the adaptation primers*

PRIMER FOUR
FACING RISING WATERS

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2018

*prim•er (Pronunciation: /ˈprɪmər/; rhymes with “trimmer”):

A small book containing basic facts about a subject, used especially when you are beginning to learn about that subject.
Source: Cambridge Dictionary Online at http://dictionary.cambridge.org/dictionary/english/primer

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SUPPORT

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CSLA | AAPC
Canadian Society of Landscape Architects
Association des architectes paysagistes du Canada

ParCA
Partnership for Canada-Caribbean Community Climate Change Adaptation

UNIVERSITY OF WATERLOO

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PREFACE

There is scientific certainty that due to global emissions of greenhouse gases our planet is already changing and will continue to change - in some cases dramatically. How global warming will affect the climate and weather patterns across Canada is complicated by the vast landscapes that comprise our nation, and the complex array of direct and indirect effects that are already anticipated. Our uncertain future should compel professionals and decision-makers to be better informed and more capable of making effective and insightful decisions.

Our hope for a stable and sustainable future requires that action be taken today. Whether the goal is to reduce the emissions that are warming the planet, or to prepare society for anticipated changes, efforts towards mitigation and adaptation must begin now. Everyone is responsible, everyone needs to act.

The **PRIMERs** are provided in a four-volume set. PRIMER ONE summarizes the science on climate weather and change. PRIMER TWO provides information on how individuals, communities and organizations can begin now to prepare for anticipated changes. PRIMER THREE presents planning and design tools, existing and emerging, that can help in the creation of resilient and prosperous communities and sustainable ecosystems. PRIMER FOUR summarizes approaches and tools focused on one of the fastest emerging challenges – rising water levels.

The Primers are intended to augment your basic understanding of the science on global warming and climate change, to provide improved access to information on anticipated impacts to Canadian landscapes, and to promote improved understanding of the options available to society through adaptive planning for change. Should you wish to expand your understanding on the topics discussed, access the materials referenced in the *Additional Readings* and *Resources on the Web*, and reach out to do your own search for newer information. Climate adaptation is a rapidly evolving knowledge area.

The Primers rely on two categories of information: reports and papers that have been freely distributed on the internet; and a selection of books and peer-reviewed papers. Many of the reports and books referenced are available from public or university libraries. Should the URLs provided for material available on the internet become inactive, it could mean only that the material has been moved, not that it is outdated or no longer relevant. We encourage you to search by author and/or title to find the document.

Peer reviewed papers are included here because they are an important source of information on climate change science, mitigation and adaptation, and the first access point for new knowledge. Some journal papers are provided freely on the Internet. Unfortunately, digital access to other journals requires paid subscriptions, or individual papers can be purchased on-line. Most university libraries in Canada provide memberships to the public for a nominal annual fee, but not all may include access to online journals. However, in addition to borrowing texts, hard and/or electronic copies of many journals can be viewed at the library. Readers can also become members of local, regional, or national communities of practice, where enrollment and access to many valuable sources of information are freely provided.

PRIMER ONE:
CLIMATE, WEATHER AND CHANGE

Chapters One and Two provide users with a summary of the current science on global warming, and the current and projected future changes in weather and climate throughout Canada. Chapter Three summarizes current thinking on the effects anticipated environmental change will have on ecosystems, on society and on local as well as regional economics.

PRIMER TWO:
PREPARING FOR CHANGE

Chapter Four focusses on managing risk and understanding the role played in decision-making by uncertainty. Chapter Five outlines the need to change what we do, to mitigate and to adapt. Chapter Six provides direction for those seeking a better future, incorporating existing instruments and tools with emerging principles and processes for guiding change.

PRIMER THREE:
CREATING RESILIENT COMMUNITIES

Chapter Seven summarizes opportunities to create resilient communities that integrate with their natural environment and promote well being and sustainability for humans and ecosystems.

PRIMER FOUR:
FACING RISING WATERS

Chapter Eight examines preventative and protective measures to rising water, whether it is fresh water (overland flooding) or the result of rising sea levels and/or storm surges.

8 PREPARING FOR FLOOD

8.1 A CHANGING PROBLEM

It is understandable why the threat of high water can be the primary issue in climate change adaptation initiatives. For inland communities, this threat will primarily derive from heavy downfalls or extended periods of precipitation. For communities at or near fresh or marine water bodies, flooding can also be the result of spring melts and ice jams, and higher than normal storm surges/seiches driven by extreme weather. Along marine coasts, flooding can result from all of the above, as well as from higher than normal tides, and as the result of increases in mean sea level (Figure 8-1). As the climate continues to warm, communities at risk, and other residents of flood-prone areas, will face a double challenge: more water coming down stream and overland and higher water levels at the shore.

As water levels rise, and precipitation and other conditions change, we must get better at **KNOWING THE PROBLEM**. We must improve our knowledge of current conditions, develop a comprehensive understanding of changing conditions, and anticipate the growing potential for dramatic impacts to local environments during extreme weather events. We need to inventory and map the physical, ecological, economic and cultural parameters of our local area, to model and map the changes to come, and to ensure that the linkages across environment, economy, society and culture are well documented. We need to increasingly rely on emerging science to continually update our understanding of when changes will pose unacceptable risks to the safety, health and well-being of humans. We need to employ digital tools to visualize changing conditions and new norms, so that causes, and effects of flooding events are fully understood, our ability to anticipate extreme events is improved, and proposed adaptive and response actions are well supported by the community.

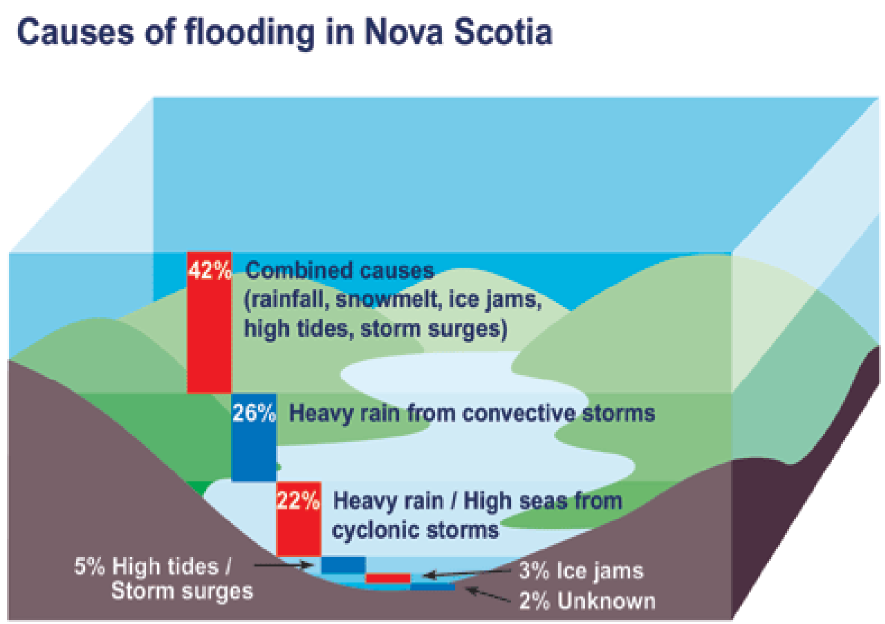


FIGURE 8-1: Causes of flooding in Nova Scotia –1759-1986 *(Image Credit; Environment and Climate Change Canada: Accessed at: https://www.ec.gc.ca/eau-water/default.asp?lang=En&n=4FCB81DD-1).*

We must also improve our capacity for **CONFRONTING THE PROBLEM**, by acting to reduce vulnerabilities of assets and populations, to conserve and sustain natural features, and to shelter assets by building protective walls and structures, with the full realization that much of what we will do may only be a temporary solution to an increasing threat. In the present, we need to confront changing conditions, by employing low-regret and no-regret options to accommodate change and to protect properties, populations and environments. Investing in infrastructure that is designed and built to perform well in a changing environment will enhance resilience over a longer term and increase the options available to future generations. **HOLDING THE LINE** commits us to preventing further flooding through deployment of protection measures intended to hold water back, and/or to manage anticipated changes to our shorelines resulting from more intense storms and changes in water levels, while recognizing that many of these mechanisms may not be effective in the long term.

In facing rising waters, we may not necessarily be prepared to plan today for future conditions that are anticipated but not yet experienced. **AVOIDING THE PROBLEM** may be the best long-term solution for sustaining assets and activities. Avoiding existing and emerging hazards will require difficult social decisions on how, when and what we migrate to less vulnerable locations.

To move these plans forward in a timely manner, we also need to accept, like King Canute, that we cannot stop the steady onset of change, and that in the coming future, migration of assets and activities to safer more sustainable locations may become necessary to ensure communities remain livable, and people are safe (Figure 8-2) Though it will be complicated and, in some cases, difficult, accepting the inevitability of the increased hazards posed to our towns, villages and environments, will protect society in the short term, and open minds towards the opportunities for a more sustainable future.

Overall, adaptation options to slow, reduce or to prepare for rising waters should include all the following:

- ensure decision-making (including planning for future opportunities) focused on the ways and means to reduce GHGs and sequester carbon, to slow the rate of sea-level rise and to reduce the intensity and frequency of severe weather;
- promote stormwater management measures such as low impact development and increased infiltration to ground water;
- waterproof buildings and homes, moving essential and/or expensive systems and assets to less vulnerable elevations;
- protect and conserve natural features (e.g., beaches, dunes, wetlands, stream banks) to ensure their sustainability and to capitalize on their potential to dampen storm effects and reduce impacts from rising water levels;
- create public understanding of the time-limited capacity for seawalls and other protective measures to reduce risks, and the costs associated with what will in some areas be a temporary solution;
- restrict human use of areas designated as occasionally or permanently hazardous;
- prevent new development in hazardous areas, and
- plan for future relocation of valued assets and activities on sites that are free of hazard.

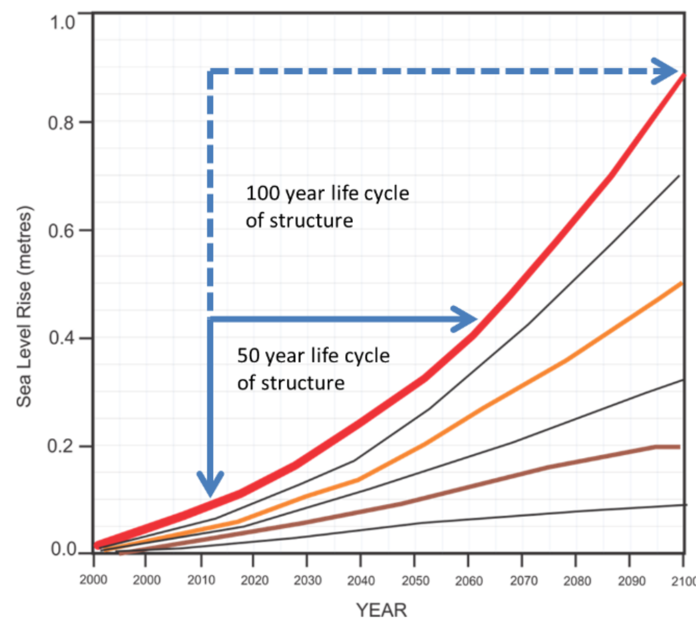


FIGURE 8-2: Practical understanding of planning and design for life-cycle expectancies for structures at threat from sea-level rise *(Simpson et al. 2012).*

Whereas flooding from unanticipated and unusual storm systems can be a fact of life in some areas of Canada, flooding that is the result of a steadily increasing rise in mean sea level, storm surges and higher waves is an ever-present danger, that will only intensify over time.

8.2 KNOWING THE PROBLEM

Mean water levels in lakes, rivers, marshes and oceans change over time - sometimes daily, sometimes monthly, sometimes seasonally, sometimes because of weather. Water levels change because of daily tides, snow melt, storms and as the result of precipitation events, or droughts.

When dealing with severe weather, some Canadians may still rely primarily on their individual or collective memory to assess their vulnerabilities and/or to prepare themselves for future storms (e.g., "the water has NEVER risen above this level, my home doesn't flood"). In parts of Canada, flooding is already occurring in areas that were not considered vulnerable, either the result of deluges of rainfall, or the combined actions of high tides, storm surges, higher waves, and downstream flooding resulting from high precipitation. When all these contributing factors occur at once, flood levels can reach previously unknown levels.

Improving our knowledge of existing and anticipated conditions and the associated changes in vulnerabilities and risk of flooding: requires (El-Jabi et al. 2015; Faulkner et al. 2016):

- a clear understanding of the terms used to describe both freshwater and marine water levels;
- monitoring of trends in low, mean and high-water levels and changes in mean sea level and extreme tides; and
- improved understanding of current flooding vulnerabilities coupled with ongoing modelling of anticipated changes to flood conditions.

On tidal waters in Canada, water levels change twice a day, resulting in two periods of high water and two periods of low water each day. Water levels change in the following steps (Figure 8-3):

- Sea level rises over several hours, creating the *flood tide*, which gradually covers the intertidal area of shorelines;
- When the water reaches its highest level, *high tide* has been achieved;
- Sea level then falls over several hours, creating the *ebb tide*;
- When the water level stops falling, *low tide* has been achieved.

Changes in mean water levels are associated with the position of the moon and the sun and are referred to as spring or neap tides, periods when mean high and mean low water levels will be higher or lower than usual.

On non-tidal waters in Canada, bathymetric charts measure water depth against an established point or *chart datum*, established so that the water level will be above the datum 95% of the time. This insures that water craft can be assured of minimum water depths suitable for navigation. In some water basins such as the Great Lakes, precipitation changes can result in periods of higher or lower water. Chart datum is set with lower water periods in mind. On rivers, chart datum is a sloping surface that approximates the slope of the river surface during low water periods, over the length of the river.

VERTICAL DATUMS

A vertical datum is a surface of zero elevation to which heights of various points are referred in order that those heights be in a consistent system. More broadly, a vertical datum is the entire system of the zero-elevation surface and methods of determining heights relative to that surface. Over the years, many different types of vertical datums have been used. The most predominant types today are tidal datums and geodetic datums.

(NOAA: Accessible at http://www.ngs.noaa.gov/datums/vertical/).

CHART DATUM CANADA

For navigational safety, depths on a bathymetric chart are shown from a low-water surface or a low-water datum called chart datum. Chart datum is selected so that the water level will seldom fall below it, and only rarely will there be less depth available than what is portrayed on the chart.

Criteria used to refine the choice of a chart datum include: 1) the datum is so low that the water level will but seldom fall below it, 2) it is not so low as to cause the charted depths to be unrealistically shallow, and 3) it should vary only gradually from area to area and from chart to adjoining chart, to avoid significant discontinuities.

On most Canadian coastal marine charts, the surface of lower low water, large tide (LLWLT), has been adopted as chart datum, but the term " lowest normal tide, " or " LNT, " has been retained on the charts since it encompasses a variety of other choices for chart datum on some older charts.

(Fisheries and Oceans Canada: Accessible at http://www.tides.gc.ca/eng/info/verticaldatums).

Established datums are a consistent system for determining the elevation of marine and fresh waters in Canada (Figure 8-3), or for elevation of land. Until relatively recently, the charting of water depths in navigable areas was separate from the mapping of land topography. In some situations, this meant that the place where mean water levels met the land were not necessarily congruent. Historical differences between the standards by which land was mapped (i.e., topography) and the standards by which sea levels were mapped (e.g., bathymetry) have in the past resulted in discontinuities in the location of the mean sea level. By example, 0.0 metres (where the land meets the water) elevation on a topographic map may not occur at exactly the same place as 0.0 metres (where the sea meets the land) indicates on a bathymetric map. This situation can result in quite different configurations of the shoreline and could significantly complicate efforts to determine the effects of changing water levels on local areas.

Establishing a common vertical datum is critical to all discussions of flood conditions. Care must be taken that the Chart Datum established for any locale is in accordance with current data on mean sea level and has been adjusted to reflect departures from the established Geodetic Datum. As sea and water levels change, and land sinks or rises across the country, adjustments are being made to established and historic mean water levels.

Before proceeding with mapping of sea-level changes, and/or trends in overland flooding, expert advice should be sought to ensure that all mapping systems used, whether national, provincial/territorial, or municipal have been ratified to a commonly understood benchmark that defines mean water level, and that all new data intended for use in GIS models has been appropriately geo-referenced to the accepted standards.

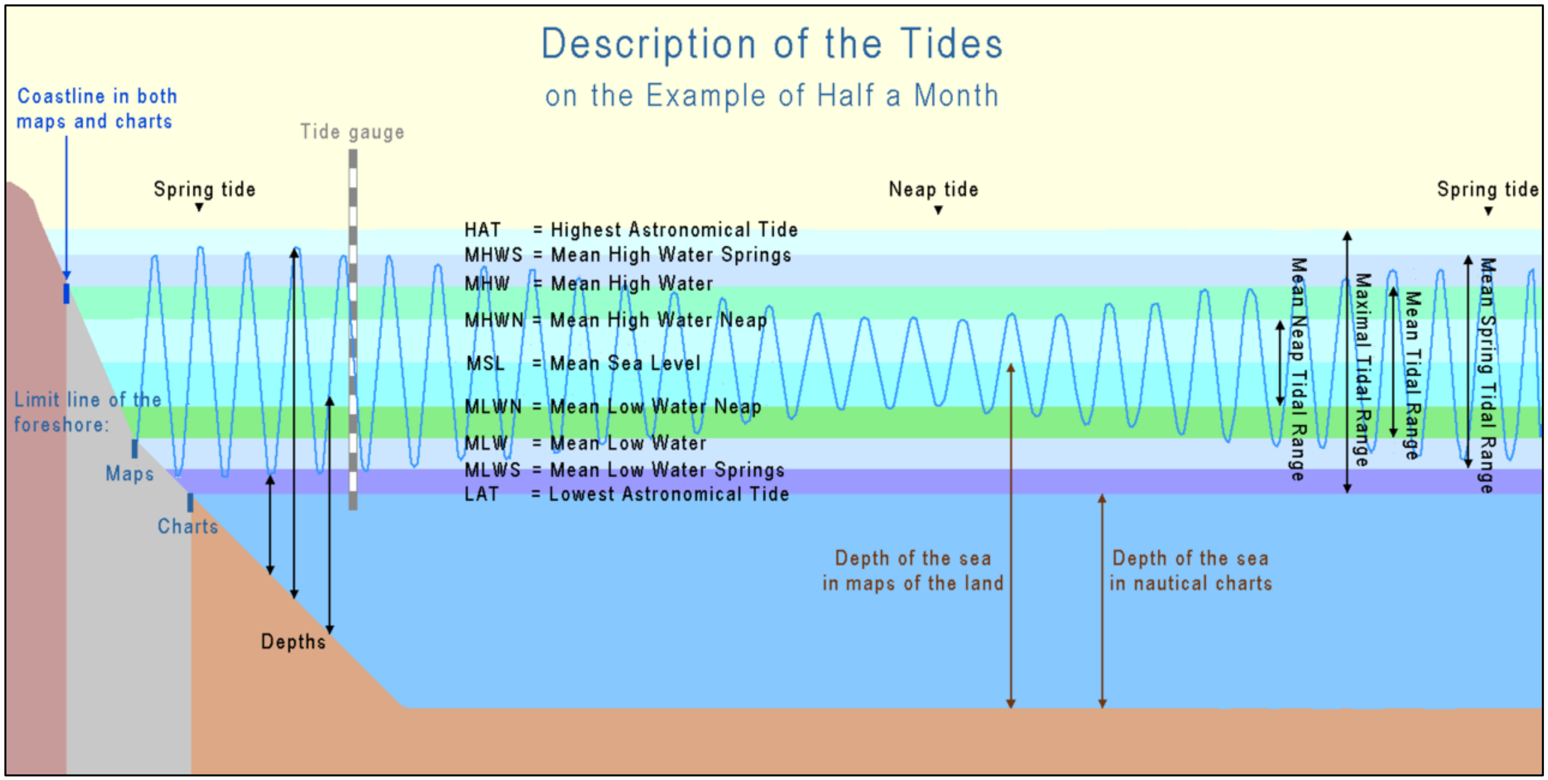


FIGURE 8-3: Terms used to describe yearly changes in tidal conditions in Canada, including spring tides and neap tides *(IMAGE CREDIT; Ulamm, Wikipedia CC BY-SA 3.0)).*

8.2.1 STORM SURGES AND SEICHES

Water levels can also change as a result of strong and persistent winds blowing across long stretches of open water that cause water to 'pile up' along the shoreline. Along marine shores, this phenomenon is referred to as a storm surge (Figure 8-4). In enclosed harbours, or along lake shorelines, the changes in water level caused by wind conditions is termed a seiche (Figure 8-5). When storm surges and seiches occur during periods of unusually high-water levels (high tides, spring or neap tides, seasonal melts), significant flooding can occur.

Today, the main changes to mean water levels that depart from that which we have come to understand as normal and exceed conditions for which we have prepared, are most often the result of severe weather conditions. It can be difficult to scientifically conclude that increasingly frequent or more severe storms is directly attributable to global warming, because we do not as yet have a statistically valid record for these extremes in severe weather. However, evidence is growing, sufficient for prudent decision-makers to alter established best practices in planning and design, and to have more trust in the scientific models that predict that even worse conditions are to come.

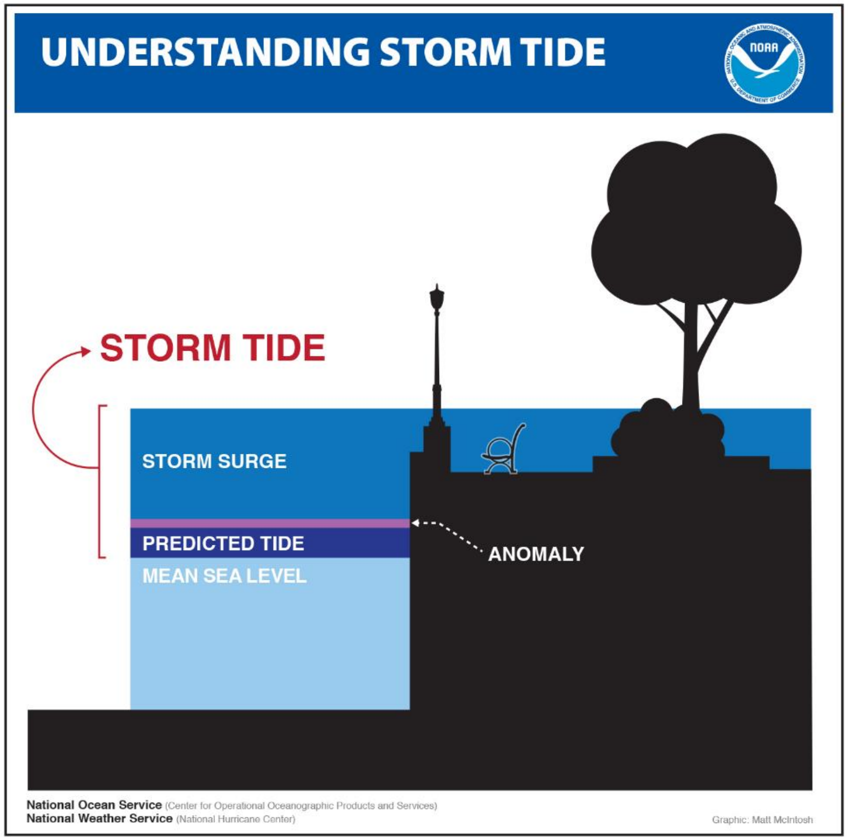


FIGURE 8-4: Storm tides and water levels *(Image Credit: NOS/NWS/NOAA, used with permission. Available at https://oceanservice.noaa.gov/facts/stormsurge-stormtide.html*

STORM SURGE: a wind and atmospheric pressure-driven increase in water level that combines with tide conditions to form the total water elevation during a storm.

And abnormal rise of water generated by a storm, over and above the predicted tide level. Water is pushed towards the shore by the force of the storm winds. The rise in water level can result in extreme flooding in low lying areas, especially when storm surge is combined with high tides. The storm surge created during Hurricane Katrina (2005) created water levels 6 to 7 metres above normal tide, resulting in damages in excess of $75 Billion USD.

STORM TIDE the water level rises due to a combination of storm surge and the astronomical tide.

HURRICANE SANDY STORM SURGE

Hurricane Sandy was directly responsible for approximately 150 deaths and $70 Billion in losses. About half of the deaths occurred in the Caribbean and half in the United States, including 44 in New York City. Sandy's 14.1-foot elevation (above mean low low water; MLLW) set the record at the Battery tide gauge. Several factors caused the extreme surge.

