus considered low cost – or cost effective since it coincided with redevelopment – to meet the new Base Flood Elevation standards issued by the Federal Emergency Management Agency. While cost effective in new developments, it also has serious economic implications to pre-existing developments as it is a means of renovation. Not only would extra costs be needed for permits and construction, there is also the cost of hiring engineers for the structural components and stability.

While permanently elevating houses is considered FEMA's solution to the problem of flooding, it does not exist as a long term solution. If building towards codes proposed by the BC Ministry of Environment to accommodate sea level rise to 1 meter by the year 2100 (MOE, 2011), the structures are still susceptible to even higher water levels in extreme events, as well as an increased vulnerability to wind damage (English E., 2009). Social implications also include present reduced quality of life and loss of neighbourhood character. Again, as elevated developments are considered solutions due to the low impact and its cost efficiency, they remain still a short term strategy and may not warrant protection in the future as the imminent damage of sea level rise will continue to be a threat (Kates et al., 2006). That is to say however, that short term strategies are not beneficial, as they offer temporary resolution in the lack of a long term solution.

Figure 2. Examples of elevated housing in New Orleans courtesy of the Make-It-Right project (Lee, 2012).

Floatable Development

Floatable development seems to be the direction of the future as it allows continued urbanization in flood prone areas, without the consequences of sea level rise. Instead of working against the water as a means of mitigation and protection – but also preventing the flow of water from its replenishing factor to nutrients of floodplains – floatable development works with the water, allowing structures to float on the surface thus making it invulnerable in times of flooding and changing tides. Often addressed as *Aquatecture* (Pasternack, 2009), or amphibious housing (English E., 2009), such housing is often anchored to the ground, shore or sea floor. While these projects have been based in New Orleans after the disaster of Hurricane Katrina (Fenuta, 2010), others have gained international status, such as the LIFT housing based in Bangladesh (Prosun, 2011).

Already prone to flooding, the delta city of Dhaka, Bangladesh is burdened with draining large amounts of water and heavy monsoon seasons, in addition to immense pressure of rapid urbanization and migration that further aggravates environmental degradation. Thus, Prosun (2011) suggests Low Income Flood-proof Technology House (LIFT housing) as a solution, built on buoyant foundations that float in the onset of a flood. In an effort to eliminate the rebuilding process and provide housing with basic amenities, LIFT housing would not only be affordable for the urban poor using indigenous materials and local skills, but would also be considered as a low impact solution. Drawing on examples of Noah's Arc Project, the Maasbommel Project, and the Buoyant Foundation Project, the designed communal space will hold 8 families. The service spine of the shared area will act as a vertical guide to the amphibious buoyant housing which is achieved by two methods. Firstly, by a hollow ferrocement foundation, and secondly by a bamboo frame foundation filled with recapped water bottles. While this design is innovative and provides solution to both urban poor and flood prone housing, the implementation is its weakness. To find architects, developers and engineers with the knowledge to create such buildings in a low income area may prove to be near impossible. However, to implement this design in developed nations with resources, workers, and funding would be highly beneficial and prove to be a key example for future urban planning, urban development and housing in coastal areas.