Sandy's minimum pressure was the lowest ever recorded at landfall north of Cape Hatteras, NC. With a tropical storm-force wind field of close to 1000 miles in diameter, Sandy was among the largest storms as well. Hurricane Sandy's unusual westward-turning track also concentrated storm surge, wind, and waves in the New York metropolitan region. Part of the extensive coastal flooding was because Sandy's peak surge coincided with high tide *(Horton et al. 2015.)*

SEICHE

Periodic oscillations of water level set in motion by some atmospheric disturbance passing over an enclosed, or partially enclosed, body of water. The disturbances that cause seiches include the rapid changes in atmospheric pressure with the passage of low or high-pressure weather systems, rapidly-moving weather fronts, and major shifts in the directions of strong winds. Seiches exist on the Great Lakes, other large, confined water bodies, and on partially-enclosed arms of the sea (*University of Wisconsin Sea Grant Institute. Available at: http://seagrant.wisc.edu/Home/Topics/CoastalEngineering/Details.aspx?PostID=694*).

Seiches are typically caused when strong winds and rapid changes in atmospheric pressure push water from one end of a body of water to the other. When the wind stops, the water rebounds to the other side of the enclosed area. The water then continues to oscillate back and forth for hours or even days. In a similar fashion, earthquakes, tsunamis, or severe storm fronts may also cause seiches along ocean shelves and ocean harbors.

In some of the Great Lakes and other large bodies of water, the time between the "high" and "low" of a seiche can be as much as four to seven hours. This is very similar to the time period between a high and low tide in the oceans and is often mistaken as a tide.
(USA/NOAA. Available at: https://oceanservice.noaa.gov/facts/seiche.html).

PERFECT STORMS

In coastal and nearshore areas, flooding from can occur year-round. When the perfect storm arrives, it generally arrives with the perfect wind direction and fetch to drive water even higher and to force dangerous and damaging waves onto the shore. When this storm also drops high levels of precipitation, and/or occurs during high water periods (e.g., snow melt, high precipitation periods, high tides), water coming downstream, and overland meets water being pushed higher and further ashore. Flooding conditions can reach new heights, wave action can damage shoreline protection measures, and in some areas, ice floes can be driven dangerously ashore.

DEADLY STORMS OF THE GREAT LAKES (CANADA AND USA)

1860 Lady Elgin: over 400 dead
1835 "Cyclone": 254 dead
1913 Great Storm: 244 dead
1880 Alpena Storm: about 100 dead
1940 Armistice Day: 66 dead
1916 Black Friday: 49 dead
1958 Bradley: 33 dead
1905 Blow: 32 dead
1975 Fitzgerald: 29 dead
1966 Morrell: 28 dead
1894 May Gale: 27 dead

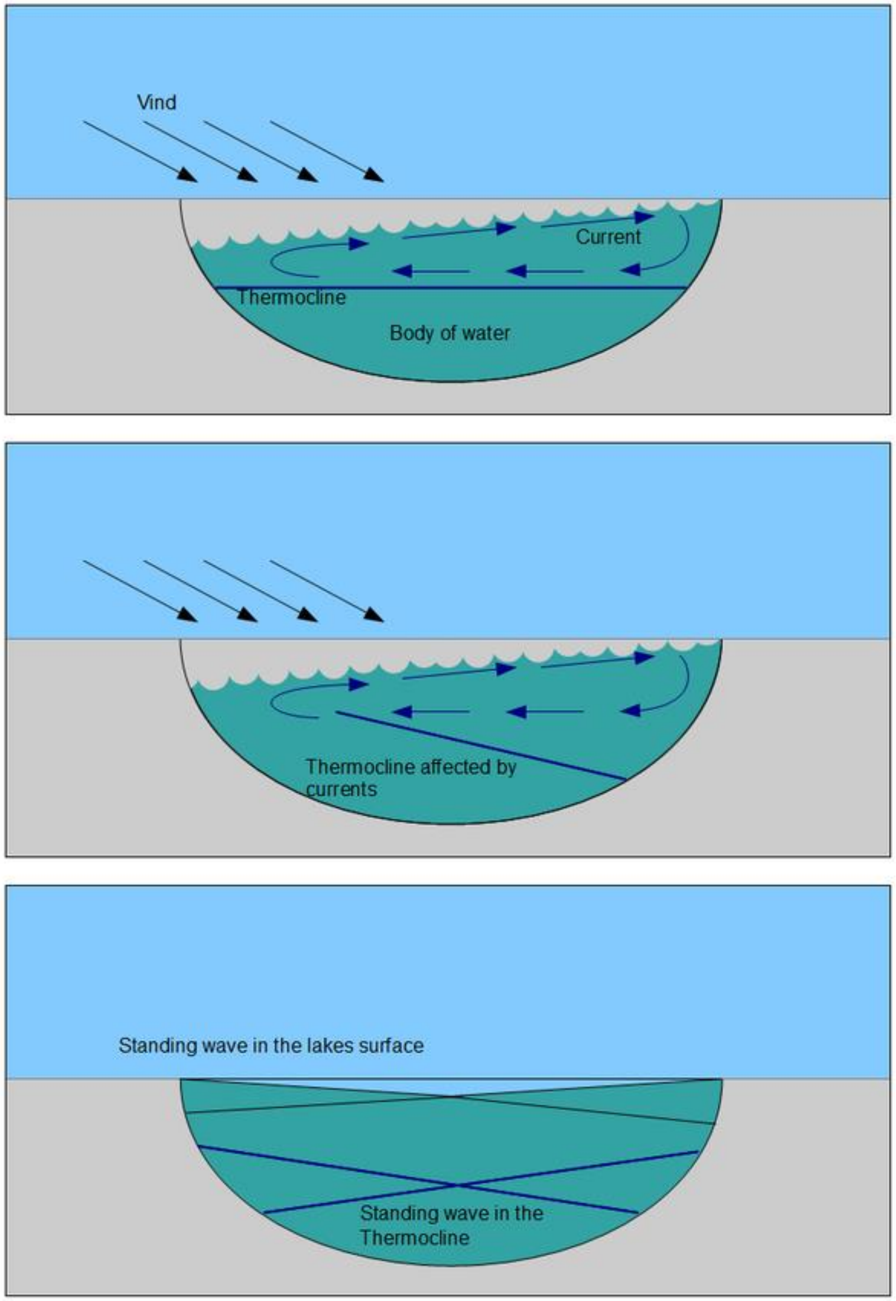


FIGURE 8-5: Graphic depiction of seiches on an enclosed body of water *(Image Credit: Frankemann; Wikiwand CC BY SA 3.0): Available at: http://www.wikiwand.com/en/Seiche).*

8.2.2 ANTICIPATING STORMS

Storms bring with them intensified precipitation, winds, storm surges along coasts (i.e., elevated mean sea or large lake water levels caused by wind), and more active nearshore waves. Coastal areas in Canada are experiencing more frequent and more intense storms during all seasons, storms that do not fit expectations of 'typical weather patterns'.

By example, in the Toronto area in the past 25 years, rainfall events have included three 100-year storms, and six 50-year storms (David Phillips, Environment Canada). In 2014, Burlington, Ontario experienced flash flooding, the result of 190 mm of rainfall in less than two hours. This '1000-year storm' was made even more remarkable because communities on either side of Burlington received little to no rainfall from the same event. Predicable storms of the past are transforming into intensive cells that may only affect individual towns or even be confined to specific neighbourhoods.

INTENSITY-DURATION-FREQUENCY CURVES

Stormwater infrastructure systems in Canada have not been designed or equipped to handle precipitation events of the magnitude being experienced, with consequential increases in the spatial extent of areas affected by local flooding. Seawalls and breakwaters are proving insufficient to withstand heavier wave action at the shore, and nearshore properties are suffering previously unanticipated damage. Future planning and design must strive not only to reduce stormwater at source, but also to avoid development in areas now deemed to have an increased potential for future flooding.

Key among the new tools being developed to assist in anticipating the impacts of more intensive storm systems are new models for predicting changes in intensity, duration and frequency (IDF) of precipitation. IDF curves can provide planners, engineers and landscape architects with an improved capacity to understand how precipitation in their area will alter during peak storm events and will aid assessment of the capacity of existing stormwater systems to carry the anticipated changes in water loads.

When IDF curves are combined with projected climate scenarios (e.g., weather patterns, temperature and precipitation models); with updated hydrologic models (e.g., rainfall -runoff); and with hydraulic models (e.g., mapping of existing and anticipated floodplain areas for surface waters), decision-makers can develop a more realistic appreciation of the potential for overland flooding.

STORM RETURN PERIODS

A 100-year storm event is a storm that has rainfall and winds at a level that we can expect there to be a one in one hundred (1%) chance of such a storm event occurring in any given year. And unlikely that there will be more than one of those storm events in a 100-year period. A 500-year storm would have a 0.2% chance of occurring in any given year

The IPCC has determined that throughout much of the world, climate change will increase the frequency and severity of storms. In Canada, some areas have already experienced several 100-year storm events in the past decade.

CLOUDBURST

A cloudburst is a colloquial term that has come to mean a sudden, very heavy rainfall, usually local in nature, that can deposit an extreme amount of precipitation in a short period of time. Most cloudbursts are associated with thunderstorms so can be accompanied by lightning and hail.

While anticipated in mountainous areas, these types of intense rainfalls are now being experienced in other geographic regions.

INTENSITY-DURATION-FREQUENCY (IDF) CURVE

An IDF curve is a graphical representation of the probability that rainfall of a particular intensity will occur, within a predicted period of time. Rainfall intensity (mm/hour), rainfall duration (how many hours it will rain at that intensity) and rainfall frequency (how often that sort of event can be expected to repeat itself) are the parameters used to calculate the IDF curve for a particular location. As periods of intense rainfall (e.g., cloudbursts) appear in some areas to be more frequent, professionals are using newly collected data on intensity and duration to recalculate the IDF curves used in local planning and design.

AN IDF CURVE LOOKUP TOOL FOR ONTARIO

The IDF Curve Lookup Tool is a high quality, precise interpolator of extreme rainfall statistics that estimates future rainfall intensity, duration and frequency (IDF). Good estimates of peak rainfall statistics are essential for infrastructure design, hydraulic structure design, or flood plain mapping.

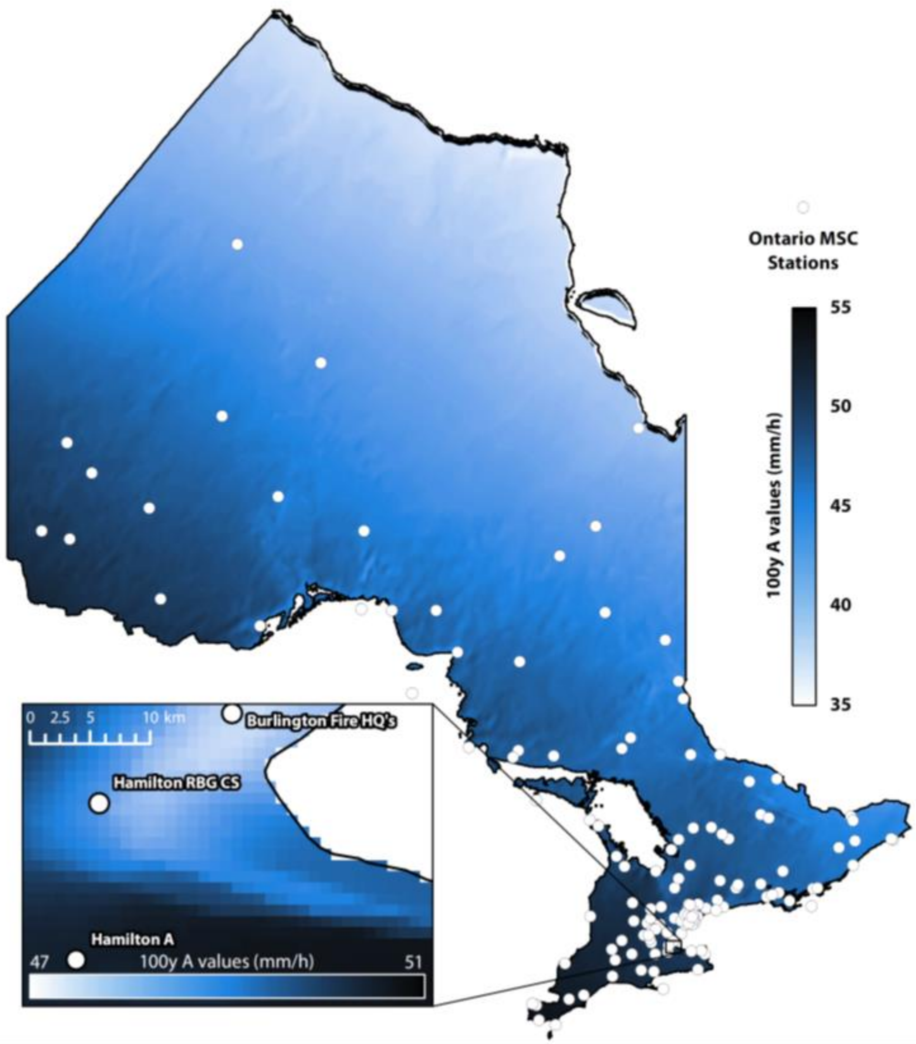
Designed by researchers at the University of Waterloo for the Ontario Ministry of Transportation (MTO), this stormwater management tool extracts local statistics with high spatial resolution and high temporal resolution (Soulis et al. 2015). The tool has a two per cent standard error in the results. The IDF Curve Look Up Tool is free to use, and while currently limited to Ontario, it easily could be expanded to other regions.

Environment Canada provides peak rainfall intensities at selected Meteorological Services of Canada (MSC) stations across Canada. Of these stations, 147 are in Ontario. Previously in Ontario, if a project did not have one of the MSC stations nearby, manual interpolation was required to estimate design rainfalls for the project location. The IDF Tool automatically interpolates the MSC rainfall data, saving planning and design professionals up to a day and a half per project. The consistency of the results—regardless of user—can greatly facilitate approval processes.

Users can either enter coordinates for their project or use the Google maps interface embedded on the IDF tool website. Once the location is defined, or multiple locations in the case of large projects, the tool produces IDF curves with an error range. The difference between the output IDF curves is different from the original MSC station curves, but their overlap is generally within the 95 per cent confidence intervals.

These new IDF curves ensure more reliable and precise representations of recent weather patterns. The curves can reflect changes in historic data and are updatable as new rainfall data becomes available. The tool is easily updated as new MSC IDF curve parameters are published.

The interface tool is available through the MTO Website at:
http://www.mto.gov.on.ca/IDF_Curves/terms.shtml



The Ontario A values are used in the equation R = A•τ-B for the generation of IDF curves. The A values are equivalent to the values for the 1-hour design storm. The values shown are for the 100-year design storm, with time-trend adjustments to 2010. The inset provides detail for the City of Hamilton and surrounding area *(Used with permission E. Soulis, University of Waterloo)*.

8.2.3 ESTIMATING FLOOD RISKS

As waters rise, whatever the source, decision-makers and owners need to improve their understanding of the properties and activities that are at risk for direct or indirect damage or loss (Table 8-1). Too often, too little emphasis is placed on the cumulative effects on flooding caused by the combination of a range of factors (e.g., rising sea levels, higher tides, storm surge, intensive wave action, snow and ice melt, cloudburst precipitation, dam or levee failures). In coastal locations such as Greater Vancouver, higher tides, rising seas, and storm surge can combine with precipitation events to exacerbate anticipated overland flooding estimates, and waters rushing downstream in rivers are blocked by higher sea levels and spill onto adjacent lands. More intensive storms can drive higher water levels and taller waves into nearshore areas, overtopping existing seawalls and adding to the water collecting behind local dykes.

Flood risks can also be compounded by associated changes in soil and stream bank stability, leading to landslides, channel collapse, and entrained debris in the flow area (Jacob et al. 2016). Rare and dangerous storms can cause precipitous change in shorelines and topography, posing significant threats to human health and safety.

Many municipalities across Canada are challenged to both identify flood risks and to manage land use in designated areas at risk due to the increased need for (SFU/Act 2014):

- updated and improved floodplain mapping, and technical information on flood hazards;
- data to close gaps on weather systems and local flood levels;
- research on projected changes in local and regional environmental conditions;
- inventories of local infrastructure and valued attributes;
- model guidelines for standardized, quantitative flood risk assessments that estimate expected consequences and factor in the potential for cascading impacts;
- enhanced local capacity and/or access to expertise and experience;
- adequate funding for flood management;
- improved coordination of planning and governance across jurisdictions and sectors;
- fora to determine acceptable levels of risk tolerance, while recognizing that risk tolerances vary geographically and socially;
- regional, strategic, adaptive, flexible and proactive flood management and mitigation strategies; and/or
- tools for effective communication of risk to the public.

FLOOD MANAGEMENT TERMS

BASE FLOOD ELEVATION (BFE): the 100-year flood elevation that results in the elevation of wave crests above the stillwater elevation resulting in wave runup on shore and overtopping of seawalls.

DYNAMIC COASTAL FLOOD MODELING: physics-based computer simulations that incorporate factors such as wind, atmospheric pressure, and friction in the determination of coastal flood elevations (also known as hydrodynamic modeling).

FLOOD EXCEEDANCE CURVES: the relationship between flood intensity and different levels of frequency. Each curve represents the flood intensity that is anticipated will be equaled or exceeded once in a prescribed number of years.

FLOOD HAZARD ASSESSMENT: the statistical evaluation of the annual likelihood of a given flood event for a range of different flood elevations.

FLOOD ZONE: a statistically-defined region whereby each point within is subject to a flooding at a given annual probability.

FLOODPLAIN: a broad, relatively flat land area subject to flooding from a river, lake, ocean, or other water body.

RETURN PERIOD/RECURRENCE: the average interval, in years, between occurrences of two floods of equal or greater magnitude, based on the probability that the given flood event will be equaled or exceeded in any given year.

STILLWATER ELEVATION: the water elevation during a storm expressed as a combination of storm surge and tide, but not including wave height.

WAVE SETUP: the rise in stillwater elevation that is driven by the unidirectional effect of waves breaking, thus pushing water onshore.

(Adapted from Patrick et al. 2015)

TABLE 8-1: Summary of assets with potential vulnerability to flooding *(adapted from Lyle and Mills 2016).*

INFRASTRUCTURE	ECONOMY	SOCIETY	CULTURE	ENVIRONMENT
Road and rail networks, airports, rail lines, tunnels and bridges, port and harbour docking and storage facilities	Commercial and retail service centres, malls, shopping areas	Single family homes, residential multiplex units and towers, some with below grade living units	Religious institutions	Shorelines, dunes, beaches
Electrical substations and transmission lines, local distribution infrastructure	Transportation hubs, including train and bus stations, rapid transit stations, ports and airports	Early childhood and daycare centres, schools, libraries, colleges and universities	Museums, galleries and archives	Wetlands, saltmarshes, seagrass beds, coastal forest
Water and wastewater systems (e.g., pumping stations, treatment ponds, piping, outfalls),	Tourism facilities (e.g., restaurants, hotels, cruise ship terminals, aquaria)	Hospitals, medical centres, laboratories	Cultural landscapes and heritage sites	Parks and protected areas
Fire stations, police stations, city maintenance yards	Industrial facilities, including food distribution nodes, some with below ground facilities	Senior housing and nursing homes	Recreation centres, pools, ice rinks, active sports fields	Open air storage of contaminants (e.g., salt, fertilizer, pesticides) at retail centres
Cellular phone communication towers, internet access, radio and television broadcasting services	Water dependent industries such as marinas, ferries	Social service centres, community centres, homeless shelters, food banks, animal shelters		Bulk storage of hazardous materials (e. g., fuels, salt, chemicals)
Industrial infrastructure, treatment ponds, effluent disposal pipes & outfalls		Previously designated emergency access routes, community shelters and mass refuges		Solid waste management areas, contaminated sites, landfills

TYPES OF FLOODING *(Adapted from Dhonau et al. 2015; GOV/UK/DEFRA 2007; Swiss Re 2016)*

PLUVIAL FLOODING is generally the result of short duration, localized precipitation events that can equal the average rainfall of one or two months. Torrential downpours overwhelm stormwater systems, triggering flash floods in hilly areas, and overland flooding in flatter locations.

FLUVIAL OR RIVERINE FLOODING, or overbank flooding, occurs when downstream channels receive more water from rain or snow melt, or from dam or dyke failures, than they can accommodate.

GROUNDWATER FLOODING occurs when infiltration of long and/or intense rainfall or snowmelt elevates the water table resulting in pooled water in low lying areas and flooded basements and/or lower levels of buildings.

COASTAL FLOODING along marine coasts as well as the shores of the Great Lakes is the result of storm surges (high winds and air pressure changes that push water towards the shore), as well as higher waves, higher tides, and in some areas, land subsidence and sea-level rise. Coastal flooding can also occur as a result of landslides and seismic events.

RESERVOIR OR DAM FLOODING is rare in Canada but can occur when reservoir containment or river dams fail or are overtopped.

BURST WATER MAINS can release considerable volumes of water, flooding streets and property and causing structural and system damage.

SEWER FLOODING is caused by blockages in sewer pipes, failures in equipment, too much stormwater/floodwater in sanitary sewer systems, and/or undersized sewers. Sewage escapes from piping through manholes, drains, or by backing up into buildings through toilets, baths and sinks, and flood drains.

Knowing more about the problem requires data not only on the potential areas to be affected by overland flooding, but also on the assets and activities that take place in those areas, and the extent to which human safely may be affected, and/or assets may be vulnerable to damage or destruction. There is a wide array of models available for estimating the risk of flood, and for calculating the direct and indirect damages and losses in areas vulnerable to flooding.

Flood adaptation strategies have become a necessity for cities such as Surrey, British Columbia – where 20% of the land area sits in the coastal floodplain, vulnerable to coastal and river flooding (Figure 8-7).

The City of Vancouver (2014) used the HAZUS model developed by the Federal Emergency Management Agency (FEMA) in the United States, which is being adjusted for use in Canada by Natural Resources Canada (Lyle and Mills 2016). HAZUS combines science and engineering with GIS (geographic information systems) technology to produce estimates of hazard-related damages and loss. While an adequate tool for estimating damage to structures, HAZUS has been found to have more limited capacity to advance understanding of the tangible and intangible impacts to human society and to individuals.

FIGURE 8-6: Flooding along the Gatineau shoreline of the Ottawa River in 2018 *(Image Credit: C. Mercer Clarke).*

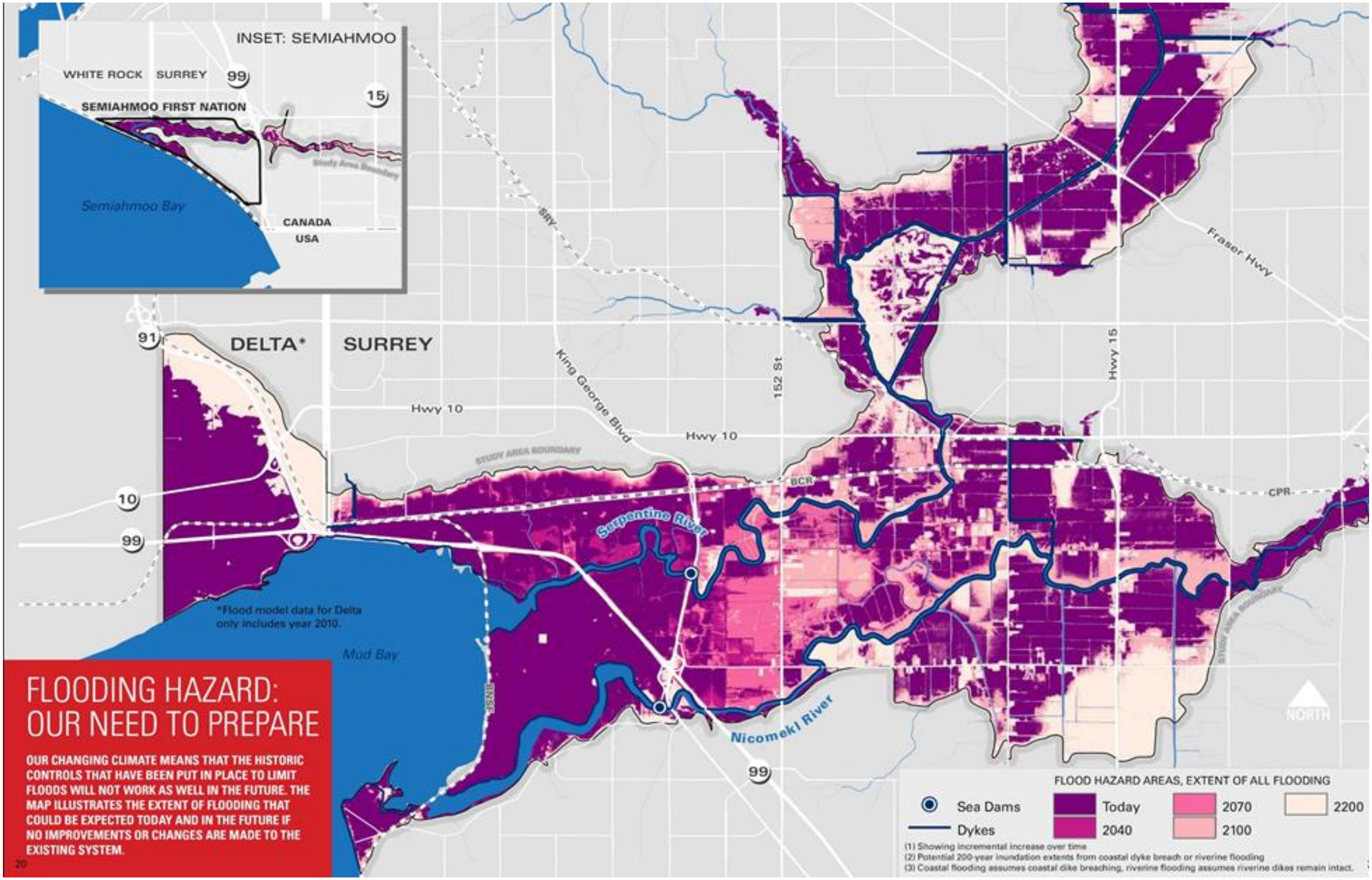


Figure 8-7: Flood hazard mapping as prepared by the City of Surrey *(City of Surrey 2017. used with permission).*

8.2.4 MAPPING THE CHALLENGES

Data collection and analyses on key changes in environmental conditions can provide a solid foundation for understanding the vulnerabilities and risks to human society and to natural environments. However, without some form of visualization of this information, or mechanisms to relate one data set to another, knowledge may not be useful to decision-making. Additionally, in some areas, available information may not be relevant to the more local scale at which decisions need to be made (e.g., anticipated changes in mean global annual temperature, national averages for sea-level rise). Managing for rising waters requires a wide range of information on topics as disparate as the capacity of existing stormwater systems and the stability of local beach dune complexes. Information on social vulnerability can direct attention where management is needed most, and/or ensure the safety of less mobile sectors of the population.