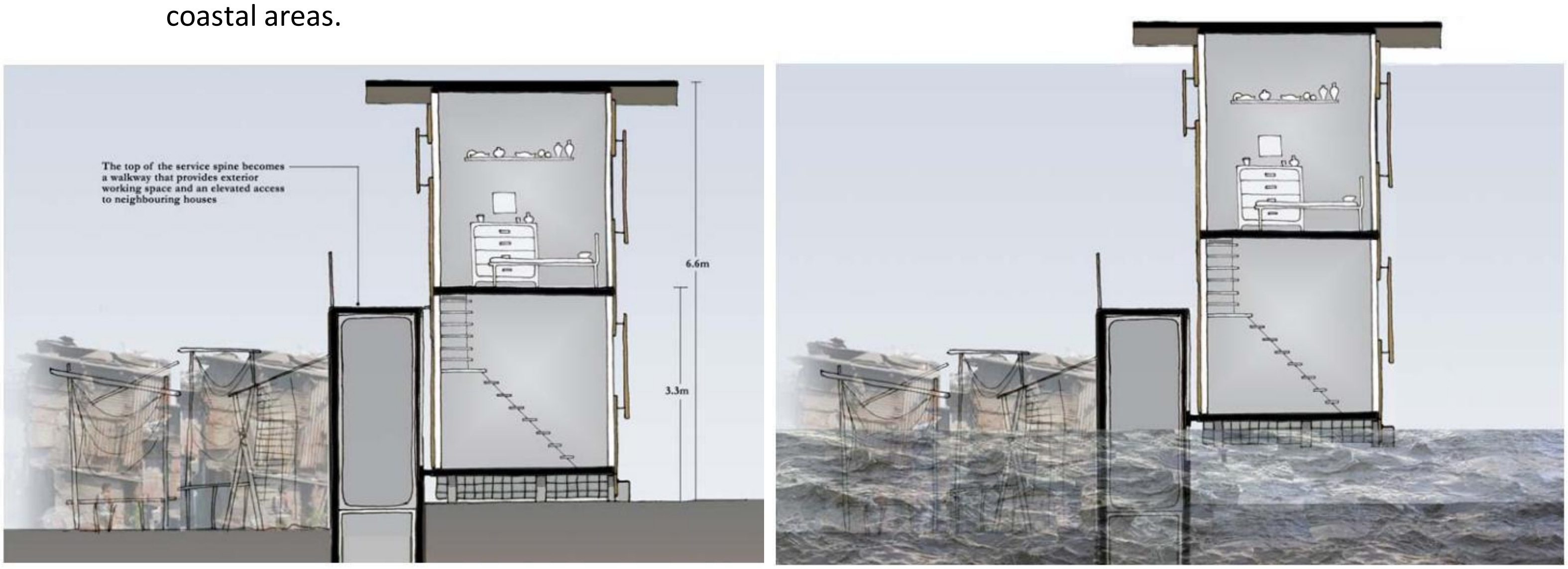

Figure 3.The LIFT housing static on ground during dry season (left) and floating on water during floods (right). (Prosun, 2011).

Advantages of floating development accommodate the uncertainty of high tides and flooding events, and allow it to be resilient towards flooding. In the case of LIFT housing, not only does it allow for low-income multifamily housing, but it reduces the time, energy and cost spent towards rebuilding a home that is vulnerable once again to future events. However, the practicality of the project being implemented in the developed world has many more variables, including a higher standard of living. Buoyant foundation developments in the developed world must account for sewage, gas and electric needs. Make it Right FLOAT housing in New Orleans accounts for these variables by implementing self sealing “breakaway” connections that disconnect utility lines when the house begins to rise (English E., 2009).

However, buoyant foundation housing is not without disadvantages. LIFT housing specifically has its limitations in terms of coastal infrastructure as it is not made to withstand multiple factors of wind and wave action (Prosun, 2011). In adaptations of buoyant foundation in developed countries, limitations also include a predetermined maximum height, thus if sea level rise continues to increase at unprecedented rates, structural changes must be implemented. Finally, not much is known of the long term consequences of floatable developments, especially with its interactions with salt water and high density cities. Speculations in the future of floatable housing are undetermined and we may still find that a secondary type of mitigation is necessary in adapting to sea level rise.

Floodable Development

Floodable developments are structures that are designed to withstand flooding or to retain storm water. The Staten Island Blue Belt Project for example, is an effort to protect an area of New York City’s natural resource and to reduce the risks of flooding from storm water (The Staten Island Bluebelt, 2007). The project was initiated to: provide and construct storm water detention ponds; enhance and create streams, ponds and wetlands; as well as to separate storm and sewer infrastructure. By temporarily storing flood waters, wetlands protect downstream property owners from flood damage, but also control storm water discharges, preventing flood prone areas. Thus, as illustrated, the idea is to create retention areas for ocean surges or heavy rainfall, where water can be contracted and stored as an example of “Low Impact Development.”

In an attempt to create multi-use urban infrastructure that accommodate storm waters in a high-density setting, parks and underground parkades have been speculated by the Dutch (Aerts et al., 2009). These water storage systems would thus accommodate flooding from rising sea levels and storm surges, as they pose a huge threat to the area (Aerts et al., 2009). In densely populated urban areas, space for open water storage is limited, as are spaces for multifunctional use as the global trends continue to change. One adaptation proposed in the Netherlands is to use public spaces such as playgrounds or sealed parts of underground parking lots to store excess water temporarily to reduce flooding in flood prone areas. In Rotterdam, for example, a water plaza can store water in times of peak events, but used as a playground in normal conditions. Secondly, sealed garage reservoirs can act in the case of extreme events and are large enough to store 50% of the expected volume of water that falls in one storm in central city of Rotterdam (Aerts et al., 2009).