Geographic information systems (GIS) have become more affordable and easier to use, all while developing increasingly sophisticated capacities for the storage and analysis of data and information. Data entered into a GIS system can be analyzed and presented in statistical as well as visual formats, improving understanding of trends and of cause and effect relationships (e.g. changes in river water levels and expansion of flooding areas). GIS systems also allow for the collection and inclusion of traditional and local knowledge in improving understanding of past, current and potential future changes. GIS products are often used as valuable tools for communication to a wider, non-expert audience (Figures 8-8, 8-9, 8-10) (UBC/CALP 2010). Complex scenarios for future land use management, and the direct and indirect consequences of failures to act responsibly, can be visually presented over a range of alternative futures.

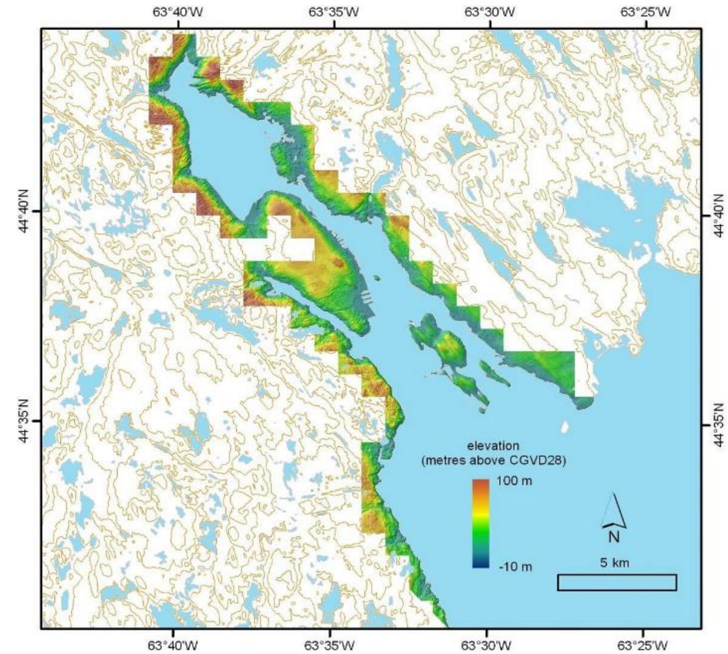


FIGURE 8-8: A subset of the 1 km2 tiles that form the digital elevation topographic model built to estimate flood hazards in Halifax Harbour *(Forbes et al. 2009)*

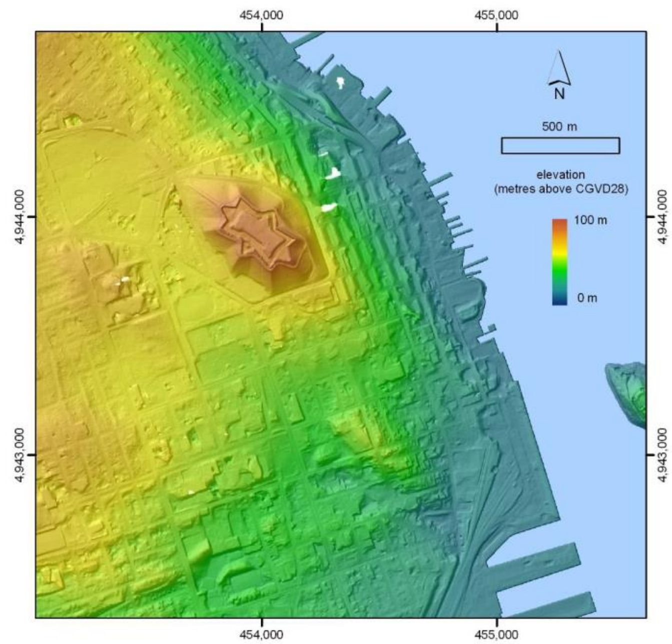


FIGURE 8-9: A section of the 'bare-earth' digital elevation model for part of Halifax Harbour displayed as a colour-coded shaded-relief image, where the colours denote elevation ranging from dark blue (sea level) to green, yellow, and orange (higher elevation) *(Forbes et al. 2009)*

However, GIS tools are only as good as the data provided. Many municipalities may not as yet have compiled the needed information on environmental, economic, social and cultural conditions that define their community. Prior to the development of options for management of rising waters, locally relevant data may be needed on:

- local geomorphology, stability and erosion and sedimentation processes, including beach dynamics (e.g., beach composition, width and slope, area and height of dunes and backshore areas);
- local, area and stability of wetlands and salt marshes, included trends in habitat loss;
- tidal range (including seasonal extremes) and wave climate exposure (e.g. wind fetch, geomorphology);
- volume of annual and seasonal riverine inputs, including sedimentation levels;
- rate of local sea-level rise (including land subsidence);
- number, location and condition of existing shoreline protection measures (e.g., groynes, seawalls, revetments);
- 25, 50 and 100-year flood zone area delineations, including storm surge inundation zones and highest highwater lines for 10, 25, 50 and 100-year storms;
- area of impervious surfaces and the number, size and condition of stormwater detention basins and areas;
- water contamination sources (e.g., piped effluents, surface water, ground water;
- land ownership, infrastructure and assets in potentially vulnerable areas;
- land cover and land use classification, zoning, setbacks and other land management tools; and/or
- valued scenic vistas and views, cultural landscapes and historic sites of significance.

Because data is loaded into GIS systems in 'layers', information on seemingly disparate topics (e.g., aging populations, evacuation routes, flood vulnerability) can be easily compared. The risks of flooding can be readily co-related to the value of potentially impacted real estate, improving understanding of the potential costs associated with sea-level rise and/or storms, assisting in priority setting for action, and providing valuable insight into future planning to reduce or avoid risks. Visualization technologies based on these tools can also be an important tool when communicating risks.

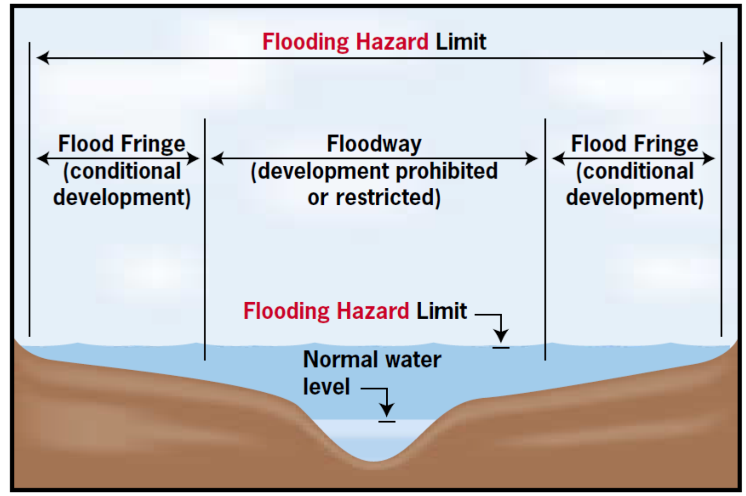


FIGURE 8-10: Flooding hazard limits as depicted by the Government of Ontario *(GOV/CAN/ON 2001)*

LIDAR, DRONE, AND RTK

Many communities in Canada have access to topographic and bathymetric (depth of marine waters) data, but in some the information can be dated or available at scales that do not translate well to local risk assessment and flood planning (e.g., 1: 50,000). In areas of the country where topographic data and maps are provided by national and provincial governments elevation changes may only be available in 5 metre contours, which is generally insufficient for flood risk assessment and planning. Three things basically determine how vertically accurate mapping needs to be when assessing food risks:

- the terrain in the area (e.g., flat, rolling, steep);
- the perceived value (e.g., economic, social, environmental) of the assets at risk; and
- the resources available for the development of better mapping.

Flatter terrain may require more accuracy in mapping because even a small increase in water levels can flood large areas. Hillier terrain requires less vertical accuracy because small changes in water levels will affect much less of the surrounding area. Unless the assets under potential threat of inundation have significant economic, social, cultural or ecological value, there may not be a need to provide detailed documentation of the threat to their sustainability now or into the future. But perhaps most difficult of all, are the situations where the land is vulnerable to flooding, the assets are important, and the community has few resources to purchase the technology needed to produce better mapping. Topographic data can be improved through a number of approaches that range significantly in cost:

- LiDAR (light detection and ranging) technology records precise, three-dimensional data on land, water and structures. For topographic surveys, the LiDAR equipment is mounted in aircraft which cover large areas in a relatively short time. The costs to obtain LiDAR data can be high, but sharing the initiative with other/nearby communities can reduce the cost to each;
- Survey grade mapping drone technology, which can be used to provide elevation information for smaller areas, can be much cheaper while still providing elevation data accurate to within a few centimeters; and
- RTK (real time kinematic) surveys use Global Navigation Satellite systems to accurately document topography in the immediate area. RTK can be implemented by individuals but is most useful when determining elevation data for specific sites.

It is important to determine the scale of information and the accuracy of the data needed before moving to contract expensive survey operations to supplement publicly available topographic information. Then too, while LiDAR data may exist, it is not always freely available and the costs to gain access can be substantial.

LiDAR (LIGHT DETECTION AND RANGING)

LiDAR is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. A LiDAR instrument consists of a laser, a scanner, and a specialized GPS receiver. Mounted in helicopters or other aircraft, LiDAR systems can use either a near-infrared laser to map land topography, or a water-penetrating green light to measure bathymetry such as seafloor and riverbed elevations.

When an airborne laser is pointed at a targeted area on the ground, the beam of light is reflected by the surface it encounters. A sensor records this reflected light to measure a range. When laser ranges are combined with position and orientation data generated from integrated GPS and Inertial Measurement Unit systems, scan angles, and calibration data, the result is a dense, detail-rich group of elevation points, called a "point cloud."

Each point in the point cloud has three-dimensional spatial coordinates (latitude, longitude, and height) that correspond to a particular point on the Earth's surface from which a laser pulse was reflected. The point clouds are used to generate other geospatial products, such as digital elevation models, canopy models, building models, and contours. LiDAR technology allows scientists and decision-makers to examine both natural and man-made environments with accuracy, precision and flexibility.

(NOAA: Available at: http://oceanservice.noaa.gov/facts/lidar.html).

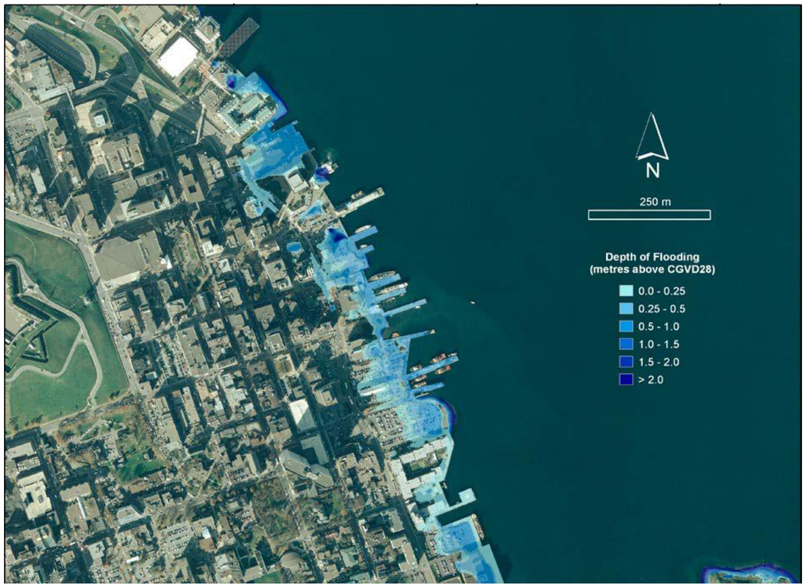


FIGURE 8-11: Projected extent of flooding in downtown Halifax in 2100 using LiDAR data and based on conditions that include a 1.3 metre sea-level rise, and a major storm (50-year return period). *(Forbes et al. 2009, Image Credit: D. Forbes).*

8.3 CONFRONTING THE PROBLEM

Whether the threat of flooding is from heavy precipitation, overbank flooding and/or the combined threats associated with higher levels in coastal water (e.g., sea-level rise, high tides, storm surge, wave action), communities and individuals have generally only two choices, stay (persist) or leave (migrate) (Figures 8-12, 8-13).

Persisting in place is not without cost. Staying, or persisting in place, requires acceptance of the intensifying impacts posed by rising waters to buildings and to activities, and/or initiation of (often costly) efforts to protect those assets from flooding by improving stormwater management systems, by waterproofing structures, by raising structures out of harm's way, and/or by building protective measures (e.g., dykes, levees, seawalls, groynes, breakwaters) to hold back the rising water. As damage from storm events and seas climbs and insurance claims rise, leaving may still not be a workable option for homes and businesses that are threatened by changes in the environment, whether those changes are the result of savage and immediate storms, or the slow onset of creeping hazards associated with climate change.

Persisting in place has challenges, not the least of which is brevity of the useful lifespan of most efforts undertaken today. Protective measures will reduce the potential for impacts in the near term. However, as seas continue to rise, and stormwater loads to increase, over the coming decades protective measures will be less effective in preventing flooding, and migration to safer areas may become the most viable option.

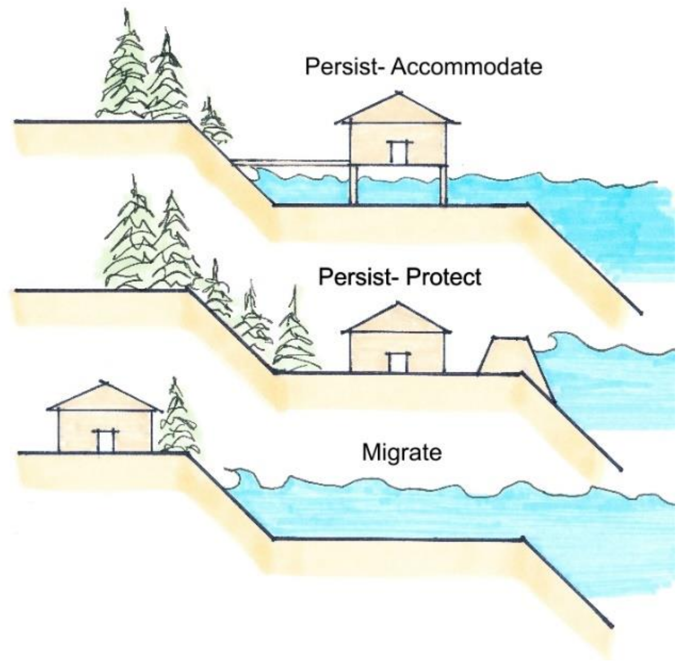


FIGURE 8-12: Generic options for planning for sea-level rise and/or flooding *(Adapted from Nicholls 2011)*

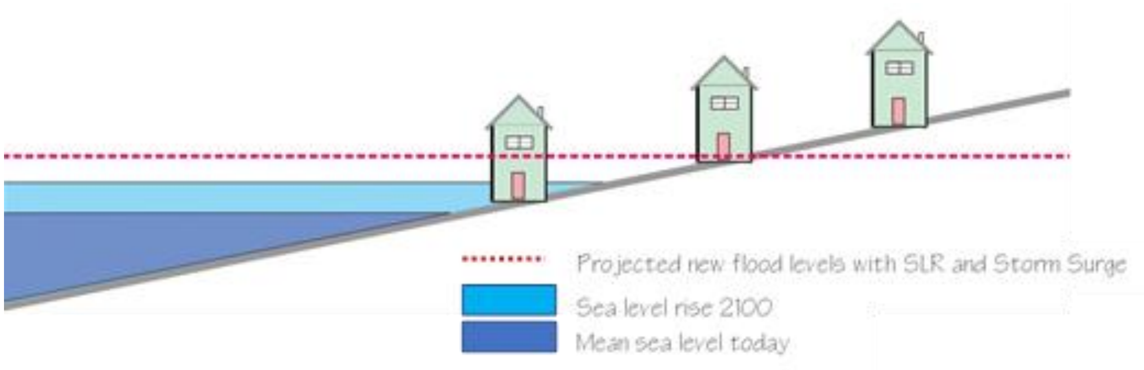


FIGURE 8-13: Graphic depiction of the creeping hazard posed over time by rising sea-levels *(Adapted from GOV/USA/EPA 2009).*

REGIONAL INITIATIVES PROGRAM

Since 2007, the Government of Canada, through Natural Resources Canada, has been implementing a cost-shared program with the Provinces and Territories designed to help Canadians reduce the risks and maximize the opportunities posed by climate change. Regional Adaptation Collaboratives (RACs) on all coasts have been working to develop resources and tools to aid in adaptation.

Information developed by RAC teams and affiliates is referenced throughout this primer. Of relevance to this Chapter, are three new reports released by the Atlantic Climate Adaptation Solutions Association (ACASA) that are intended to aid communities in Atlantic Canada in efforts to plan for and to adapt to rising waters. While the information is keyed to the east coast, readers will find resources and information appropriate to a wider audience. Linkages to the reports by van Proosdij et al. (2016), Manuel et al. (2016), and Leys and Bryce (2016), have been included in the Web Resources and Key Reports at the end of this Chapter, as well being cited in the References.

Adaptation efforts that intend to promote persisting in place should be guided by the following goals (Georgetown Climate Center 2011):

- **ACCOMODATION GOAL:** Continued use and development of lands deemed in harms way will be allowed if structures and systems are built, retrofitted and/or operated so as to reduce risks and to become more resilient to sea-level rise, severe weather and overland flooding.
- **PROTECTION GOAL:** Protection of people, property and infrastructure from sea-level rise, severe weather and overland flooding is the priority for adaptation efforts. Hard engineered solutions (e.g., seawalls, levees, dykes, shoreline armouring) will be used to reduce risks of damage and to ensure human health and safety.

Persisting in place will require management of stormwater at source, improving the flood resilience of buildings and systems, strengthening natural features to enhance their capacity for sheltering, and building protective structures to reduce the potential for overland flooding.

Twelve key principles have been articulated for management of flood risks in urban areas (Jha et al. 2012):

- each scenario for flood risk is different, there is no one blueprint for action that works everywhere;
- planning and design for flooding must also address a changing and uncertain future;
- flood risk management should be integrated into regular urban planning and governance;
- integrated flood risk management must include a combination of structural and non-structural options;
- engineered flood risk management measures can transfer risk upstream and downstream or along coasts;
- it is entirely impossible to remove all risks of flooding;
- flood risk management approaches can have additional co-benefits beyond their primary mandate;
- flood risk management measures must also consider the wider implications to social and ecological conditions;
- accepted responsibility for construction and maintenance of flood risk management measures is critical;
- implementation of flood risk management requires agreement and cooperation across multiple stakeholders;
- continuing communication to ensure awareness and to reinforce preparedness is essential; and
- flood recovery is an essential element and must address the opportunities to build capacity.

FLOOD MANAGEMENT TERMS

FLOOD FRINGE: The portion of the flood hazard area outside of the floodway. Water in the flood fringe is generally shallower and flows more slowly than in the floodway. New development in the flood fringe may be permitted in some communities and should be flood proofed.

FLOOD HAZARD AREA: The area affected by the design flood under encroachment conditions. The flood hazard area is typically divided into floodway and flood fringe zones and may also include areas of overland flow.

FLOODWAY: The portion of the flood hazard area where flows are deepest, fastest and most destructive. The floodway typically includes the main channel of a stream and a portion of the adjacent overbank area. The floodway is required to convey the design flood. New development is discouraged in the floodway and may not be permitted in some communities. *(Kovacs and Sandink 2013)*

READYING FOR DISASTER

Planning for resilience must also address situations that can arise when risks cannot be avoided. While adaptation planning may focus on creating resilient communities, all efforts must address readiness for disaster, ensuring that resources are available, critical systems will operate and recovery will be rapid and effective (GOV/USA/NAS 2012, 2013, 2015a, 2015b; Howes et al. 2013; UNISDR 2015).

FIGURE 8-14: The Government of Canada has disaster preparation and assistance programs intended to assist Canadians in reducing the impacts of flood waters and to respond to the financial needs of provinces and territories in the wake of natural disasters, including the FLOODREADY program and the National Disaster Mitigation Program. More information is available at: https://www.canada.ca/en/campaign/flood-ready/communities.html?utm_source=Acart&utm_medium=FCMnewslett

8.3.1 HOW WATER MOVES ACROSS THE LAND

Four characteristics of water are critical to how it performs in the environment and how it can best be managed, whether it falls continuously or sporadically:

- the way water collects on the land;
- the materials over which the water runs, including vegetation;
- the steepness of the surface over which the water drops, or flows;
- and the shape of the land in which the water collects.

When small amounts of water move slowly across a gentle slope comprised of porous soils or vegetation, most of the water will be absorbed. If any of these conditions change, stormwater movement also can change dramatically. Larger volumes of water, or water moving faster over steep grades, will flatten vegetation and/or erode soft soils. Large or small volumes of water flowing quickly, or slowly over relatively hard or impervious surfaces will not be absorbed (Figure 8-15) (Thompson and Sorvig 2008)

In some Canadian communities, especially older cities with combined storm and sanitary systems, intensive storm events can result in sewer overflows when capacity is exceeded. Overflows during peak rainfall events can result in untreated municipal waste and contaminated urban runoff reaching local watercourses and increasing the risk of contact with local residents (CWN 2015), especially when the overflows empty to parklands or to water bodies that serve as drinking water sources.

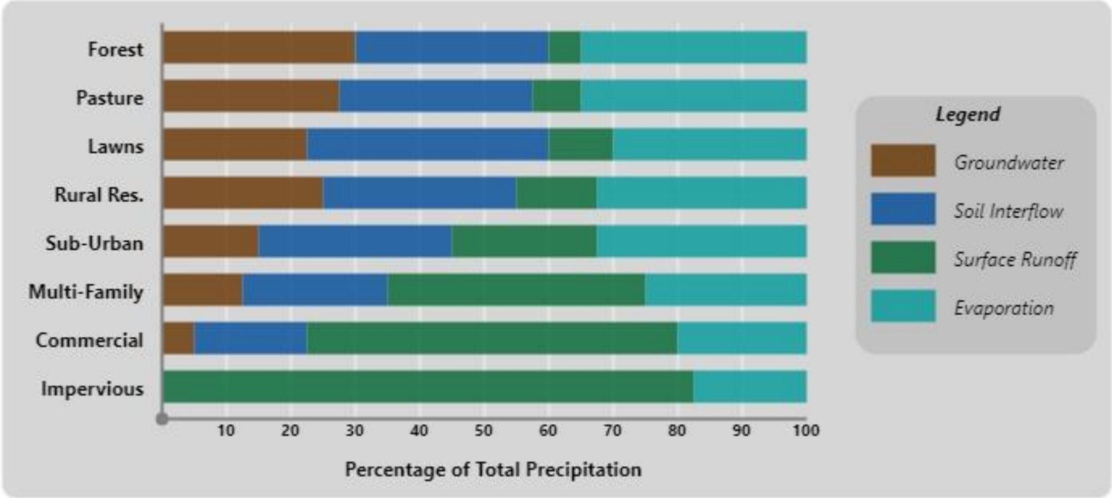


FIGURE 8-15: The effects of land cover on the movement of rainfall through the hydrogeological cycle *(adapted from Schreier 2014).*

STORMWATER: Water that accumulates on land as a result of precipitation events. Impervious land cover like roads, driveways, sidewalks and roofs prevent stormwater runoff from naturally soaking into the ground, thereby creating faster and greater volumes of surface flows. Stormwater can be contaminated with nutrients from fertilizers and wastes, and with other pollutants such as pesticides and heavy metals. Unmanaged stormwater can cause serious physical and chemical damage to ecosystems (e.g., streams, wetlands, lakes and estuaries) and to property, particularly where land cover and land use change from natural to rural, urban and/or industrial. *(Adapted from Peterson et al. 2010)*

IMPACTS OF INTENSIVE STORMWATER RUNOFF

- Lower rates of infiltration to groundwater
- Less snow, more rain may change the runoff/infiltration balance, altering base flow in streams, especially spring run-off pulses
- Increased concentration of pollutants in surface water and groundwater
- Overcapacity flows in combined storm and sanitary sewer systems and treatment facilities
- More scour and erosion of natural watercourses
- More flooding in settled areas
- Overtopping of flood management infrastructure and containment ponds (e.g., dykes, dams, detention basins, sewage treatment, farm manure management)
- Failures in septic systems

8.3.2 MANAGING STORMWATER

Stormwater accumulates either from steady periods of heavy rainfall, as the result of cloudburst (i.e., short, intensive and localized periods of rain), or as a combination of precipitation with snowmelt. As the climate changes and weather patterns become more erratic, regions of the country may be subject to periods of drought and periods of intense precipitation. Stormwater management systems in Canada were designed along established parameters typically derived from historical averages for anticipated precipitation and have seldom been sized to contain and transport stormwater from the increasingly frequent occurrence of 100-year storms. Natural watercourses, the eventual recipient of most stormwater, evolved to carry typical water loads; such as have been the tradition of one in 10 or one in 25-year storms. The unanticipated changes in precipitation events and patterns that have been experienced in Canada in the past few decades have exceeded the capacity of existing stormwater infrastructure and natural systems to carry the load, resulting in overland flooding, sometimes in areas that have not experienced floods in the past.

Traditional methods for stormwater management were based on the conveyance of surface runoff as quickly and directly as possible from the site to the nearest receiving natural watercourse (e.g., streams, lakes, rivers, wetlands, marine waters). In general, runoff is channelled into pipes and sewers, without consideration of entrained contaminants (including nutrients) that accumulated from urban or rural land uses. Because runoff is moved directly to the watercourse, during storm events the water levels in those features reach peak flows quickly, contributing to increasing erosion of stream banks and channel bottoms, suspending and transporting sediments, and diminishing water visibility and water quality. As peak flows from precipitation events are increasing with climate change, the tendency has been to consider upsizing stormwater management piping to address the higher flows.

Adapting to the changing conditions in precipitation events and in stormwater management will best be achieved not by enlarging the capacity of stormwater systems, but by managing water where it falls, rather than moving it quickly over impervious surfaces to discharge into the nearest receiving natural environment (e.g., streams, lakes, wetlands, ocean). Expertise in a range of approaches that contribute to rainwater management (i.e., Low Impact Development, Green Streets) is growing, inspiring new visions for urban living, and challenging stormwater managers to see what more can be done with the water at hand. Innovative planning and design are retrofitting inner city neighbourhoods to create parks and waterways, to daylight piped streams and rivers, and to green hard surfaces such as rooftops and parking areas (Porter-Bopp et al. 2011). Stormwater management has become a multi-functional planning and design approach to urban living. Captured rainfall, an integral element of urban living, can be a valued resource for livable cities, harvested to support urban plantings, and to provide interest and variety to urban landscapes. Management of stormwater through capture, infiltration and reuse, will reduce pressures on the flow capacity of stormwater systems during peak events, reducing the potential for urban flooding, negating the costs to upsize infrastructure, and improving water quality overall.

STORMWATER MANAGEMENT TERMS *(Adapted from Kovacs and Sandink 2013)*

MINOR SYSTEM: Underground sewers, catch basins and other drainage works that convey stormwater from minor storms. Minor storms have been considered to be those with a return period of 5 years or less.

MAJOR SYSTEM: The drainage system in place to convey stormwater from major storms (100 Year), including municipal infrastructure, but relying also on managing flows across private and public property through lot grading, roadways and water storage facilities.

MASTER DRAINAGE PLAN: Municipal and regional plans that ensure development of an optimal drainage system to meet present and future stormwater drainage requirements.

SEWER BACKUP: Sewers flowing in a surcharged condition can result in the backup of water with the potential to cause basement flooding and structural damage. This risk is increased when weeping tiles and roof leaders are connected to the sewer system.

BACKWATER VALVE: A backflow prevention valve that prevents sewage from backing up into property through the sewer lateral.

COMBINED SEWER: A sewer intended to receive both stormwater and wastewater.

SANITARY SEWER: A sewer intended to receive human wastewater.

STORMWATER SEWER: A sewer intended to receive only stormwater.

SANITARY SEWER OVERFLOW: A discharge to the environment from a sanitary sewer system.

COMBINED SEWER OVERFLOW: A discharge to the environment from a combined sewer system.

RISK REDUCTION GOAL: A goal used when practical, stormwater management focused on reduction in stormwater runoff through limitation of impervious surfaces, and/or collection at source for storage, reuse, infiltration and/or slow release to the environment. Efforts are made to attain acceptable water quality before release.

The simplest and most successful rules for stormwater management are (Table 8-2) (Thompson and Sorvig 2008):

- deal with stormwater first where it falls (i.e., impoundments, pervious pavements);
- use vegetation to slow water flow and to improve water quality before it reaches groundwater or surface waters;
- provide vegetated buffers to natural channels, avoid straightening from natural configurations, do not harden the channels and find ways to reduce the first flush quantity of water generated by storm events;
- store water where it falls to allow for evaporation, infiltration and for reuse in the landscape;
- isolate and treat runoff from pollutant collecting pavements (e.g., gas stations, storage pads);
- make stormwater retention useful and beautiful; and above all,
- reduce paved and impervious surfaces, including setting a maximum width for streets.

STORMWATER POLICY ADAPTATION

- Update provincial stormwater management requirements to require flow reduction and management and to ensure water quality entering surface waters
- Update watershed and sub-watershed management plans ahead of any proposed expansion of urban boundaries, or any major urban development or redevelopment to ensure that adequate care has been taken to assess the cumulative effects of climate change
- Advance stormwater management that promotes control at source through low impact development (LID), system resilience to severe storm events, and the promotion of green infrastructure
- Require incorporation of LID principles and resilience to climate change in all new development, including urban design, roads and buildings. Require the same of retrofit projects. Link requirements to funding opportunities
- Separate stormwater and sanitary wastewater systems
- Provide for treatment of stormwater before disposal to the environment
- Ensure that natural landscapes important to retention and filtering of runoff from developed lands (e.g., wetlands) and to the safe passage of floodwaters (e.g., floodplains) are protected and/or restored to ensure their effective functioning

TABLE 8-2: Comparison of traditional stormwater and newer rainwater management approaches *(adapted from Schreier 2014).*

RAINFALL MANAGEMENT SCALE	Traditional Stormwater Management Approach	Alternative Rainwater Management Approach
SITE	Drain and remove rainfall and runoff	Reduce impervious surfaces
	Collect roof drainage and direct to stormwater system	Retain rainfall from roofs and impervious surfaces for reuse on site.
		Slowly release water through green roofs, and groundwater infiltration systems
		Improve soil conditions to maximize infiltration and water storage
		Plant trees and vegetation
NEIGHBOURHOOD	Upsize collector pipes size and number of roadside catchment basins	Minimize road widths, parking lots and reduce use of impervious pavements
	Harden stream channels and lake shores	Direct road and impervious surface runoff to infiltration swales and rain gardens
	Store water in engineered detention ponds	Protect, enhance and create wetlands in local neighbourhoods
		Slow runoff by directing first to naturalized swales and detention ponds
WATERSHED	Increase size of outfalls to natural watercourses	Promote slow release and infiltration systems.
	Upsize protective structures (e.g., dykes, levees, dams)	Create large, continuous riparian buffer zones along water bodies and wetlands
	Restrict land use in designated flood plain areas	Diversify stream channels into meandering and side stream systems
		Provide for overbank flooding areas adjacent to water bodies
		Enforce land use restrictions in designated flood plain areas.

8.3.3 LOW IMPACT DEVELOPMENT (LID)

Sometimes implementation of low impact development practices requires a new vision for land development and water storage and movement. Sometimes it provides needed justification to abandon perceptions that wider roads and larger parking lots are best. Most LID initiatives are based on the principle of stormwater as a resource that should be captured, harvested and reused (Figures 8-16, 8-17). LID approaches can create livable spaces in which stormwater management systems are integral components of greening cities and streets – a win-win situation that provides many related benefits to city dwellers and to local environments (City of Edmonton 2011). Many communities are adopting a low impact development approach in switching from traditional stormwater management initiatives to rainwater management. Rainwater management focuses on creating more positive relationships between urban drainage and ecosystems (GOV/CAN/BC 2011), and includes LID approaches such as:

- collecting, storing, reusing and/or infiltrating rainwater to reduce the volume of runoff;
- minimizing the area of disturbed lands, and maintaining natural buffers around aquatic resources;
- minimizing impervious land cover through design practice and the use of alternative (pervious) pavements;
- reducing opportunities for soil compaction; and
- creating rain gardens, bio-swales, improved street tree planting methods.

Porous concrete. *(Image Credit: JJ Harrison/WikiPedia CC BY-SA 3.0)*

LOW IMPACT DEVELOPMENT (LID)

Low Impact Development is an innovative approach to land development that mimics the natural movement of water to manage stormwater (rainwater and urban runoff) close to where it falls

LID uses small, simple design techniques and cost-effective landscape features that allow water to infiltrate, filter, store, evaporate, and detain runoff located at the lot level. *(CVCA 2012, CVCA and TRCA 2010)*

PERMEABLE PAVING refers to a range of sustainable materials and techniques that utilize a base and subbase to allow the movement of stormwater through the surface. In addition to reducing runoff, permeable pavements can effectively trap suspended solids and filter pollutants from the water *(adapted from Wikipedia)*.

Permeable pavements have become much more than pavements with spaces for water penetration. New developments in concrete and other materials have developed pavement materials through which water can pass unobstructed.

FIGURE 8-16: Low impact development enhancing tree canopy in Ampersand Green Park (*GOV/CAN/CMHC 2013*).

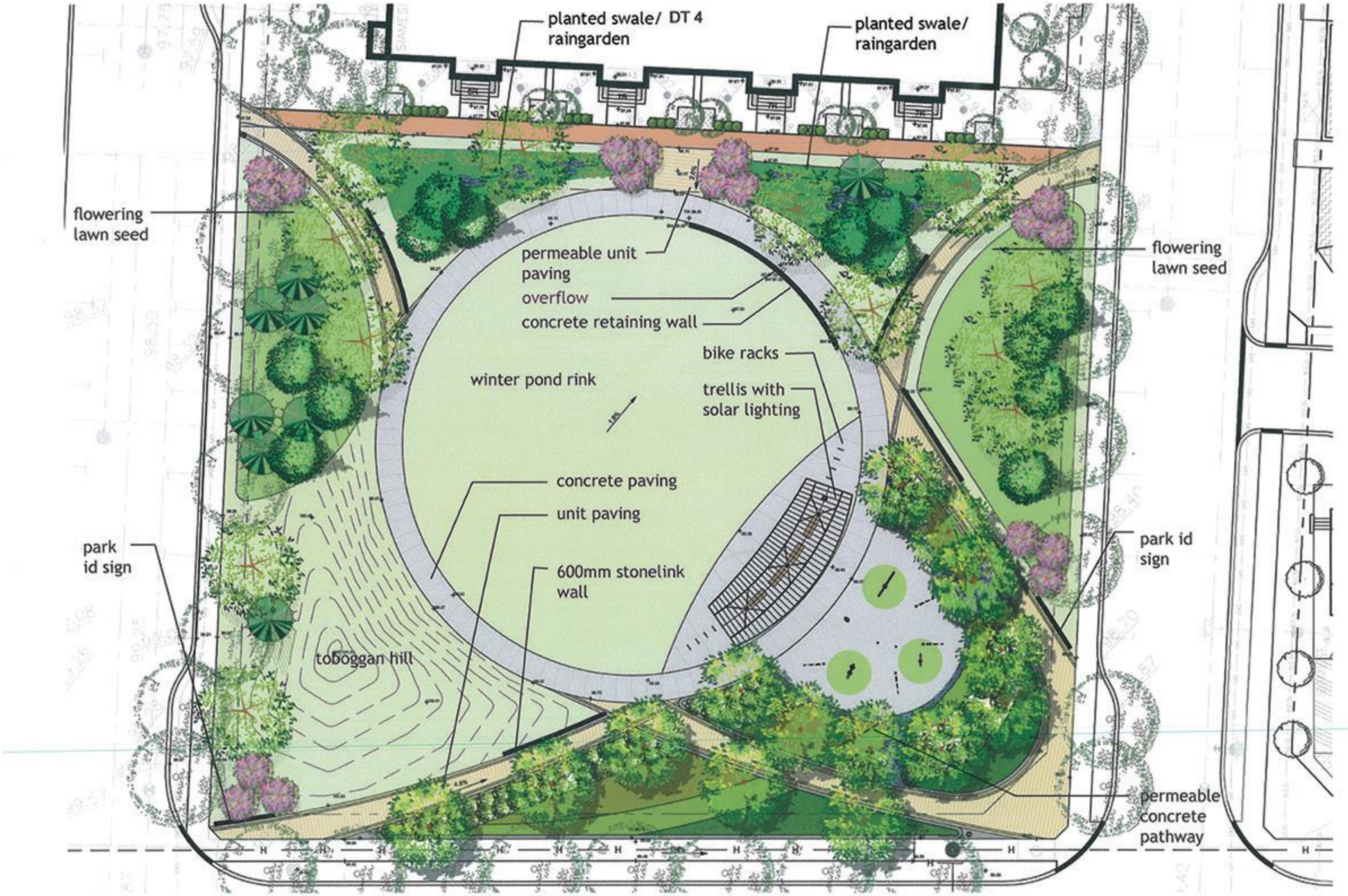


FIGURE 8-17: Low impact development utilizing rain gardens and permeable pavers benefit stormwater management and local environments in Ampersand Green Park (*GOV/CAN/CMHC 2013).*

8.3.4 GREEN STREETS

Green Streets are designed and maintained to mitigate the impact of stormwater runoff. Green Street designs begin with narrower streets and often include multi-use pathways and drainage swales that receive runoff from non-permeable pavements (Figure 8-18). Not only do these approaches reduce the volume and slow the pace of stormwater runoff, they enhance groundwater, improve the quality of fresh water receiving environments (e.g., streams, lakes, wetlands), reduce peak flow pressures on stormwater infrastructure, improve air quality, reduce urban heat effects, and reduce the need for stormwater treatment.

Along urban streets, greater attention is being given to enhancing the well-being of street trees, and improving infiltration of rainwater through the use of bioswales.

ROADS AND RUNOFF

In traditional settlements in much of Canada, roads were narrower, and often followed local topography rather than grid patterns. While these meandering paths may not be as efficient as modern connectors, repairing rather than replacing traditional road networks can have value. Narrower streets slow traffic, generate less runoff, improve aesthetics and raise property values.

Efforts to improve roads in areas of steep slope can require significant cut and fill. On a 30% slope, widening the paved area by as little as a foot on either side can increase fill requirements by more than 60%, and increase the width of the road footprint by more than 10 feet. For every inch of rain that falls, the addition of two feet of pavement to the road surface would add 700 gallons of runoff for every mile of road. This runoff must now go somewhere. *(Thompson and Sorvig 2008)*

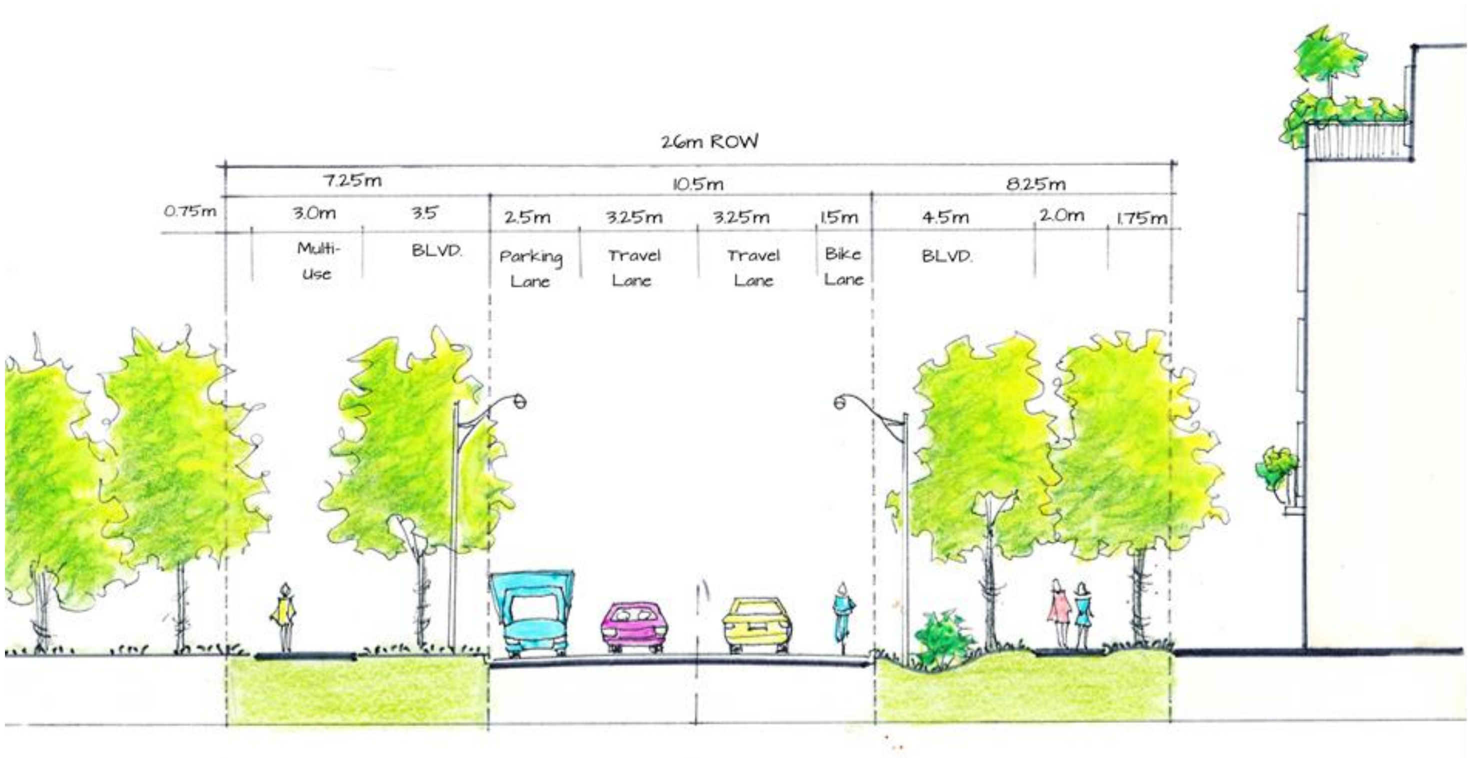


FIGURE 8-18: Sample guidelines for green street dimensions *(Adapted from City of Ottawa: Available at http://ottawa.ca/sites/ottawa.ca/files/migrated/files/con040683_123462995.jpg).*

BIOSWALES are landscape elements designed to concentrate or remove silt and pollution out of surface runoff water. They consist of a swaled drainage course with gently sloped sides (less than 6%) and filled with vegetation, compost and/or riprap. *(Wikipedia)*

BIOSWALES are created when land is contoured to create positive overland drainage to a collection area, that provides improved infiltration to soils and to groundwater. In urban areas, the relatively unused land between the street edge and the sidewalk is renovated to provide storage for the slow release of rainwater and planted with hardy and aesthetic species that reduce the concentrations of silt and urban pollutants in the water. (Figures 8-19, 8-20).

FIGURE 8-19: Use of street edge as bioswale and planting area. (Image Credit: *Wikimedia Commons. USA/EPA. Public Domain).*

FIGURE 8-20: Typical parking lot/street edge design for bioswale installation (*University of Michigan School for Environment and Sustainability, CC BY 2.0).*

8.3.5 IMPROVING RESILIENCE TO FLOODING

Accommodation to flooding can be passive or active. Passive accommodation accepts that areas will be inundated periodically, limiting the use of the site until waters recede. Designated flood plain areas, parking lots, open fields and forests, recreation fields are all examples of urban land uses that can be flooded without incurring significant costs for loss of access or damage. Active accommodation to flooding usually requires retrofitting existing assets, and/or application of new design and construction standards to new development, to reduce their vulnerability and enhance their resilience to flooding.

Four significant factors determine preparation and response to anticipated flooding:

- **Flood Depth:** The depth of water anticipated to occur at specific locations. Higher water depths can threaten human health and safety, and/or cause damage to building walls and foundations.
- **Flood Duration**: The length of time flood waters can be expected to remain. Temporary measures can deal with short term flood, but longer periods of inundation provide water with more opportunities to seep into structures and systems and threaten the long-term health and safety of humans.
- **Flood Onset**: The time it takes for overland and other flood waters to reach a location from the source of the flooding. Short-onset flooding (flash floods) are particularly dangerous because there is too little time to warn the public or to protect assets.
- **Flood Frequency**: How often flooding might be expected to occur, complicated now by climate induced environmental changes. Frequent shallow floods may be dealt with by localized protection or altered use. Less frequent but deeper floods may require retrofit for existing structures, rezoning to prevent new construction, and/or updated building codes.

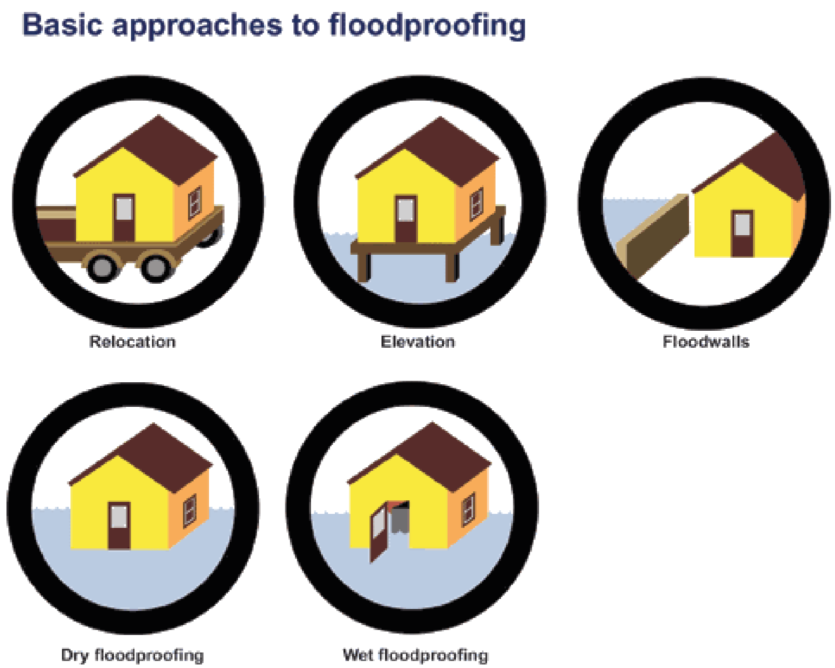


FIGURE 8-21: Basic options to avoid and/or reduce flood damage to structures *(GOV/CAN/ECCC: Accessible at: https://www.canada.ca/en/environment-climate-change/services/water-overview/quantity/reducing-flood-damage.html).*

Water can enter a building through several avenues including (GOV/UK/DEFRA 2007)

- groundwater seepage through foundations and basement and cellar floors;
- air vents and gaps around windows and doors;
- gaps around pipes and cables that pass through walls and floors;
- backflow through overloaded drainage and sewer systems;
- foundation walls above the waterproof treatment; and/or
- permeable brickwork, cracked bricks, and/or weathered or damaged mortar.

In addition to moving the structure, or providing protection walls, decision-makers can choose between two strategies for improving the resilience of structures to flood waters (Figure 8-21):

- **Water Exclusion** (Dry flood-proofing): water entry to buildings is prevented, structural integrity is maintained and the use of materials and construction techniques that facilitate drying and cleaning is promoted. Most appropriate for areas where anticipated flood conditions will not exceed water depths of 0.3m.
- **Water Entry/Exit** (Wet flood-proofing): flood waters can enter the building however provisions have been made for easier exit and draining and for drying when flood water recedes. Favoured where high flood levels are possible, as standard masonry buildings can be at significant risk of structural damage when the difference in water levels between the outside and the inside of the building exceed 0.6 metres.

TABLE 8-3: Flood resilience capacity for building materials as tested in the United Kingdom *(GOV/UK/DEFRA 2007).*
NOTE: Comparison with similar materials offered in the Canadian marketplace is needed.