Figure 4. Multi-functional underground parking garage used as a reservoir for floodwaters and storm waters (Aerts et al., 2009).

Floodable development could be effective in small scale low impact situations and while experimental, have the potential to work better in urban environments than in agricultural or rural areas. Storm water retention infrastructure and ponds, however, pose a magnitude of hazardous effects. This includes pollution of heavy metals and organic chemicals, sediment build up and bacteria; without proper treatment in water storage areas, it becomes a huge threat to any population. As a result, besides outreach management to include these hazards, there is the need for emergency communication tools to prevent misuse or entrapment in flooding zones.

Living Shorelines

As wetlands are a natural form of our shoreline, they have the ability to absorb floods, slow erosion and provide habitat. In addition, certain organism populations along the coast - such as oysters - provide a breakwater effect that further prevents erosion and degradation of shorelines. In San Francisco, in an effort to save their wetlands, the South Bay Salt Pond Restoration Project was implemented (Bay Area Council Economic Institute, 2011). Since the 1800s, as the wetlands were diked and filled for development, they found that without the wetlands, there was an increase in urban runoff and higher impact of high tides and storm surges. Thus since 2006, after an analysis of the economical impact wetlands have as a buffer against flooding and protection from erosion, with the collaboration of Federal, state and regional funding the Wetlands restoration project began (Bay Area Council Economic Institute, 2011).

However, living shorelines not only include restoration projects and land use change, but may also include oyster reef habitats. In restoration of oyster reef habitats that have disappeared from much of the Gulf Coast, the project will also stabilize an estimated 1500 meters of eroding shoreline, threatened by rising sea levels and storm surges (Gregg, 2010). To test the effect of oyster reefs along coastlines as a form of mitigation, Scyphers et al. (2011) devised an experiment to examine the ecological effects of constructing sub tidal breakwater oyster reefs for coastal and estuarine shoreline protection. The two study sites were selected depending on oyster supply and moderate wave climates. The experiment was tested with one control shoreline that remained unaltered and the second shoreline with oyster settlements that measured shoreline, bathymetric change and oyster, fish and mobile macro-invertebrate abundances. It was found that along the shores of the control showed a 40% higher shoreline retreat than the one mitigated with oyster reef breakwaters. By testing their hypothesis scientifically and providing quantifiable results, the study strongly demonstrated the effects of biogenic breakwater reef and its ability as a form of flood and erosion mitigation. Not only did these biogenic structures reduce water velocities, but they were found to increase sedimentation rates and enhance propagule settlement and retention, thus creating suitable environments for future development.

Unfortunately, living shorelines pose the greatest accumulation of cost. While initially projects will not take much funding, they require space and time to work. In addition, continued management, monitoring and time makes these projects financially draining. Since the beginning of the South Bay Salt Pond Restoration Project in 2003, a status report filed by the project itself totalled a public/private investment of $183 million and in the future will continue to accumulate in cost to maintain (Bay Area Council Economic Institute, 2011).

Recommendations

While managed retreat would seem to be the most logical response to encroaching shorelines and further subsidence and inundation, there are enormous challenges that encompass technical, social, political and economical aspects. The economic cost of relocating one building may often outweigh the cost of rebuilding a home over and over in a flood-prone area (Round Table, 2011). However, the cost of relocation increases with the possibility of relocating several assets as they may include infrastructure such as roads and utilities. Thus, the practicality of relocating an entire city let alone an entire metropolitan area such as Greater Vancouver becomes implausible. In addition, the social and political implications of managed retreat may become overwhelming as it is often the case that property values along the coast are much greater than that inland (City of Vancouver, 2012). Even at a local political level, municipal taxes will be affected from the retreating of developed land by removing tax bases, furthermore is the cost of attainment of land making retreat an even more unattractive option. However, in the case of New Orleans and Hurricane Katrina, an option that should be exercised is strategic retreat that enables rebuilding, but in areas not prone to flooding. Consequently, the more practical option may be climate-wise development planning, limiting the further development and construction in areas at risk of flooding (Round Table, 2011). The economic benefits would reflect the avoided costs of development. Figure 2 (Round Table, 2011) below demonstrates a cost-benefit analysis between strategic retreat and climate wise planning, illustrating potential and accumulating costs and management. What we find is strategic retreat, being the abandonment of damaged homes, yields higher economic benefits as the cost of rebuilding is invested in less risky areas (Round Table, 2011).