MATERIAL	RESILIENCE CHARACTERISTICS*		
	Water penetration	Drying ability	Retention of pre-flood dimensions, integrity
EXTERNAL FACING			
Engineering bricks (UK Classes A & B)	Good	Good	Good
Facing bricks (Pressed)	Medium	Medium	Good
INTERNAL FACING			
Concrete blocks	Poor	Medium	Good
Aircrete	Medium	Poor	Good
CAVITY INSULATION			
Mineral fibre	Poor	Poor	Poor
Blown-in expanded mica	Poor	Poor	Poor
Rigid PU foam	Medium	Medium	Good
RENDERS/PLASTERS			
Cement render- external	Good	Good	Good
Cement/lime render-external	Good	Good	Good
Gypsum plasterboard	Poor	Not assessed	Poor
Lime plaster (young)	Poor	Not assessed	Poor
BRICKS			
Engineering bricks (Classes A & B)	Good	Good	Good
Facing bricks (pressed)	Medium	Medium	Good
Facing bricks (handmade)	Poor	Poor	Poor
BLOCKS			
Concrete (3.5N. 7N)	Poor	Medium	Good
Aircrete	Medium	Poor	Good
TIMBER BOARD			
OSB2, 11 mm thick	Medium	Poor	Poor
OSB3, 18 mm thick	Medium	Poor	Poor
GYPSUM PLASTERBOARD			
Gypsum plasterboard, 9 mm thick	Poor	Not assessed	Poor
MORTARS			
Below d.p.c., 1:3 (cement: sand)	Good	Good	Good
Above d.p.c., 1:6 (cement: sand)	Good	Good	Good

*Resilience characteristics are related to the tested that was carried out and exclude aspects such as the ability to withstand freeze/thaw cycles, cleanability and/or mold growth

Structures can vary in their vulnerability to flooding, depending on factors such as (City of New York 2013):

- the kind of flooding experienced (e.g. storm surge, wave action, overland flooding);
- the physical characteristics of the structure (e.g., building height, construction type);
- how the building is used (e.g., residential, industrial, health services);
- the mechanical and electrical equipment housed in basements or lower floors (e.g., electrical panels, water, wastewater, heating/cooling systems, electronics);
- the design and construction regulations in effect at the time of construction or renovation; and
- the age of the structure.

Resilience in structures can be improved through:

- application of damp-proof membranes and other water-proofing measures to foundation, basement, and cellar walls;
- elevated thresholds on doors;
- use of closed cell insulation in flood prone areas;
- installation of sump pumps to assist with local drainage and to facilitate dewatering after flooding;
- elevation of electrical services (e.g., sockets) and location of building services on levels less vulnerable to flooding;
- use of water resistant construction materials in floors, foundations, windows and doors; and
- provision of additional protection measures for lower level utilities and systems.

When selecting construction materials for use in flood prone areas, careful attention should be paid to the following characteristics (GOV/UK/DEFRA 2007) (Table 8-3):

- Water penetration: the rate and volume of water that can seep through the material;
- Drying ability: the capacity for the material to regain its original moisture content (as determined by the average amount of time needed to dry); and
- The ability to return to pre-flood dimensions and integrity, without deformation or (significant) change in form or in the appearance of the material.

FLOOD INSURANCE

Not all Canadians are aware of the scope of coverage provided by their home insurance for water damage, whether the source of water is failure in plumbing systems, overland flooding, leaks or sewer backflows (Figure 8-22) (Feltmate et al. 2017).

Common sense actions include prohibition of use of lower levels in buildings as residential areas, or for the storage and/use of expensive electronics and/or furnishings. However, flooding of residential basements continues to rise in Canada, as do the insurance claims for damages.

Typical Insurance Policy Coverage for Sudden and Accidental Damage	Type of Water Damage	Simple Definition
INCLUDED	Plumbing and Fixtures	Water that enters your home from a tear or rupture of plumbing pipesor fixtures (e.g. toilets, hot water heaters, dish washers)
OPTIONAL	Sewer Back-Up	Water that flows from the sanitary or storm sewer or your home's foundation drains and backs up into your home through the sump pit, toilets and drains
OPTIONAL	Overland Water	Water that flows from a lake or river, heavy rain or rapid snow melt and enters through cracks and gaps in your home's exterior from a point at or above ground level
OPTIONAL	Ground Water	Water that has saturated the ground and enters your home below ground level through gaps, cracks and seepage through your home's foundation
OPTIONAL	Water and Sewer Lines	Water that enters your home due to a tear or rupture of a water supply and/or sewer lines

FLOOD INSURANCE

When bodies of water (e.g., rivers, creeks, lakes, wetlands, coastal marine waters) overflow onto normally dry land, buildings, streets, systems and environments can be damaged. Overland flooding such as this is typically not covered by property insurance in Canada. Water damage to structures has historically only been covered by private insurers if the water originated from a sewer backup.

Some insurers in Canada now offer Overland Water Protection coverage for damage caused when ground water enters a dwelling through the foundation, basement floors, or walls and/or sewer line. This coverage includes damage caused by flooding from fresh water, such as overflows of rivers, lakes or other bodies of water, or damage from the sudden accumulation of water due to heavy rainfall, spring run-off or natural overflow of a dam, levee or dyke.

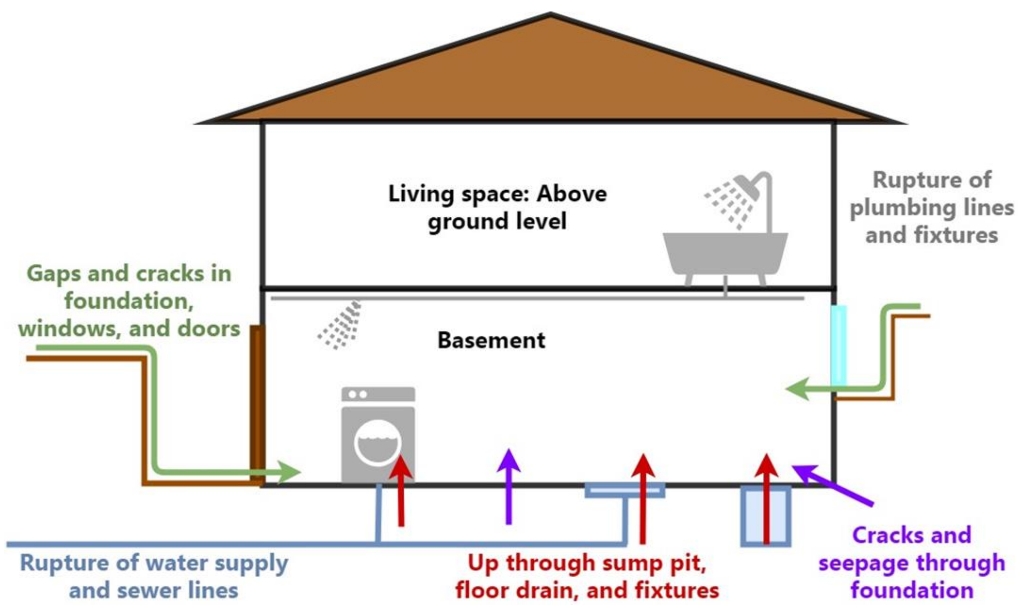


FIGURE 8-22: Range of risks and insurance coverage for water damage in homes in Canada *(Adapted from Feltmate et al., 2017).*

8.3.6 STRENGTHENING NATURAL FEATURES

Throughout the country, flooding and other damage from extreme weather and rising seas is increasingly putting valuable property and vulnerable populations in harm's way. On coasts (including the Great Lakes) and along streams, rivers and wetlands, erosion resulting from sea-level rise, storm surges, wave actions and increased flows can significantly alter river channels, deltas, beach and dune complexes, offshore islands and reefs and barrier beaches. Storm conditions can rapidly destabilize shorelines and unprotected river banks, leading to major changes in erosion and sedimentation patterns. Entire beaches and dune complexes can be lost during one storm event, or a season of unusual weather, with little opportunity remaining for their (natural) return. Erosion along coastal and riverine environments can result in:

- steadily increasing or catastrophic losses in land area and/or in land stability;
- increased risks to the structural viability of existing buildings and valued property;
- loss of natural sea defences such as dune systems and barrier beaches; and
- loss or impairment of engineered protection measures (e.g., breakwaters, seawalls).

Since Hurricane Katrina devastated New Orleans in 2012, interest has been growing in the role played by natural features (e.g., offshore reefs, beaches and dunes, flood plains, deltas, wetlands, seagrass beds and shoreline and bankside vegetation,) in attenuating wave energy and storm surges, preventing erosion, and containing flood waters.

Salt marshes and wetlands can dissipate wind and wave energy, increase sedimentation, and reduce erosion and sediment movement. As water passes through the vegetation, flow velocities and turbulence are reduced. Wetland plants improve water quality, and their roots anchor sediments. Offshore reefs and islands, barrier beaches and beach/dune complexes work to dissipate wave energy and are part of the natural processes that provide sand and cobble resources to replenish beaches. Coastal and riverine trees, shrubs and plants are critical to maintaining channel character, and river bank and dune stability. In the shallow nearshore, marine seagrass beds increase capture and settlement of sediments, and prevent erosion of the shoreline. Most natural features also contribute additional services to society in the form of improved water quality and maintenance of amenities (e.g., beaches, tourism infrastructure, waterfront homes) (Arkema et al. 2013).

Despite growing understanding of the importance of natural systems (e.g., riffle-run alignments in rivers, delta and estuarine dynamics, erosion and sedimentation in beaches and dunes, and longshore sediment drift patterns), society continues to develop in ways that can result in their disruption, deterioration and/or loss. As a result, piped and channelized streams and rivers are increasingly unable to support the challenges posed by increasingly severe weather and increasingly intensive flows. Foreshore dune complexes necessary to the continued replenishment of beaches are disappearing, and coastal geomorphology is changing at rates not previously experienced.

CONSERVATION GOAL: Natural features will, where practical, be preserved and enhanced for natural resource and habitat values and to ensure sustainability of habitats and functions. Special care will be taken for areas under threat of severe weather and sea-level rise to facilitate inland migration as water levels rise.

Cavendish backshore dunes, Prince Edward Island (Image Credit: Adapted from WikiPedia CC BY-SA 3.0)

The economic benefits of protecting, restoring and/or enhancing natural features (i.e., soft engineering) as a component of strategic responses to climate change is relatively poorly documented. Recent research by Arkema et al. (2013) has identified that, for the State of Florida alone, protecting existing nearshore habitats and coral reefs could reduce anticipated damage to real estate from sea-level rise by $4 Billion (US). In much of Canada, shoreline and nearshore vegetation (e.g., coastal forests, bankside vegetation, wetlands, salt marshes, algae and seagrass beds) are not generally valued or protected. On-going threats to these systems compromise their resilience to impacts, and their capacity to shelter ecosystems and society from the full onslaught of changing conditions. In some areas of the country, sea levels are rising faster than marshes can accommodate. In other locations, sea-level rise combined with landward topography may prevent marshes from migrating inland, resulting in catastrophic loss of the marsh, and exposure of the previously sheltered lands to wave and tide action. Changes in water chemistry, resulting from climate change, threaten marine plants and animals, and cloudburst contributions of rainwater result in flash flooding, channel erosion, and landslides along the banks of streams and rivers. There is an increasingly desperate need to improve our understanding of the role that natural systems play in enhancing ecological and societal resilience to storms and rising seas, preferably before they are damaged or lost to development pressure, and/or water contamination.

Traditional approaches to reduce stormwater, to raise dams and levees, and to flood proof buildings can be expensive and costly to maintain, yet hard engineering solutions (e.g., breakwaters, seawalls, larger pipes) tend to be the first line of defence against changing conditions, especially along marine shorelines experiencing damage and flooding from storm surges. What is needed is a more inclusive examination of the existing and potential capacity of natural features to assist in ameliorating the impacts of flooding associated with climate change, and a careful understanding of the costs and benefits of all approaches. Clearly, natural features will not be helpful in some areas, such as highly exposed coastlines, where only engineered solutions may protect resources at least for a time. But in those areas already sheltered by salt marshes, river deltas, and/or beach and dune complexes, careful stewardship of existing resources could reduce current impacts, and put off to the future the need to either engineer protective measures and/or to move away from the shore (Figure 8-23).

As conditions continue to change, a multi-pronged approach that weighs the benefits of working with natural systems against the costs of engineered solutions and the stability of engineered solutions against the loss of the natural coastline (Figures 8-23, 8-24, 8-25, 8-26, Table 8-4) could offer flexibility to many communities facing rising waters.

TABLE 8-4: Comparison of engineered options with options to enhance and sustain natural features

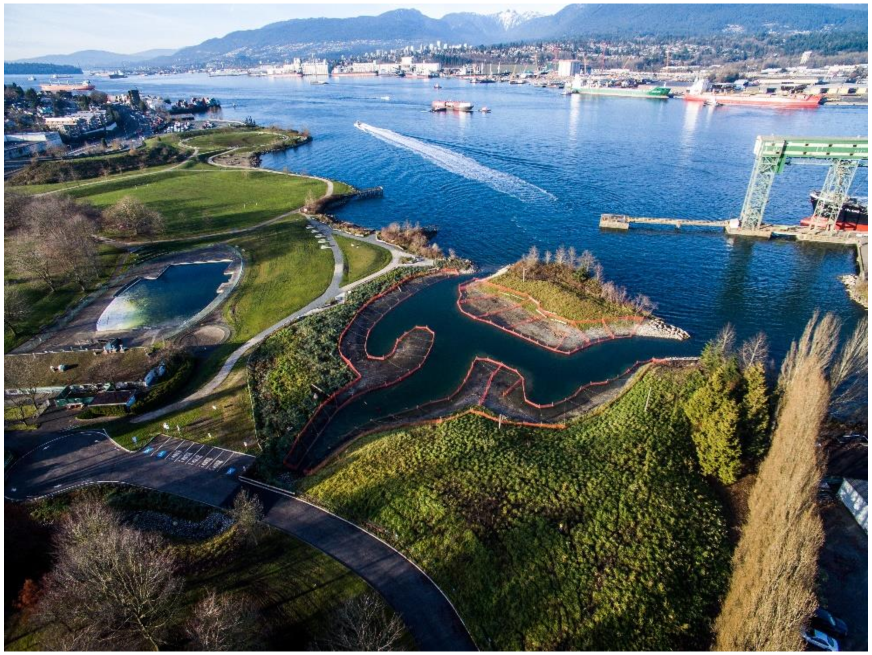
DISADVANTAGES OF ENGINEERED OPTIONS	DISADVANTAGES OF MAINTAINING NATURAL FEATURES
• temporary measures for protection from sea-level rise	• temporary measures for protection from sea-level rise
• require multi-disciplinary expert design to avoid direct and related impacts to local systems	• require multi-disciplinary expert design to avoid direct and related impacts to local systems
• (often) high costs of construction, and responsibilities for upgrading and maintenance accrues to future generations	• annual costs for enhancement (e.g., beach nourishment) can place burden on future
• coastal defence measures can interfere with natural sedimentation and erosion processes	• can require the relocation of infrastructure at distance from existing and anticipated coastlines and river banks
• can interfere with or replace traditional use of an area and access to the former shoreline	• challenged by social perspectives on historic and continuing rights of access and use
• loss of aesthetic appeal of the coastal or riverine landscape	• require sufficient enforcement capacity to withstand economic and social pressures
• seawalls and breakwaters do not generally support recolonization by local species and habitats common to rocky coasts	• constructed and/or nourished beaches do not have as diverse ecosystems as natural beaches

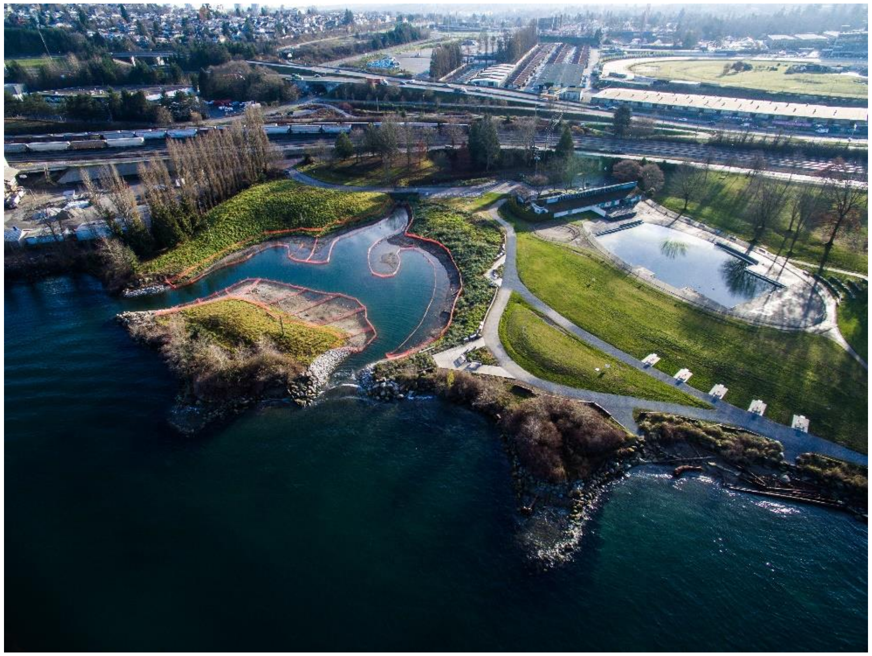
FIGURE 8-23: Spectrum of coastal protection approaches ranging from engineered changes through to the use and protection of natural features and ecosystems.

FIGURE 8-24: THE NEW BRIGHTON PARK SHORELINE RESTORATION PROJECT, VANCOUVER BC
The Vancouver Park Board and the Vancouver Fraser Port Authority are working together to create a salt marsh on the eastern sided of Brighton Park. The Project represents a unique approach to the restoration of coastal habitats on the southern shores of Burrard Inlet. The restored salt marsh will promote habitat for juvenile fish and wildlife, including shorebirds, waterfowl and songbirds. It will also create new opportunities for the public to view local wildlife and enrich the experience of nature in the local area and the region. *(Port of Vancouver: http://vancouver.ca/parks-recreation-culture/new-brighton-park-shoreline-habitat-restoration.aspx. Used with permission)*

Across all the types of extreme events, maintaining existing vegetation is one of the most affordable options for enhancing protection. (The Royal Society 2014)

FIGURES 8-25, 8-26: The Brighton Park shoreline restoration project, Vancouver BC *(Port of Vancouver, used with permission).*





Efforts toward strengthening natural features could include:

- improved knowledge of river, estuary and coastal processes (e.g., hydrology, longshore drift, winter-summer beaches);
- assessment of the capacity for natural environmental features to reduce or delay anticipated impacts from climate change and the environmental, economic and cultural values associated with those services;
- early recognition of the threats posed by climate change to natural features and habitats;
- protection of valued natural features and systems (e.g., protected areas, zoning, setbacks, buffers), and the protection and restoration of shoreline vegetation (e.g., coastal forests, dunes, riverbank vegetation);
- flood plain management that restricts development and allows for flooding into adjacent areas during high flow periods;
- installation of rock sills or breakwaters seaward of salt marshes to reduce wave damage;
- beach nourishment (adding sand/cobble to bolster beach resources lost to storms and erosion);
- restoration of dune complexes and dune vegetation;
- designation and protection of inland areas for future migration of marshes as sea levels rise;
- reduction of contaminant loads to marine and aquatic ecosystems, including nutrients from fertilization, animal wastes and human sanitary waste systems; and
- eradication efforts of invasive species in wetland and dune complexes.

Image Credit: C. Mercer Clarke

Wetlands at the river edge. Image Credit: C. Mercer Clarke

Arichat Cape Breton Harbour Islands. Image Credit: C. Mercer Clarke

While there is value in protecting and maintaining natural systems, there can also be significant costs. Beach nourishment and dune replacement programs can require annual replenishment of large quantities of sand which can only be justified where there are significant economic gains to be made (e.g., tourism). Mining sand from the seabed may not be environmentally sustainable and could impact both the marine ecosystems where the sand is sourced, and damage ecosystems where the sand is placed. Mining sand from land-based sources will change the natural strata of the beach and may require significant resources for transportation and placement. Dune restoration is an emerging science, that requires expert knowledge of local coastal geomorphology as well as patterns for long shore drift, and weather and wave exposure. Phillips and Jones (2006) noted that in the previous 10 years, Italy had used 20 million cubic metres of sand to nourish its beaches, and Britain had replaced over 20 million tonnes. Prices quoted for annual beach replenishment have been estimated at US$ 4-15/m3. When working to restore either beaches or dunes, the costs will be affected by factors such as (Linham and Nichols 2010):

- the size of the project, with benefits from economies of scale and detriments when sourcing for large quantities of sand is difficult from single sites;
- the distance and number of journeys required to transport sand between the supply site and the deposition site;
- where seabed mining is permitted, the depth and shape of the sea bed, the dredge equipment required, the availability of the equipment, and the number of days the recovery site or the deposition site will be subject to bad weather;
- tidal range on the deposition beach, which constrains working hours;
- the type of beach material needed (some beach replenishment projects may be on coarser gravel or cobble beaches);
- estimated loss of materials during sourcing, transportation and placement, including losses to coastal erosion;
- the costs to revegetate and/or to fence and enforce restrictions on use in new beach and dune areas;
- the costs for planning and design, including the costs for any required environmental impact assessment, regulatory approvals, and/or monitoring during and after construction; and
- the frequency with which the beach or dunes must be artificially replenished as opposed to gaining some capacity for natural accumulation.

Before attempting any form of physical shoreline restoration, it is critical that appropriate technical expertise be included in planning and design efforts. Some areas of Canada have naturally eroding beaches, in which longshore patterns of erosion and deposition can change the character of the shore over time. In other areas, beach profile and beach substrate differ radically between the 'winter' beach and the 'summer' beach. Sand and stones erode from the beach during active weather (e.g., larger waves and winter storms), are deposited offshore, and returned once again during quieter water in the spring and summer.

Dune restoration on the Pacific Coast (Image Credit: Parks Canada)

8.4 HOLDING THE LINE

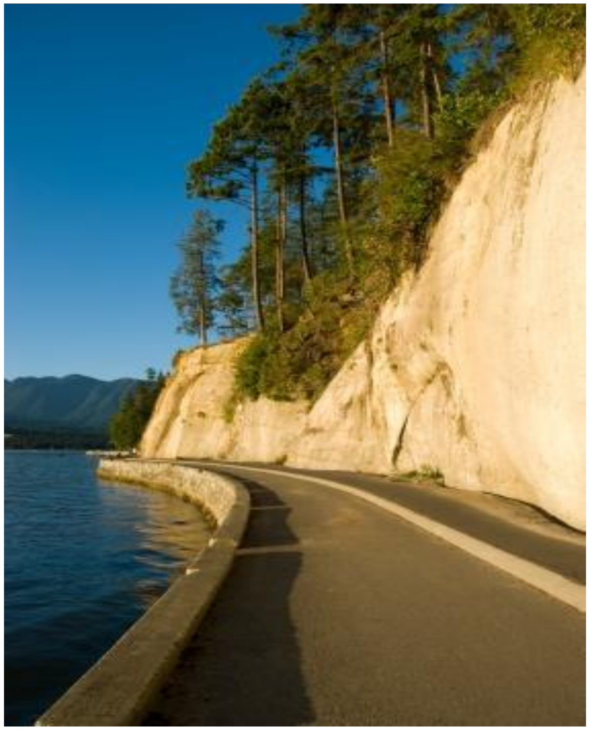


FIGURE 8-27: Coastal highway in British Columbia leaves few options for adaptation but relocation. *(Image Credit: Mills NRCan).*

One of the most traditional approaches in Canada to the problems of rising water is to build structures to hold the water back, to prevent erosion and to ensure the safety of people and property. Construction of flood barriers, revetments, dykes, seawalls, groynes, breakwaters and other options for hard armouring of the coast can still be an effective measure to protect shorelines and to defend against storm damage. However hard armouring requires expert design and management, can be expensive, creates a large footprint for construction, and can result in interference with natural shoreline processes, habitat destruction and loss of public access to the water edge. Perhaps most importantly, hard armouring of shores must increasingly be seen as a temporary option for many locations. As sea levels rise and storms become more intense and frequent, building walls to protect low lying property or to prevent land erosion will become less feasible, less effective and more expensive (Figure 8-27). Todays breakwater or seawall may well be tomorrow's reef.

Armouring, defending, and/or protecting are all terms that have been used interchangeably to describe the process of holding the line against flood waters. The barriers used to prevent wave and water action from eroding river banks and coastlines, and to keep flood waters from damaging environments or property generally fall into the following categories:

- flood barriers;
- dykes and levees;
- revetments;
- seawalls;
- groynes/artificial headlands/shoreline stabilization measures; and
- offshore breakwaters, islands and reefs;

It will be increasingly important to note that, in some situations in Canada, development in, at or near vulnerable areas has reduced and/or complicated the options available for protection from flood waters (Figure 8-28). The past century of relatively stable weather and climate conditions have entrenched what are now unrealistic expectations on the capacity for planners and designers to provide options that ensure the continued stability, use, and safety of all structures in all environments. Even in those areas where an engineered solution is possible, the costs for construction and maintenance, together with the potential disruption to communities and to natural environments, will not be merited for installations with a limited lifetime of practical use.

FIGURE 8-28: Would you buy this house? It has a great view, limited options for protection from floodwaters, and consequently, a short life expectancy.
(Image Credit: Essex Region Conservation Authority, used with permission. Available at: http://erca.org/programs-services/flood-forecasting/).

8.4.1 CHANGING EROSION AND SEDIMENTATION PROCESSES

One of the most critical considerations to changing riverine channel patterns, estuarine dynamics and coastal geomorphology is the resulting effects on local and near-local erosion and sedimentation patterns, and the potential for substantive land loss.

Rivers establish vertical and horizontal profiles for the movement of water, including complex, and repeating patterns of pools and fast water (riffle-run sequences). Interference in riverine hydraulics by altering the channel configuration, hardening river banks or bottoms, inserting water control structures, and/or piping sections of the stream, will disrupt some upstream processes and most downstream processes. It may take years for the river to return to a stable condition.

Along marine coasts and the shores of the Great Lakes and other large water bodies, longshore transport or drift of sediments can alternatively erode shorelines and create landforms such as beaches, bars, spits, and barrier islands (Figure 8-31). Longshore transport of sediments often occurs in well-established littoral cells along designated sections of a coastline. In some areas of Canada, wave action, currents and nearshore ice can impact coasts, moving not only sand, but also cobble and rock. While some movement of sediment is normal, significant erosion can result in major changes in geomorphology. Hard armouring of eroding shorelines can prevent erosion and stabilize near shore lands but armouring also interrupts the balance in erosion and sedimentation processes and can have significant impacts on the viability for depositional features of the coast such as beaches, sandbars, and offshore islands.

Land and gravel beaches naturally require constant replenishment of materials to maintain the balance between erosion and sedimentation. Some of this material is supplied from local dunes and eroding shores, and some is transported from some distance by longshore currents and wave action. On Lake Erie, much of the North shore has been hardened to prevent erosion, loss of land, and/or damage to property. Prominent natural features such as beaches and dunes are now eroding, because the sediment source has been interrupted (Figure 8-32). Similar situations occur on marine coasts when inappropriate placement of protection measures (maladaptation) such as revetments, seawalls, breakwaters and groynes can interfere with both longshore and cross shore sedimentation and erosion processes.

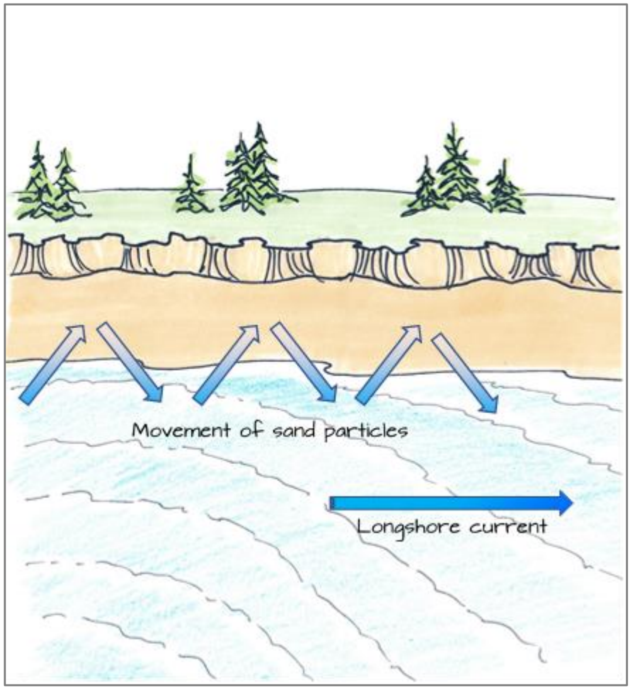


FIGURE 8-29: Longshore movement of sediments

COASTAL GEOLOGY AND GEOMORPHOLOGY encompasses the origin, structure and characteristics of the bedrock, rock and sediments that characterize a shoreline. Coastal sediments can range from tiny particles of sand or silt to larger gravels and cobble and may include consolidated formations of sediment and rock. Some sediments may be highly erodible, some resistant to erosive forces.

COASTAL PROCESSES (wind, waves, tides currents). The physical processes that act upon and shape the coastline, and that influence the configuration, orientation and movement of coastal landform. *(GOV/USA/FEMA 2011)*

LONGSHORE SEDIMENT DRIFT
Breaking waves and surf in the nearshore can combine with a number of horizontal and vertical nearshore currents to transport sediments along the coast. Sometimes this results only in a local rearrangement of sediment into bars and troughs or a series of rhythmic patterns along the beach. In more pronounced cases, thousands of cubic metres of sediment can be displaced along the shore each year. Longshore drift is one of the most important of coastal processes and is a significant determinant of where shores erode, accrete or remain stable. *(GOV/USACE 2008)*

CROSS SHORE TRANSPORT OF SEDIMENT
Cross shore transport is the movement of nearshore and beach sediment (sand) towards or away from the shore and is the result of the combined action of tides, winds, waves and currents. Cross-shore transport is important to the sustainability of beaches and contributes to the formation of winter and summer beach profiles.

Even without barriers to erosion and sedimentation, beaches can naturally change over years and seasonally as a result of both nearshore and cross-shore transport of sediment. The granular composition of some oceanic beaches can alter over time from predominantly sand to predominantly stone or cobble as finer sediments are moved by wave action and longshore transport along the coastline.

In some high wave energy areas, winter storms remove most of the sand and rearrange cobbles on beaches, depositing them in deeper offshore waters and dramatically altering the beach profile (Figure 8-30). This entirely natural and recurring seasonal phenomenon can provide an emotional shock to beach visitors who become alarmed when visiting their favourite shoreline in winter, who may have difficulty believing that, with the return of calmer weather in the spring, the beach will also be restored to its summer profile in time for vacationing.

Rocky shorelines are also affected by wave action and erosion, which can eat away at bluffs, creating islands, caves and arches. In some areas wave and current action can destabilize the toe of embankments and cliffs, resulting in significant landslides and shoreline reconfiguration. While most of the shaping of coastlines happens over decades or even longer timeframes, a single intense storm event can result in dramatic reshaping of the shore.

Eroding coastal bluff at Eastport NL (Image Credit: C. Mercer Clarke)

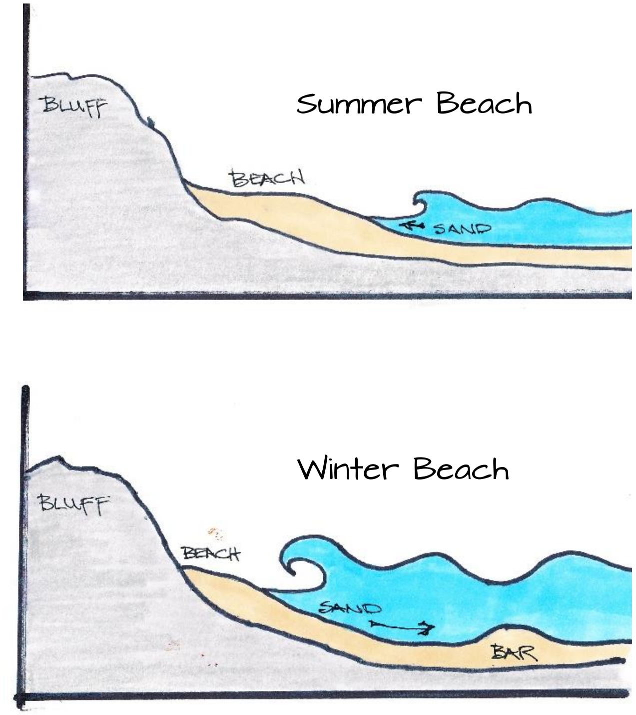


FIGURE 8-30: Seasonal changes in beach profiles. As wave energy increases in winter storms, sand and gravels are eroded from the beach area and deposited in berms in deeper water. With the return of calmer weather in the summer, the eroded material is once again deposited on the beach.

8.4.2 MALADAPTIVE PLANNING AND DESIGN

When planning and design fail to take into account all the necessary factors for coastal and water edge construction, there can be problems with the stability of the structures created as well as with the continued stability of local and nearby coastal geomorphology and river channels (Figures 8-33). Failure to address all the environmental factors that can and will affect flood protection measures inevitably result in structures that are time-limited in their usefulness, that destroy rather than enhance local habitats, that reduce access to local water resources; and that are inherently unsightly.

Maladaptation is the term for poorly planned and executed adaptation efforts that not only provide an ineffective solution to the problem at hand, they limit the options for other solutions, both now and in the future. Too often maladaptation occurs because of:

- too little attention to planning and design because of the rush for immediate action;
- in sufficient understanding of important factors that are or will contribute to the problem at hand;
- application of generic solutions, rather than solutions that are place-based; and
- lack of financial resources and needed expertise.

MALADAPTATION

A process of planning, design or construction that can directly or indirectly increase rather than reduce vulnerability to climate variability and change, and/or that could significantly undermine the capacity or opportunities for present and future adaptation. *(Magnan 2014)*

FIGURE 8-31: Inappropriate use of gabions as coastal beach protection (*Image Credit: C. Mercer Clarke).*

8.4.3 THE NEED FOR INTERDISCIPLINARY PLANNING AND DESIGN

Most shoreline defense initiatives require planning and design by interdisciplinary teams that include planners, landscape architects, ecologists and coastal engineers. Planning ensures that all design fits with the overall plan for the community or the location, and accounts for the many social and commercial perspectives of a community (Figure 8-32). Landscape architects bridge between the natural environment and the built environment, ensuring that structures enhance community resilience but not at the cost of damage to the environment or loss of cultural values and aesthetics. Ecologists and professionals from other natural sciences ensure existing environmental processes are respected, and all opportunities for enhancing the sustainability of ecosystem services to the community are realized. Coastal engineering is a special discipline of civil engineering that requires technical knowledge of the structural and non-structural options and must account for the potential for positive and negative impacts on coastal environments and societies. To avoid catastrophic damage to systems and to society, in ALL situations where structural options (large or small) are being assessed, interdisciplinary teams are responsible for consideration of the impacts of processes such as (GOV/USACE 2008):

- environmental (chemical, biological, ecological);
- hydrodynamic (wind, waves, water level changes, sea-level change, currents);
- meteorological (seasonal storms, hurricanes, changing weather patterns, shifts in local climate);
- sedimentary (sources, transport paths, sinks, material characteristics);
- geological (soils, bedrock, land subsidence, groundwater); and
- social and political (land use, public access, development trends, regulatory instruments, pubic safety, property values, local and regional economics).

"An **interdisciplinary team approach** is recommended in planning coastal projects to ensure the involvement of physical, natural and social sciences personnel.

The disciplines of the coastal project planners should be appropriate to the problems and opportunities identified in the planning process, and range from coastal, geotechnical, structural and hydraulic engineers, through meteorologists, oceanographers, biologists and geologists, to economists, urban planners and transportation specialists.

Not all disciplines are needed on all studies, but the team leader needs to be cognizant of the possible need for such talents during the project development."

The Coastal Engineering Manual, US Army Corps of Engineers (GOV USACE 2008: EM 1110-2-1100, V-1-1)

FIGURE 8-32: Hard armouring must not only be designed to withstand rising water levels and increasing wave and current energy, it must also strive to protect and enhance natural habitats and to continue the traditions of public access to the shore. Is this a good or bad result? *(Image Credit: Wikipedia Oikos Team Public Domain)*

8.4.4 REVETMENTS

A revetment is a facing of stone, concrete or other durable material placed on shorelines, banks or cliffs to absorb the energy of moving water and waves to protect the slope and to prevent erosion (Figures 8-33). Modern revetment design requires much more than piling stone along the shoreline. Revetments are designed to account for local water movement and sedimentation processes and constructed of materials selected and sized to withstand local water energy (waves, currents) and to prevent displacement of the revetment materials. An integral component of revetment construction is the use of geo-textiles to separate the revetment material from the underlying slope (Figure 8-33). Geo-textiles stabilize the new slope and prevent storm waves from eroding base materials.

Each revetment must be constructed upon a stable foundation, the core of which is the toe of the slope. If the toe materials are undermined or eroded by waves and currents, the entire revetment will become unstable. While traditional revetment materials used a range of appropriately sized stone, modern revetments can also employ concrete formed structures such as tetrapods. A tetraopod is a tetrahedral (four-legged) concrete structure designed to dissipate the force of incoming waves by allowing water to flow around rather than against it, and to reduce displacement in the revetment by allowing a random distribution of tetrapods to mutually interlock.

Increasingly, revetment materials are being selected based on their capacity to mimic existing environmental conditions, and to provide the basis for recolonization by marine and aquatic species and other coastal vegetation and wildlife.


Revetment wall Mumbai (*Image Credit: Kelisi. Wikipedia Commons CC BY-SA 3.0)*

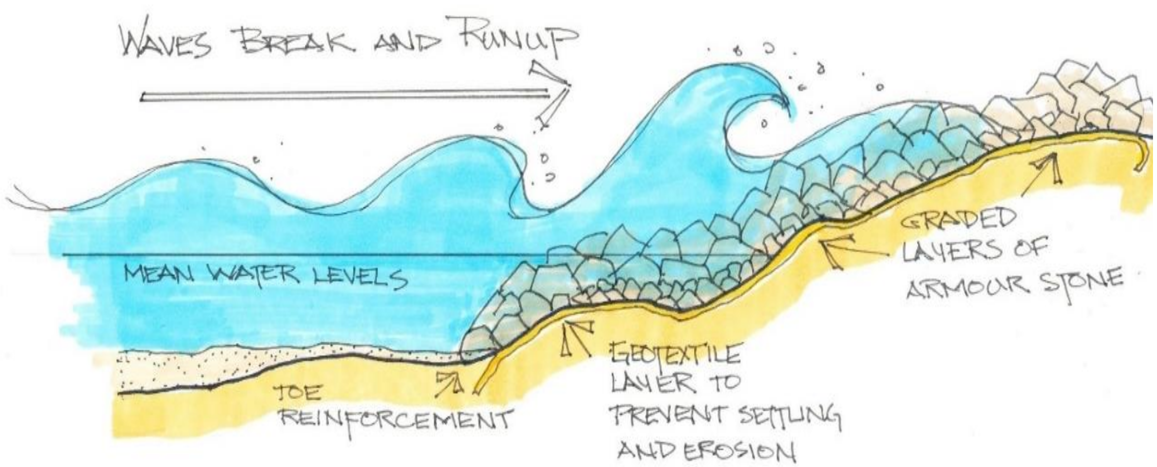
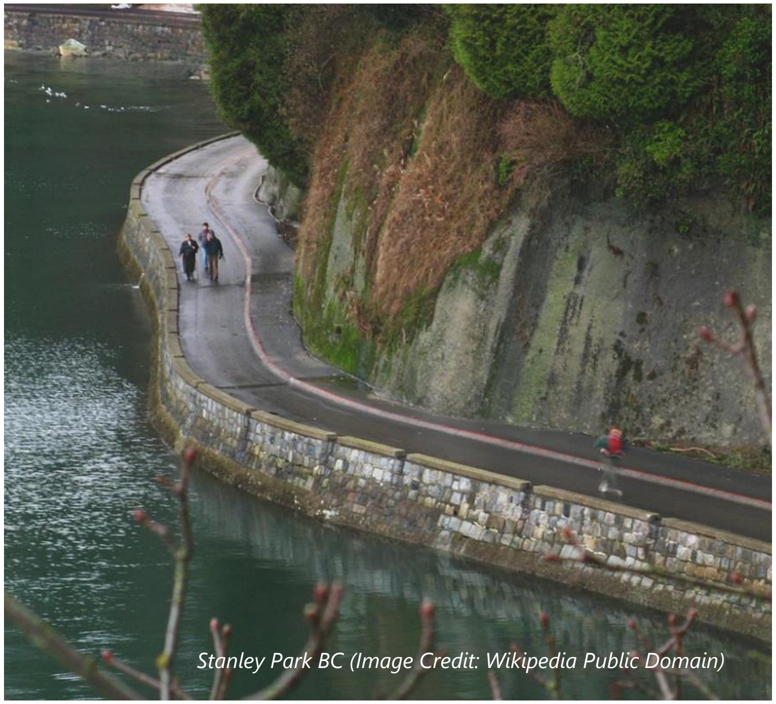


FIGURE 8-33: Graphic depiction of armour design *(Image Credit C. Mercer Clarke).*

8.4.5 SEAWALLS



Stanley Park BC *(Image Credit: Wikipedia Public Domain)*

Seawalls are vertical walls constructed to protect land and structures from high tides, storm surges, wave action and changing water levels. Seawalls (which can be deployed on both freshwater and marine shorelines) can be temporary or permanent and may be constructed from a range of materials (e.g., stone, concrete, metal, wood).

The constructed costs for most vertical seawalls can be affected by factors that include (Linhan and Nicholls 2016);

- design height which also affects the footprint required for the wall and any associated structures, as well as the time needed for construction;
- anticipated wave energy dictates the resilience required in materials and construction with walls intended for deeper waters and more exposed coasts requiring more robust materials;
- type of seawall design selected;
- construction materials (e.g., rubble blocks, pre-cast concrete elements, metal, soil) and availability;
- single or multi-stage construction methods and complications (e.g., needed de-watering, footprint stabilization); and
- expert planning and design services, together with construction inspection services.

Seawalls can serve many purposes. When incorporated into the landscape in an aesthetic design, they become art forms (Figure 8-34). When integrated to serve additional waterfront functions, seawalls can become the foundation for innovative approaches that restore the semblance of a natural coastline while improving public access to the waterfront.

Cities like Vancouver have historically made their seawalls a part of the community. The 28 km Greenway in Vancouver, an uninterrupted pathway, runs over sections of the seawall, and is amongst the most popular recreational spots in the city (Figure 8-35).

FIGURE 8-34: A new approach to making a Vancouver seawall also a piece of landscape art.
(Image Credit: Paul Sanga Landscape Architecture, used with permission).

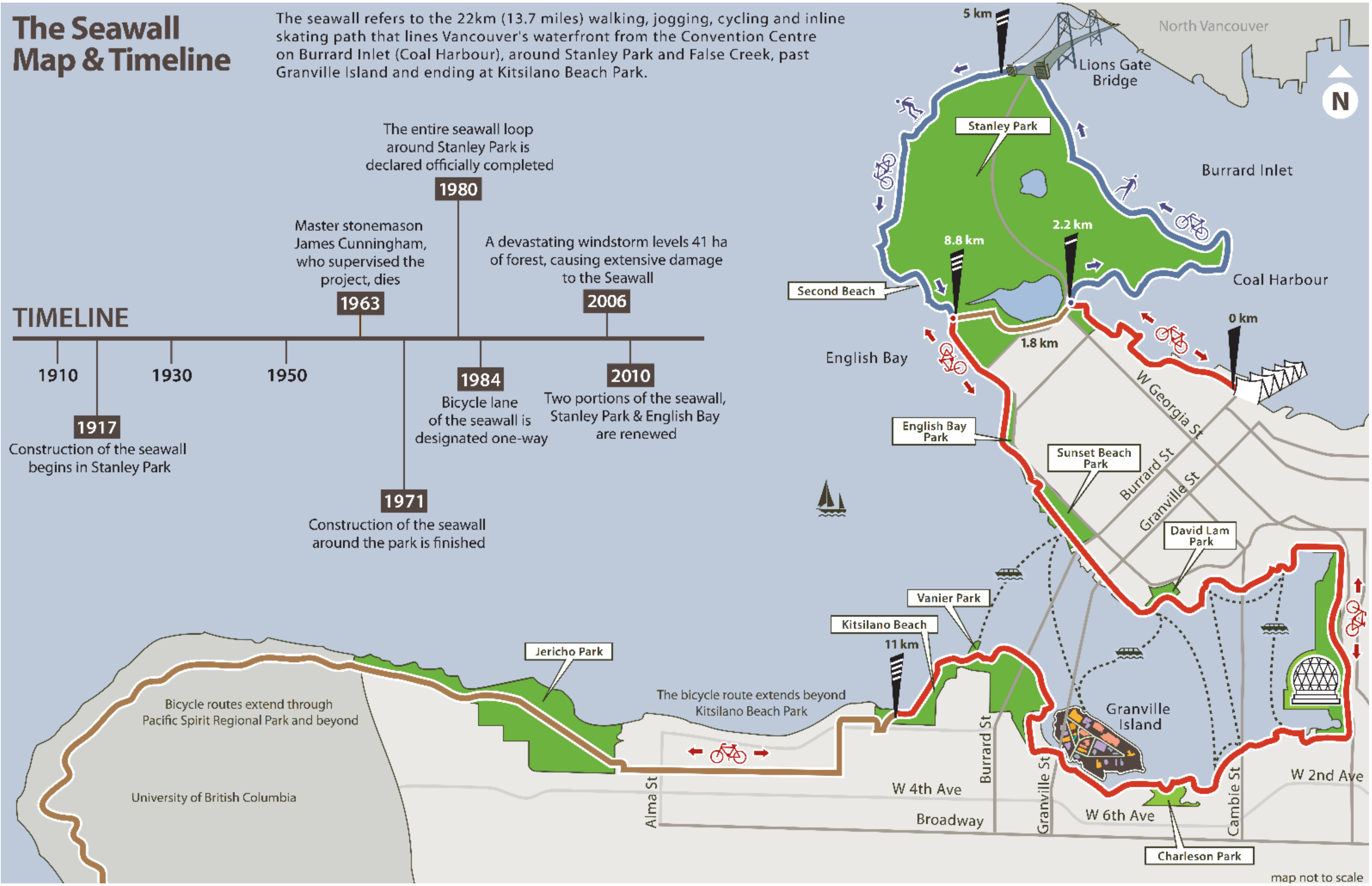


FIGURE 8-35: The Vancouver Greenway *(Image Credit City of Vancouver, Used with permission. Available at: http://vancouver.ca/parks-recreation-culture/seawall.aspx/).*

8.4.6 FLOOD BARRIERS

Flood barriers, which can also take the form of tidal barriers and storm surge barriers, can be permanent or moveable structures intended to hold water back and prevent flooding. Flood barriers may protect large expanses of the landscape or may be employed to protect specific property or low-lying structures of importance. Tidal gates or storm surge barriers may only close during anticipated high-water periods.

Perhaps the most famous of recent projects to construct tidal barriers to sea-level rise and storm surges is the Thames River Barrier in the United Kingdom. Protecting the City of London and the surrounding area from higher high tides and storm surges, the Barrier is the world's second largest moveable flood barrier. Used only during high tides, the Barrier remains open to marine traffic during low water periods. Similar approaches have been deployed in the Netherlands (Delta Project), in Venice (MOSE Project), and in New Orleans LA (IHNC Lake Borgne Surge Barrier) and New Bedford MA (New Bedford Hurricane Barrier) in the United States.

There is also a range of technologies available today that provide moveable, or deployable flood barriers, that can rapidly be placed in areas under threat of inundation.

Thames River Barrier (Image Credit: Adapted from Wikipedia CC BY 2.0)

Moveable flood gates, Maeslent, Netherlands (Image Credit: adapted from Bertknot, FLICKR CC BY-SA 2.0)

8.4.7 DYKES AND LEVEES

Dykes and levees have traditionally been earth and stone embankments constructed to protect land or structures from river flooding, tidal water, storm surges and wave action. Dykes and levees have a relatively large footprint in the landscape and are built to a crest height sufficient to prevent overtopping by flood waters. The large volume of material used helps to resist the water pressures associated with deepening depths. The sloped sides reduce the impact of wave action. Figure 8-36 provides schematics for a typical set back dyke profile.