SUMMARY OF TWO COASTAL ADAPTATION STRATEGIES

	ADAPTATION STRATEGY #1				ADAPTATION STRATEGY #2			
STRATEGY	Climate - wise development planning: Prevent new development in areas that will be at risk of flooding				Strategic retreat: Rebuild homes in areas that are not prone to flooding			
OBJECTIVE	Reduce costs of flooding				Avoid rebuilding a home multiple times			
COSTS OF IMPLEMENTING STRATEGY	Assumed zero cost				Assumed zero cost			
BENEFITS OF IMPLEMENTING STRATEGY (PRESENT VALUE, 2010-2100)	-		+		-		+	
	SLOW	RAPID	SLOW	RAPID	SLOW	RAPID	SLOW	RAPID
	$4.3B	$15.3B	$16.6B	$55.1B	$16.7B	$44.7B	$70.7B	$173.0B
BENEFIT-COST RATIO	Not applicable				Not applicable			
REMAINING COSTS OF CLIMATE CHANGE AFTER ADAPTATION (PRESENT VALUE, 2010-2100)	-		+		-		+	
	SLOW	RAPID	SLOW	RAPID	SLOW	RAPID	SLOW	RAPID
	$13.2B	$32.2B	$56.8B	$127.0B	$0.9B	$2.7B	$2.7B	$9.1B
POTENTIAL CO-BENEFITS	• Avoided injury and loss of life • Avoided interruption to communities and households • Reduced flooding damage from baseline risks				• Avoided injury and loss of life • Reduced flooding damage from baseline risks			
IMPLEMENTATION CHALLENGES	• Difficult in densely populated areas where property is already expensive • Financial loss for current property owners				• Disruption to communities • Reduction in value of homes • Costs of servicing new developments • Limited options for relocation in densely populated areas			

Slow Canadian economic and population growth
Rapid Canadian economic and population growth
— Low climate change
+ High climate change
$(2008), 3% DISCOUNT RATE

Figure 5. Cost Benefit Analysis Between Climate-Wise Development Planning and Strategic Retreat (Round Table, 2011).

Finally, in most situations where development already exists, a mix or integration of options provide temporary if not longer term solutions to climate induced sea level rise and flooding. While many methods alone have several shortcomings, an integration of methods that overlap might eliminate individual vulnerabilities.

Limitations

Unfortunately for the purposes of this research, only adaptation strategies that fit the four categories of elevated development, floatable development, floodable development and living shorelines were taken into consideration. Additionally, the strategies examined were all structural in origin and adaptation strategies should not be limited to infrastructure. As such, recommendations for future research include looking into the impacts of sea level rise in aspects of agriculture, and transportation.

Conclusion

While at the present Canadians living in coastal areas are relatively accustomed to climate change induced sea level rise through the reliance of human engineered infrastructure, a nationwide study found that climate change will exacerbate existing risks. By the mid-century, Canadians will find that 3,000 to 13,000 homes will be affected by flooding and in British Columbia alone, about 8,900 to 18,700 homes will be at risk of permanent flooding from sea level rise and temporary flooding by storm surges (Round Table, 2011).

Traditional adaptation strategies that often encompass the construction of seawalls and other engineered defences are not reasonable strategies as not only do they provide only temporary short term alleviations, but can be problematic in operational costs, maintenance and interference with coastal ecosystems (Round Table, 2011). Through careful assessments of different adaptation strategies internationally, we find several innovative approaches to mitigation that are both low impact and cost effective. In addition, a general theme we find across these strategies is the aim of accommodating sea level change rather than protecting and resisting against. Thus, it is not necessarily innovative strategies that we should seek, but rather planned adaptation strategies that seek to accommodate changes in climate induced sea level rise.

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