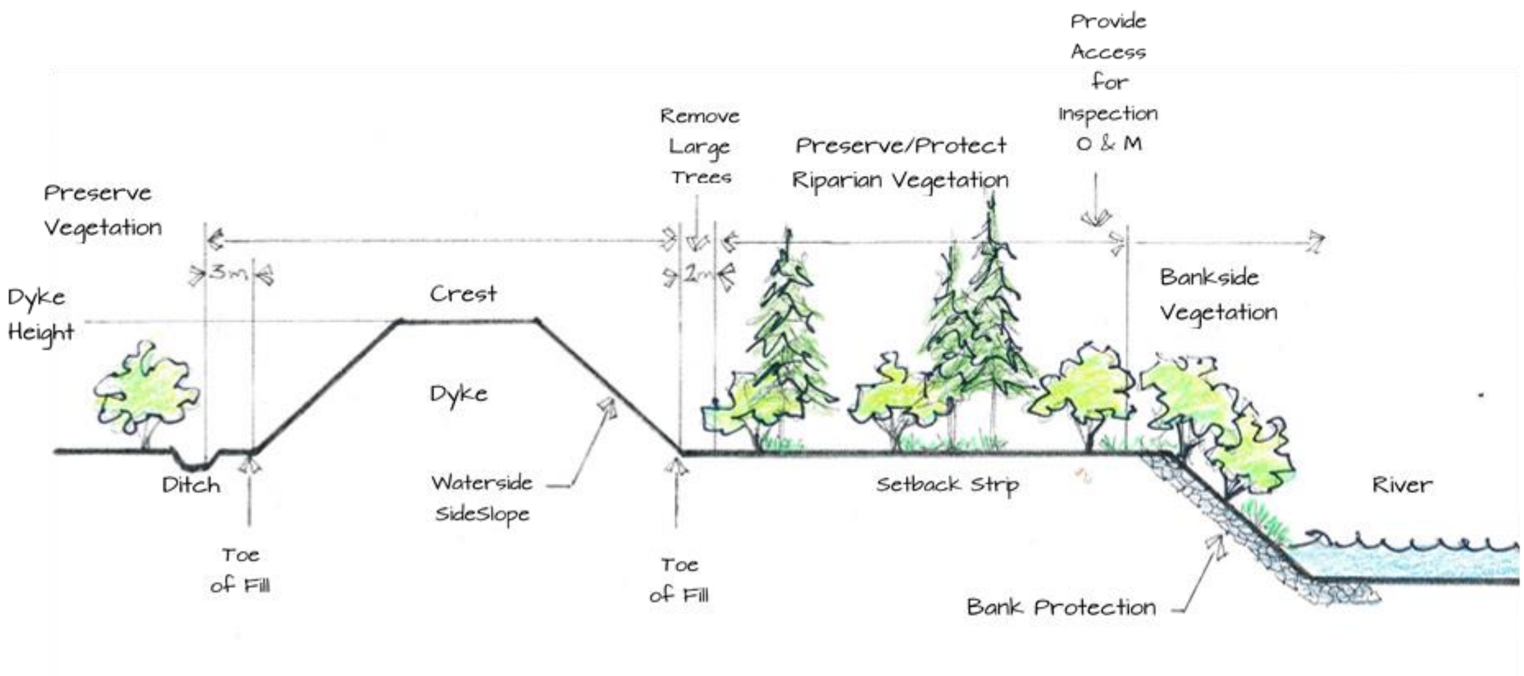


FIGURE 8-36: Illustration of typical setback dyke design for use in British Columbia *(Adapted from GOV/CAN/BC 2003).*

HISTORIC ACADIAN DYKES

Some of the dykes that will need retro-fitting include historic dykes and levees that have been part of the Canadian landscape since the earliest days of European settlement. Dykes have been used in Canada for hundreds of years, to reclaim low-lying land from coastal areas and riverine flood plains, and to protect communities that developed on low-lying lands prone to seasonal or storm event flooding. Many of the Acadian dyke systems of Atlantic Canada were constructed by early French settlers and are still in place and working today (Figure 8-37).

In areas of Nova Scotia, mechanical drainage of the land behind the dykes was not required, because low tide in areas of the Bay of Fundy falls considerably below land levels. The traditional mechanism for drainage, the aboiteau, opened to allow freshwater to drain from the marsh behind the dyke, and closed to prevent sea water from entering. In well settled areas of the Bay of Fundy, notably areas such as the Tantramar Marshlands on the isthmus that connects Nova Scotia and New Brunswick, major road and rail routes continue to be protected from coastal flooding by these Acadian dykes.

Some of the dykes in this and other areas are now more than 300 years old and are finally falling into disrepair, and/or are insufficient to protect the area from flooding associated with sea-level rise and storm surges. In some areas of the eastern coast, efforts are being made to breach the historic dykes to allow natural restoration of the early salt marshes, which by themselves offer the potential to attenuate wave energy and reduce damage during storm events.

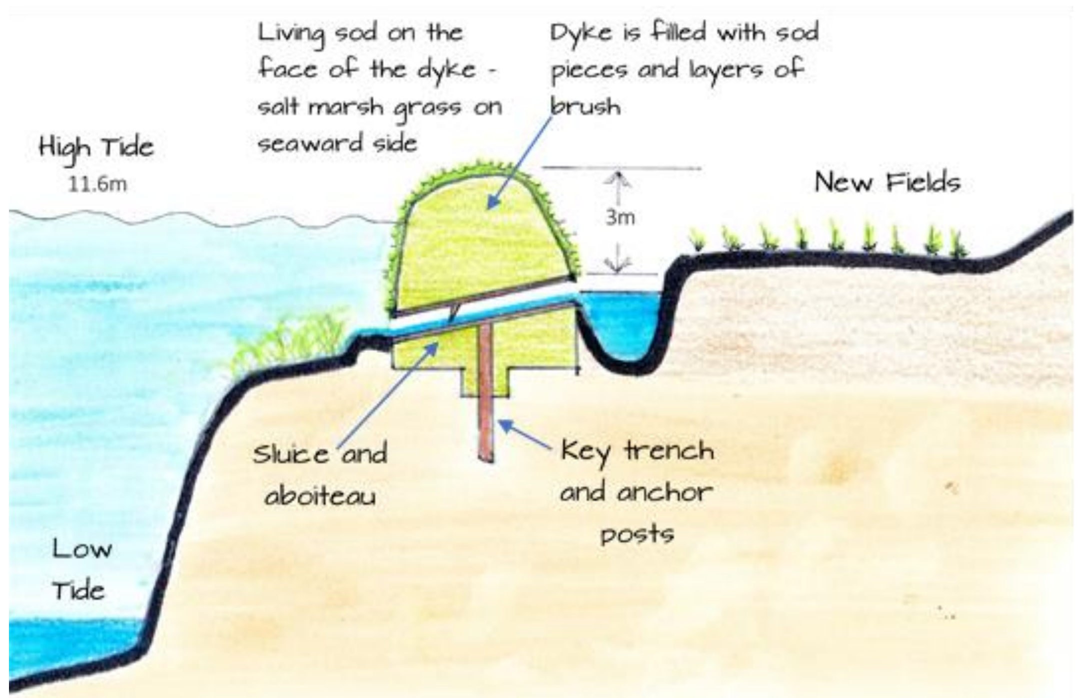


FIGURE 8-37: Illustration of the construction methods used for the historic Acadian dykes at Grand Pré, Nova Scotia, including the mechanics for drainage using an aboiteau *(Adapted from: le Paysage de Grand Pré. Available at: http://www.landscapeofgrandpre.ca/the-acadians-and-the-creation-of-the-dykeland-1680ndash1755.html).*

RETROFITTING DYKES TO MEET PROJECTED INCREASES IN FLOOD WATER LEVEL

As sea levels rise and water levels in rivers are heightened by intense weather, flood crests for existing dykes may be insufficient to contain the water. Neither historic dykes nor even dykes built in the last 50 years are likely to have flood crests capable of withstanding the projected flood water levels. It is also important to note that even more modern dykes (e.g., 1970s) were often designed using fewer criteria than would be considered the norm for today (Figure 8-38). In addition to data on historical maximum water levels, plus an additional height added as freeboard, modern dyke design criteria include maximum high tide water levels, relative sea-level rise (where applicable), historical storm surge data, local prevailing winds and storm winds direction and magnitude, fetch, and anticipated wave energy. Where dykes intended to contain riverine flood water are being adjusted, factors must also include the impact of anticipated heightened sea levels during storm and high tide events. As sea level rises, the capacity for riverine water to spill into the sea can be diminished, especially in low-lying deltas and estuaries, resulting in larger amounts of freshwater that will back up into the floodplain.

For many areas currently protected by dykes and levees, the options to increase the crest height may be limited. For each unit of crest elevation, a disproportionate area of land will be required to enlarge the footprint for the dyke, to ensure structural stability and strength) (Figure 8-39). In areas where development has been permitted near the toe of the landward slope of the dyke, costs escalate where land uses must be changed and/or properties moved or abandoned, or where alternative methods for construction are employed.

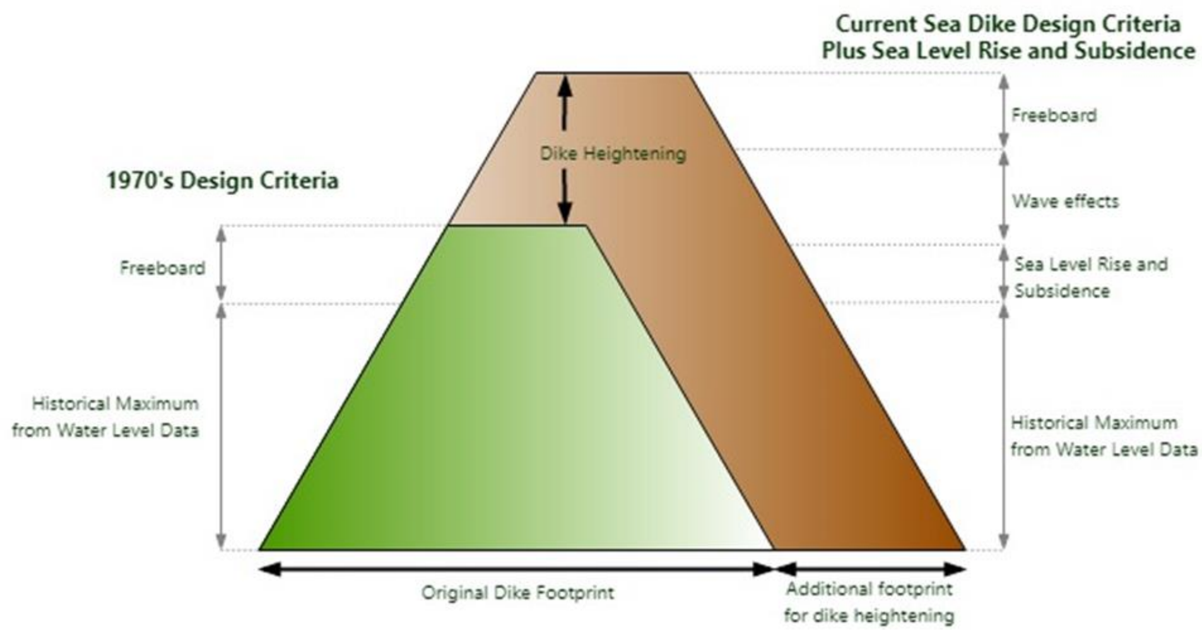


FIGURE 8-38: Changes in the design parameters for dykes in British Columbia *(Adapted from GOV/CAN/BC 2003).*

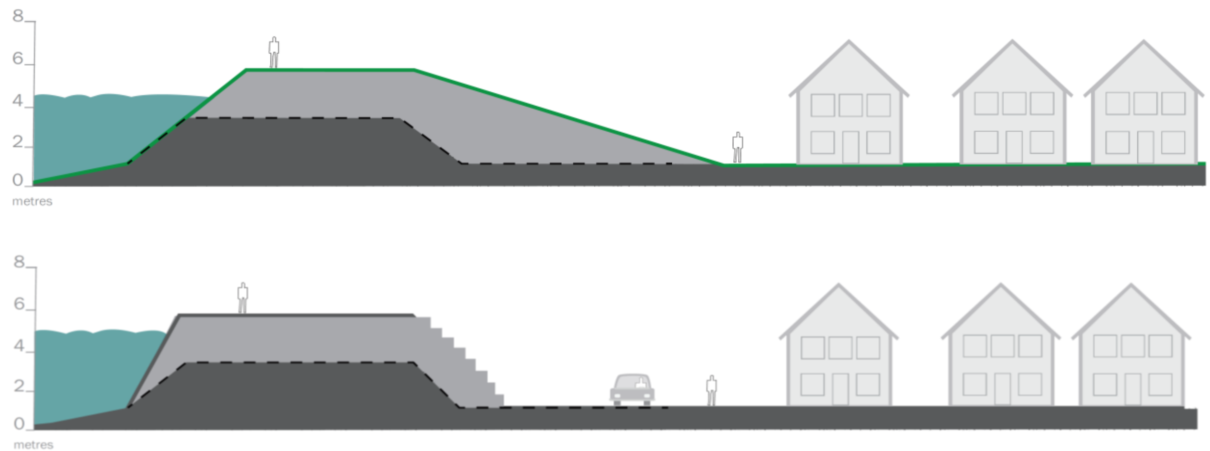


FIGURE 8-39: How raising dyke heights and/or changing profiles will affect neighbourhoods *(Image Credit: Adapted from CALP (UBC CALP Delta-RAC): extracted from Barron Et al. 2012).*

8.4.8 GROYNES AND OTHER SHORELINE STRUCTURES

Groynes are the oldest and most common shore-connected stabilization structures for beaches. Groynes are usually built of wood, stone or concrete units piled perpendicular to the shore or at an oblique angle and extending from the foreshore to a water depth determined to be sufficient to interrupt wave driven longshore sediment transport processes. Groynes are also used to dissipate wave energy, and/or to reduce the offshore or alongshore transport of sediment (Figure 8-45). Perhaps more than any other shoreline structure, improper design and placement of groynes have resulted in unanticipated damage to local coastal conditions. Other structures such as piers, and infilled shorelines can also affect shoreline processes if not well-designed and constructed.

Groynes are generally used to promote the accretion of sand on the up-drift side of the groyne. Multiple groynes constructed along a section of shoreline, can be used to manage shore erosion, especially when coupled with beach nourishment programs. Groyne design is varied and complex, and the structures can be built using a range of locally available and imported materials including (Engineers Australia 2012):

- quarried rock armour placed to protect a core of smaller rock;
- concrete armour units protecting a rock core;
- sand filled geotextile containment units;
- steel or concrete sheet piles;
- structural concrete in the form of caissons, and
- heavy timbers.

Groyne design is a complex undertaking, requiring considerable knowledge of local coastal hydrodynamics and geomorphology. Special care must be taken where there are valued beach and dune systems, wetlands and riverine deltas, to insure there are no detrimental effects on local sedimentation and erosion processes. Where improperly designed and/or placed, groynes can impact the coastline through:

- reductions in the supply of sand to down-drift areas, resulting in loss of beach area and/or shoreline erosion; and

- increased conflicts with private and public stakeholders who hold differing views on the value the groynes bring to the area, especially when the aesthetics of the landscape and public access to the shore are compromised.

In some situations, groynes designed and placed to achieve multiple goals can improve local access to the water for viewing or fishing and can be incorporated into local longshore pathways,

FIGURE 8-45: Groynes on the beaches of the Toronto Islands *(Image Credit: C. Mercer Clarke).*

8.4.9 BREAKWATERS, OFFSHORE REEFS, AND BARRIER ISLANDS

Breakwaters are rigid structures constructed generally for reducing the amount of wave energy that reaches the shore (Figure 8-46). Natural breakwaters include offshore reefs, sand spits, barrier islands, and barachois beaches. Constructed breakwaters are usually formed using large rock or preformed concrete units, however in some areas of Canada, derelict ships have deliberately been sunk on pre-determined locations to provide a basis for marine habitat and to aid in coastal protection.

Offshore breakwaters, and bulkheads are also intended to reduce the intensity of wave action in inshore waters, reducing the potential for shoreline and bluff erosion and improving harbour conditions. Where detached breakwaters are well designed and placed along shorelines, the interruptions to long-shore drift patterns can create situations highly supportive of sediment accumulation along the shoreline, reducing erosion and recreating beaches (Figure 8-467. This ‘tombolo’ effect promotes sediment accretion between the breakwater and the shore, where wave energy and longshore drift currents are reduced, improving conditions for the deposition of sands and sediments. Natural tombolos occur where nearshore islands become attached to the land by a narrow beach or spit. Man-made tombolos are the result of carefully designed and placed breakwaters intended to supplement sedimentation on the nearby shoreline.

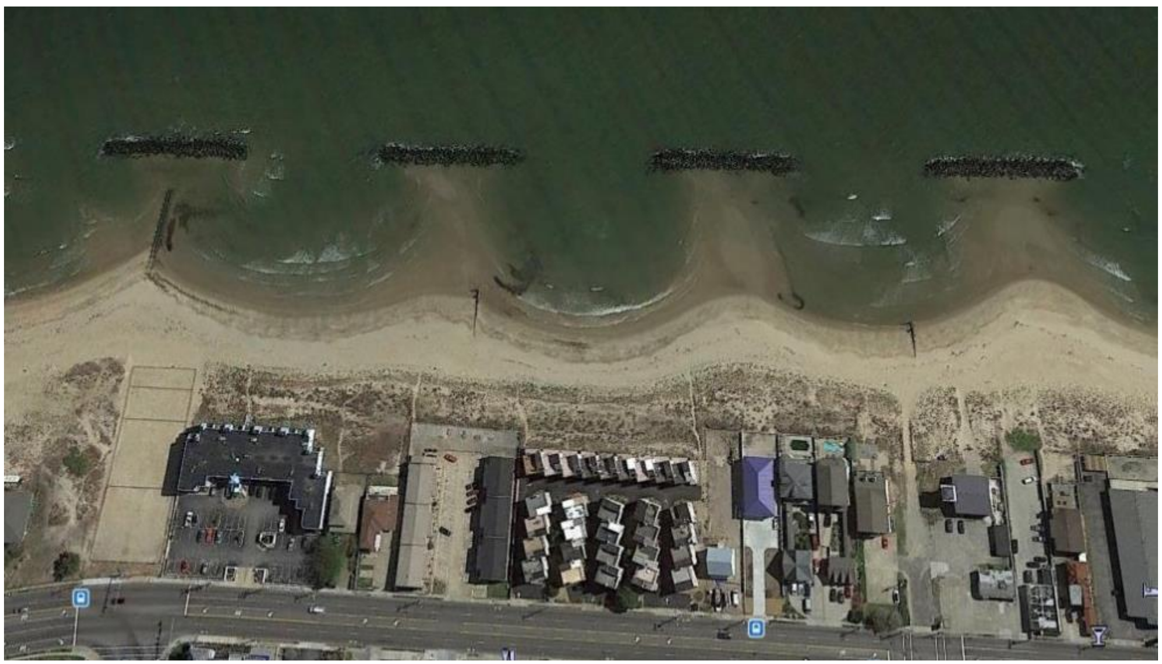


FIGURE 8-47: Offshore breakwaters used to create beach area along the shoreline at Norfolk VA *(Google Earth Maps 2016)*

FIGURE 8-46: Breakwaters used to protect shorelines and create harbours at Grand Manan and Shediac Beach NB *(Google Earth Maps 2016)*

8.4.10 HYBRID APPROACHES

There is increasing interest in the potential for combining approaches to coastal protection such that proposed works are a hybrid of enhanced natural features and built structures (Figure 8-48). As has been seen in some of the examples already presented, natural features may benefit from structural assistance (Figure 8-49). In some circumstances, constructed breakwaters can mimic the performance of naturally occurring formations, generating benefits such as diminished wave energy - and improved deposition of beach materials (Figure 8-50). Under other conditions, constructed coastal defences (e.g., revetments, seawalls) benefit from the reduction in wave energy reaching the shore made possible by their association with enhanced natural features (e.g., seagrass beds, salt marshes).

There is no one perfect combination of engineering and natural features that will answer the flood protection measures for all situations, or for all time (Table 8-5). Each approach has advantages and disadvantages, but they do share one common attribute – when used to abate flooding associated with sea-level rise, both approaches must be considered as temporary measures. While many sea-level rise projections extend into the future as far as 2100, it is important once again to note that seas will continue to rise past that date, reaching levels that will be determined by the rate and scope of global warming the planet experiences. To this end, all protection measures will either have to migrate landward, or be themselves flooded.

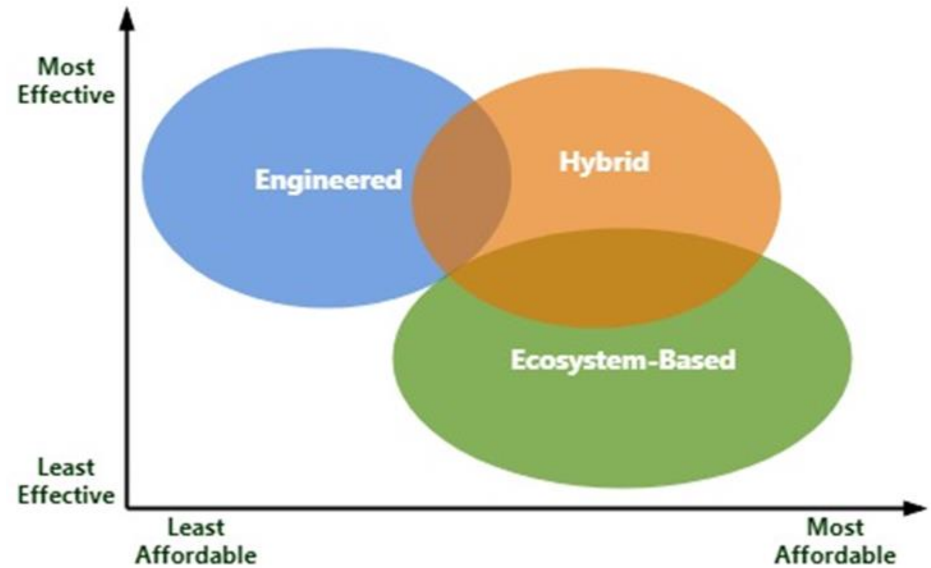


FIGURE 8-48: Relationship between built protection measures and restoration of natural features *(adapted from The Royal Society 2014).*

FIGURE 8-49: Restoration of dunes at Crowbush Cove PE. Low-lying armour stone was buried in a reconstructed dune system. The dunes, which are still erodible, were stabilized with marram grass *(Image Credit: M. Davies, Coldwater Consulting Ltd., used with permission).*

FIGURE 8-50: Placement of intertidal reef-style breakwaters at Souris, PE, as a demonstration of hybrid approaches to shoreline stabilization. Note the cuspate beach deposits which are beginning to accumulate in the lee of the breakwaters. *(Image Credit: M. Davies, Coldwater Consulting Ltd., used with permission).*

TABLE 8-5: The benefits and costs of built, natural and hybrid flood protection infrastructure *(adapted from Sutton-Grier et al. 2015).*

INFRASTRUCTURE TYPE	STRENGTHS	WEAKNESSES
BUILT INFRASTRUCTURE (gates, dykes, revetments, seawalls, groynes, breakwaters, etc.)	• Ready availability of significant knowledge and expertise to design and build these structures • Decades of experience • Excellent understanding of how these approaches function, how they interact with the natural environment, and what level of protection to expect. • Immediately ready to withstand flooding upon completion of construction	• Structures do not easily adapt to changing conditions such as sea-level rise • Structures weaken over time, and have a determined life expectancy before replacement • Often require expert design, high construction costs and regular maintenance • Can negatively impact local ecosystems, and natural processes • Offer what can be a false sense of security against all threat of flooding • May sustain more damage during storm events than natural systems • Provide benefits only during storm events, not during good weather
NATURAL INFRASTRUCTURE (seagrass beds, salt marshes, beaches and dunes, river bank vegetation, etc.)	• Many co-benefits in addition to flood protection, including enhanced habitat, water quality improvements, carbon sequestration, recreational and aesthetic amenities, which are available all the time • Restored ecosystems such as salt marshes continuously improve and become stronger and more resilient • Can keep pace with sea-level changes • May be cheaper to construct and to maintain • Can survive storm events with less damage than built infrastructure and will (generally) self recover	• Less readily available expertise or experience in construction or restoration • Need for best practices in planning, design, construction and maintenance • The range of nearshore protection services provided is not well understood, quantified or immediately replicable in a different location • May require lengthy period to establish before shoreline protection benefits are realized • Requires substantial land and/or water area for implementation • Little data on the cost of implementation • Regulatory approvals may be more difficult to obtain than for established built infrastructure practices
HYBRID INFRASTRUCTURE (combinations of built and natural)	• Capitalizes on the best characteristics of built and natural systems • Encourages innovation in design for shoreline protection • Provides some co-benefits in addition to shoreline protection • Can provide a higher level of confidence than natural systems alone • Can be used in areas where there is not enough space to implement full natural system approaches	• Little data on performance to date • Does not provide all the co-benefits of a natural system • More research is needed • Growing but still limited expertise and experience • Will still have some negative impacts on biodiversity and ecosystem functioning • Insufficient data on cost to benefit ratios • Regulatory approvals can be more difficult to obtain than for established built infrastructure practices

8.5 AVOIDING THE PROBLEM

Unlike earlier approaches that advocated 'do nothing' or 'no active intervention', avoiding the problem of sea-level rise and overland flooding is not about ignoring anticipated changes or heightened risks. Avoiding the problem is a thoughtful, and often long-term planning process for reducing the risks to property and to human well-being of anticipated higher and/or more frequent flooding.

Avoiding the problem can entail using a range of options over time that may include some or all of the following:

- managed realignment of shorelines,
- planned migration of structures and/or activities;
- zoning and other land development and management instruments,
- setbacks, buffers and easements, and the
- relocation of critical services and assets to maximize public and private benefit and to minimize risks to property and safety.

How society plans and manages land use and land development now and for the future can enhance community resilience to changes in the environment if efforts are made to:

- responsibly **alter shorelines** as an (understood short-term) measure to protect property and uses;
- **manage migration** by initiating long term planning processes that involve public education on risks and benefits, on the temporal limitations of protective measures, and on the need to plan now for migration of property and activities to lower-risk locations; and
- **update planning and development instruments** (e.g., zoning, setbacks) for land and resource development to provide for anticipated changes in local conditions.

Projections of future environmental change are modelled expectations of what is to come. If some uncertainty still exists in the science on climate change, it is uncertainty over the scope, intensity and timing of anticipated changes in local weather and regional and national trends in climate. While much can and must be done to meet these challenges, it is important to accept, that in some circumstances, society will have to migrate away from the coming hazards to places of greater stability and safety. There is little doubt that migration will be disruptive to communities and to individuals, or that it will be an unpalatable but inevitable option for many. Migration need not be promoted as losing the battle, or as a retreat from unassailable threats. Thoughtful long-term consultation, planning and design has the potential and the promise to create modern, exciting and highly livable communities, resilient, transformed and sustainable, and highly capable of meeting the demands of the changing future.

"Informed planning for development in areas affected by sea-level rise is critical"
(Batterson and Liverman 2010, p138)

Decisions on restricting new development and/or relocating existing structures and activities will have to reach a balance between the escalating costs for protective measures, the increasing risks to property and to safety and the values imbedded in each asset or activity that is at risk.

8.5.1 ALTERING THE SHORELINE

Altering the shoreline from its natural configuration is increasingly referred to as managed realignment (Figure 8-51). Shoreline realignment has also been used in beach-dune complexes where dunes are being eroded. In this situation, the eroding shoreline is restructured, and the dunes are relocated inland, maintaining the cross-shore supply of sediment and creating new longshore patterns for sediment drift. In areas where the natural shoreline has been overtaken by hard armouring, removal of seawalls and revetments allows the coast to return to a more natural form, albeit some time is required to achieve a degree of stability.

The line of actively maintained defences is moved to a new location, inland of the original and (preferably) on higher ground. In the process, new shallow water habitat is created in the area between the location of the old defences and the new defences. On marine coasts, the objective can often be to create new salt marshes, and in some circumstances, such as the breaching of dykes, to restore the original marsh. As noted earlier, marshlands can be effective in reducing wave energy and in securing sediments otherwise lost to erosion.

Attempts to undertake a managed realignment of the shoreline would require that the following conditions exist (GOV/CAN/BC 2014; Linham and Nicholls 2010):

- presence of existing shoreline defences, including natural dune formations;
- availability of (affordable and available) low-lying land at the shore;
- need to improve shoreline defences against flooding;
- commitment to long-term, strategic action requiring maintenance;
- suitability of land to be flooded (e.g., no sites of historic or cultural significance, economic or ecological importance);
- support from local coastal management and other regulatory authorities;
- support for the creation of nearshore habitats to support local flora and local and migratory fauna; and
- public awareness of the values of realignment projects.

Managed realignment is itself a form of migration away from the sea. Land must be sacrificed to create both the new shoreline defences and the marshlands. Unless some of this property is used to also create a new, waterfront with amenities for public use, local controversy can lead to opposition.

MANAGED REALIGNMENT is a deliberate process to alter a coastline, and/or to remove or to breach existing flood defences to allow flooding of low-lying areas. It has also been defined as a landward relocation of the land: sea border from its natural position.

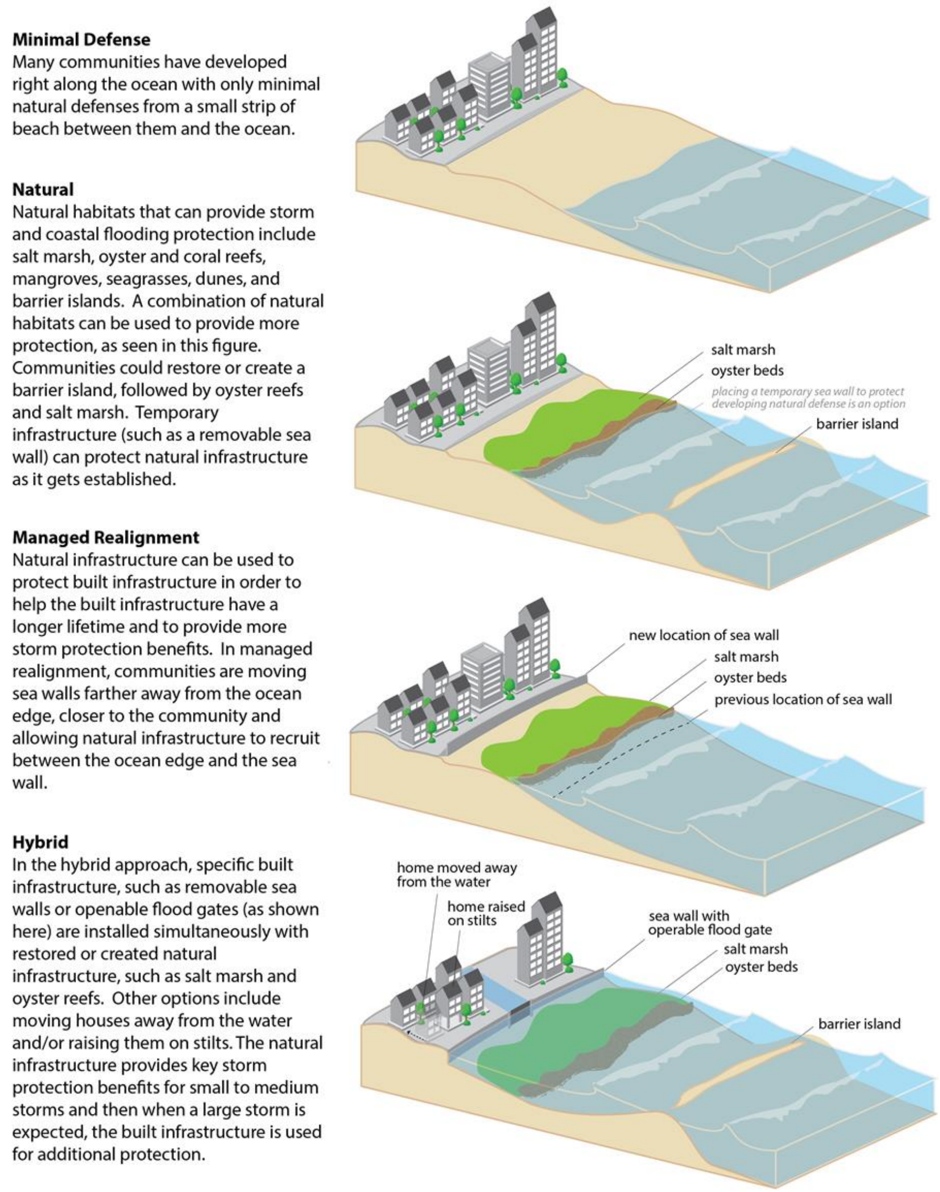


FIGURE 8-51: Approaches to coastal protection that include natural infrastructure, managed realignment, and hybrid measures *(Image Credit: USA/NOAA Available at: http://www.noaanews.noaa.gov/stories2015/20150429-noaa-study-finds-marshes-reefs-beaches-can-enhance-coastal-resilience.html).*

8.5.2 MANAGING MIGRATION

The movement of society and property away from areas of increased risk is not a retreat away from harm but a migration towards a safer more resilient location. The use of the terms 'defend' and 'retreat' in the adaptation literature has supported the often-traditional human view that the environment is to be controlled, and if it cannot be controlled, we have somehow lost and must depart the field of battle, broken and defeated. Because of the prejudicial context of the current language on adaptation, moving away from increased threats, especially those posed by rising seas, has generally been considered as the least preferable option. In reality, flooding that is the result of intensive precipitation or rising sea level will continue to be an escalating threat to human settlement and activities that lie in harm's way. Reactive measures to accommodate those risks, or to protect against them, must be considered to be temporary measures whose effectiveness has a prescribed and deteriorating life expectancy. Whether accommodation or protection measures become impractical to implement, or the costs to build or to maintain too burdensome, the inevitable result will be the same – structures and uses will need to move. When retreating from a hazard is well planned, it becomes a migration – something humans have been doing for thousands of years – to a better life. The key to the transformation from communities at risk to vibrant, resilient, and sustainable communities is vested in planning processes that work now to better enable that relatively unknown future.

Managing an effective migration of assets and uses will require a careful examination of the risks and opportunities as well as the costs and benefits associated with persisting in place or planning for thoughtful relocation of assets and activities. Migration processes must be based on the need to (Niven and Bardsley 2013).

- lower or remove risks to lives and to infrastructure;
- protect both valued environmental features and amenities of importance to society;
- limit expectations of costs associated with relocation of structures, services and activities;
- encourage future long-term and equitable use of the (changing) coast; and
- ensure that (to the greatest capacity possible) the sense of place important to so many societies transfers to the new location.

While migration is, admittedly, a costly option economically, environmentally and culturally, in some locations it may be the only practical option. Communities and societies that are ready to embrace that reality, will plan now for changes to come. Proactive planning ensures that when risks become too high to bear, acceptable alternatives are available. When major decisions are made to relocate essential services or irreplaceable cultural assets, there are locations that have been designated as potential sites for migration. In areas where the lands under threat have already been built upon, communities can alter allowable land uses to reflect the increases in risk and prepare new sites in safer areas. In the aftermath of flood events, acquisition of damaged properties will contribute to planned migration, and provide acceptable options for often beleaguered land owners.

"Planning shapes the places where people live and work and the country we live in. It plays a key role in supporting the Government's wider economic, social and environmental objectives and for sustainable communities." *(GOV/UK 2010)*

"We will have to retreat sooner or later as sea-levels rise - the financial costs of holding the shoreline in place … will eventually force our hand."

(Andrew Cooper, Professor of Coastal Studies, University of Ulster)

PLANNED MIGRATION GOAL

Armouring of shorelines, development and redevelopment in areas under threat will be limited. Renovation and reconstruction will not be permitted for properties damaged by flooding and/or weather events. Eventual relocation of structures, systems and users to safer locations will be planned for and implemented as threat levels increase. Planning will ensure public access to the changing shoreline, recreation of cultural spaces, and other important attributes of liveable landscapes.

Careful planning will improve public understanding of changing vulnerabilities and risk (Figure 8-52). The array of complex information necessary for planning for change includes (Georgetown Climate Center 2011; GOV/AUSTRAL/NSW 2010):

- **land tenure and use:** ownership and use (e.g., public or private) of currently and potentially affected lands will affect the capacity for communities to plan migration and may result in acrimonious relationships with property owners and public users, especially when their use is infringed upon – whether or not the proposed constraints are in the best interests of the individual or of the public.
- **critical infrastructure:** there will be trade-offs between the economic and environmental costs of maintaining expensive infrastructure in its current configuration or phasing out its use at that location over time and planning for relocation to less hazardous areas.
- **cultural landscapes:** the sense of place that so often defines personal and community identity can be tied to structures or activities located in a place of deep cultural or historical significance, a situation that does not readily translate to a new location.
- **developed lands:** while protection measures may be a feasible option for the near future, in reality there will also need to be enforceable limitations on hard armouring, or other protective measures, and on reconstruction of storm-damaged property.
- **developable lands:** land that is considered to have a high potential for future development, even lands where development permits have already been granted, will need to be re-examined against existing and mounting threats and the potential for damage to future development. land with a high potential for development, and few risks of damage, should be considered now for relocation of structures and systems in the future. advance planning efforts can ensure the creation of livable, sustainable communities for the future.
- **undevelopable lands** (e.g., floodplains, beach areas, wetlands, important forests, eroding shores): Lands that are considered inappropriate for development now and into the future, could be used to preserve and enhance valued nearshore, aquatic and marine ecosystems, providing opportunities for the inland migration of wetlands and beaches, and improving the potential of natural features to shelter local environments, structures and communities.

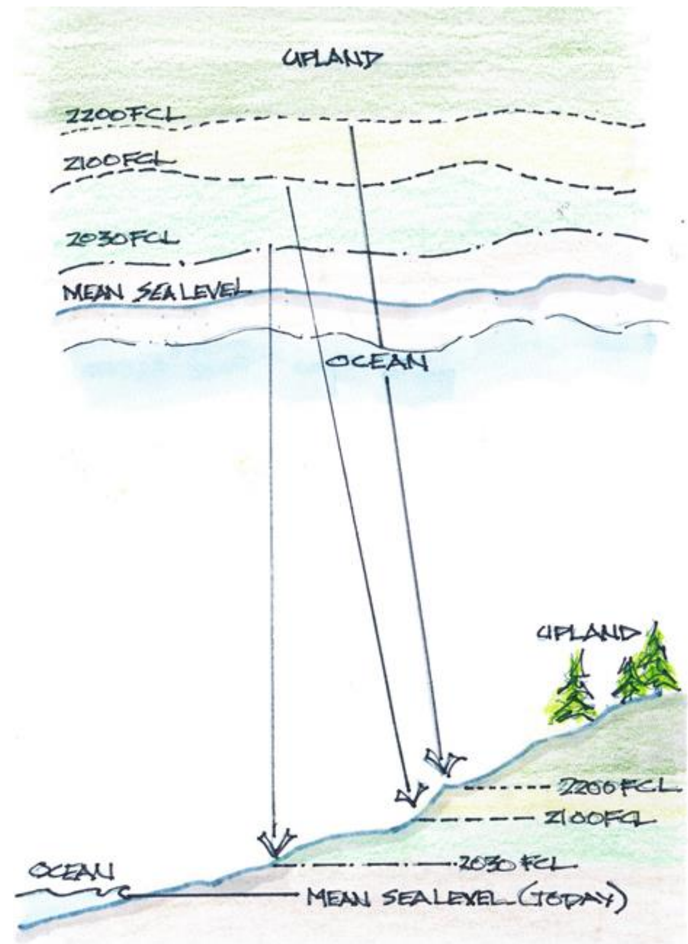


FIGURE 8-52: Planning considerations for coastal land use as flood control levels (FCL) rise with sea-level rise and more severe weather *(adapted from Kerr Wood Lidal 2011).*

8.5.3 UPDATING PLANNING INSTRUMENTS

Some communities have chosen to address the changes in environmental conditions through specially focussed climate adaptation plans, but the real strength in regional and community planning lies in integrating these efforts into established planning and development instruments such as county/district plans, town plans, development agreements and enforceable bylaws (Table 8-6). Processes to review and to alter these legal instruments can be open and collaborative, engaging support from the community and ensuring that all perspectives have been heard and all options transparently assessed.

Planning and regulatory instruments are powerful tools that can assist in incorporating mechanisms to respond to the science and recommendations on anticipated changes in flood levels, storm surges, and wave and wind damage. Integration of climate adaptation into existing planning and management tools also increases the potential for successful implementation and enforcement. Planning instruments can also provide incentive for the development of emergency response and disaster recovery measures, ensuring regular updates to address the effects of changing conditions on critical elements such as evacuation routes, shelter location safety, and threats to emergency and health services.

Comprehensive community plans (e.g., official plan, general plan, town plan, master plan) are one of the most powerful tools for development planning and management. In general, community plans are long-term plans, with time frames that span up to 20 years. In Canada, provincial regulations require the regular review and update of community plans, sometimes on five-year intervals. The processes for plan development and plan review are transparent and include multiple options for stakeholder and public participation. Plans are generally implemented through a range of legally binding instruments that include zoning, bylaws, development permits, and other special conditions (e.g., stormwater, wastewater).

Zoning is the primary mechanism by which local governments control the kind and scope of development that takes place in their jurisdiction. Zoning provides direction for the type of use permitted (e.g., residential, commercial, industrial, greenspace) and specifies through Bylaws the associated conditions to govern the construction and operation of that development. Zoning is increasingly being used to prevent development in hazardous areas, and to limit the lifespan of development and occupancy in locations at threat from rising water levels.

Subdivision regulations and controls apply when a developer wants to divide a parcel of land into one or more separate land ownership units, often for residential development. Subdivision plans are required to provide details on roads, water, and sewer infrastructure, to meet minimum lot size and access requirements, and to address issues related to financial, environmental and other impacts to the local area. In areas near water bodies and/or wetlands, subdivision requirements can include buffers between the toe of built structures and local vegetation or high-water marks and may also carry additional requirements for on-site septic systems.

"…the old legal rules must shift to make sense in a rapidly changing world"

(Bailey 2010, p319)

"**MAINSTREAMING** adaptation means ensuring that planning and decision-making take climate change impacts and vulnerability assessment into account wherever relevant. It puts in place an integrated response to a changing climate, assists in ensuring that opportunities to address vulnerabilities are explored, and also helps to avoid policies and projects that have an adverse effect on adaptation because climate change impacts were not considered. Mainstreaming will not happen overnight, but it is an open-ended process that can be improved over time." *(GOV/CAN/BC 2012, p 22)*

RULES FOR PLANNING IN FLOOD PRONE AREAS

- People and development should be located away from areas vulnerable to current and anticipated hazards
- Shorelines, whether on lakes, rivers or marine coasts should be protected. Setbacks should ensure restricted development and use.
- No new construction, and only temporary use should be allowed within designated flood areas. Flood area designations should be assessed every five years.
- Critical infrastructure (e.g., hospitals, emergency, police) should be sited outside of high-risk areas to ensure continued operation during severe weather events.
- Water and wastewater treatment plants should be sited outside of high-risk areas and designed to operate throughout disaster events.
- Transportation networks should be designed and integrated into a land use plan to reduce exposure and vulnerability and to ensure operability during and after severe weather events.

(Beatley 2009)

In addition to zoning, some areas also use **Floodplain Guidelines and/or Regulations** to delineate the boundaries of areas prone to flooding, to limit the kinds of development and use permitted in those areas, and/or to dictate conditions for construction, occupancy and operation.

In some municipalities, **Development Permits** are used successfully to designate acceptable land uses, and/or to enforce site specific guidelines for development. As sea levels rise, the option for implementation of **Rebuilding or Renovation Restrictions** for structures located within areas now deemed hazardous, or with the potential to become hazardous, can offer a compromise for property owners wishing to remain on the site for the near future. While occupancy continues to be permitted, it is accepted that damage to the structures as the result of inundation and/or extreme weather cannot be repaired.

Cluster Development also offers some opportunities to continue living near the shore. Subdivision regulations can allow for development in areas that are or will be at threat of flooding by reducing the area of each building lot, combining services and locating roadways to remove some of the risk of impacts from flooding and wave action. Where developers own large tracts of nearshore lands, permits can be issued for development plans that contain residences on smaller, move favourable areas of the site (e.g., higher lands) while allowing the remainder of the site to continue as greenspace and to act as natural flood attenuation areas.

Setbacks or buffers require that all development is situated at a specified distance from a designated baseline, typically a shoreline or vegetation feature. Land within the buffer/setback that is considered to support important ecological habitats and services is left in its natural state

In all review and readjustment of land planning instruments, care must be taken to ensure that there is coordination among the policy and regulations of all levels and sectors of government, to avoid conflicts and to reduce the opportunities for legal challenges by property owners and/or users. Care must also be taken to address the rights of access of the public to the shorelines they love, when the publicly owned lands upon which those shorelines once stood are disappearing beneath the water.

Samples of land planning instruments used across Canada and in other nations have been included in the Additional Reading section at the end of this chapter.

LAND PLANNING AND MANGEMENT TERMS

(adapted from Curran 2003; GOV/CAN/BC 2013)

BROWNFIELD: an unused area of former industrial lands that may or not be contaminated, or that have been remediated.

CLUSTER DEVELOPMENT: concentration of development on smaller lots on a portion of a larger site to provide room for green infrastructure.

DENSITY: amount of residential, commercial or industrial development permitted on a land area

DEVELOPMENT PERMIT: a land use regulation that combines objectives and guidelines with requirements for development that are site specific. Development permits can be used to regulate use of a site in ways that protect the natural environment from impact, and/or that protect development from conditions deemed hazardous.

EASEMENTS, COVENANTS: a legal agreement in which the landowner grants the use of some real property rights to another for a specific purpose such as the right to pass over. Can also be used to restrict the use of the land for a specific purpose (e.g., conservation, flood protection).

FORESHORE TENURE: the lease or licence of operation of the area of land from the Crown below the natural boundary (e.g., the highwater mark) to allow for integrated management (and use) of the foreshore.

LAND ACQUISITION: local governments can gain ownership of land for the primary purpose of addressing public safety through purchase or expropriation. Land can be acquired for a range of purposes including construction of shoreline protection measures, setbacks for public safety, prevention of development and/or exclusive public use.

LAND TRUST: a legal entity established for the management of land for conservation or other non-development purposes.

NATURAL BOUNDARY: the visible highwater mark on any lake, river stream or body of water, the edge of marshes of dormant channels. Along marine coasts, it can include the natural limit of permanent terrestrial vegetation.

SETBACKS, BUFFERS: a horizontal or vertical distance that buildings or other structures must be set back from an established boundary, or a designated reference point.

SUBDIVISION REGULATION: regulatory instrument to protect/restrict property development in areas vulnerable to coastal hazards, and/or where the natural environment could be adversely affected by sea-level rise and overland flooding.

TRANSFER OF DEVELOPMENT POTENTIAL: where land is at risk, the 'as of right' potential for development could be transferred to another area or parcel of land not at risk.

TABLE 8-6: Managed migration planning tools *(Adapted from Georgetown Climate Center 2011 and GOV/CAN/BC 2012).*

TOOL	DESCRIPTION	APPLICATION TO SLR AND FLOODING
PLANNING TOOLS		
COMPREHENSIVE PLANS, TOWN PLANS	Enunciate local vision and policies and are a long-term planning tool that guides existing land use and future development. Comprehensive plans establish the basis for zoning changes, bylaws, ordinances and approvals.	Inclusion of flood risks and anticipated effects of sea-level rise and severe weather provide direction for current decisions related to land-use, while ensuring that future risks are also considered.
SUBDIVISION ACTS AND REGULATIONS	Place restrictions on the kind of property that can be subdivided, govern the minimum size of lots, require allocations for public open space, control occupation densities, and encourage concentration of new development in preferred areas.	Concentration of new development in areas at low risk of flooding or wave action. Dedication of areas vulnerable to flooding as open space and/or setback or buffer areas.
FLOODPLAIN AND COASTAL DEVELOPMENT REGULATIONS	Used to restrict development in areas designated as the 100-year floodplain, and/or to require new and existing structures to meet requirements to minimize flood damage and promote safety.	Limits permitted uses in the floodplain to recreational, agricultural, forestry (i.e., exclude residential, commercial, health uses). Regulations used to designate expanded boundaries anticipated for changing conditions, and to impose design and construction restrictions on structures in those areas (e.g., setbacks, minimum base elevations).
SEA-LEVEL RISE PLANNING AREAS	A potential tool to deal with areas at risk, requiring periodic reassessment and adjustment to define and to alter setbacks and restrictions for development.	Used to restrict new development in areas deemed hazardous and to provide for eventual abandonment and/or relocation of existing structures and activities. Also used to designate needed land area for seawall/dyke construction and upgrade.
LOCAL REGULATORY TOOLS		
ZONING	Used to designate areas as not suitable for development, or to restrict the kind of development, the density, and/or the use. Bylaws dictate the criteria for development by limiting building footprint and specifying drainage management.	Hazardous area zoning often delineates flood prone areas. Can also be used to restrict development in steep slope areas.
BYLAWS	Set infrastructure requirements for buildings and other structures, as well as specifications for roads, lighting, water and sewage and drainage.	Bylaws can be used to restrict protective structures such as shoreline armouring or to encourage low impact development, green infrastructure, water management.
WATERFRONT DEVELOPMENT PLANS	Used to designate land use in nearshore areas for commercial, industrial, and/or residential development.	Can include setbacks from the shore, limit activities and occupancy, establish expected life cycles for structures and require planning for removal of assets to safer areas over time.
DEVELOPMENT AGREEMENTS	A more flexible approach than zoning because they can specify site-specific requirements not normally included within zoning legislation or bylaws.	Used to apply special case requirements such as protection of the natural environment, protection of the community from hazards, requirement for low-impact development; setbacks, buffers or easements.
STORMWATER MANAGEMENT PLANS	Measures to address stormwater collection, storage and disposal.	Infiltration, slow release and/or reuse of stormwater
SITE PLANNING AND DESIGN TOOLS		
SETBACKS, BUFFERS, EASEMENTS	Rolling easements provide a changing boundary that preserves capacity for shorelines to move inland.	Rolling easements used to compel owners to remove structures threatened by flooding and erosion.
CONSERVATION EASEMENTS	Flexible measure for preservation of land while allowing it to remain in private ownership.	Public acquisition of easement lands ensures use as natural habitat, floodable areas, and/or migration corridors.
DESIGN GUIDELINES AND BUILDING CODES	Specify what can be built and how it must be built (and maintained).	Require additional measures for wet or dry flood protection, foundation strengthening,
RENOVATION RESTRICTIONS	Limits the scope of renovation and/or rebuilding permitted.	Used to prevent property owners from continuing occupancy in hazardous locations.
SHORELINE ALTERATION PERMITS	Used to regulate the kind and scope of hard and soft armouring of marine and freshwater shorelines.	Permitting processes can dictate design and construction methods, and limit armouring in areas where erosion and/or flooding are deemed to be continuing and escalating hazards.

8.5.4 SETBACKS AND BUFFERS

Setbacks (also buffers) are land management and building restriction tools that prevent development and/or human use in certain designated areas (Figure 8-53). The terms setback and buffer have often been used interchangeably. In some areas they refer to two different aspects of low or no development zones: setbacks being the distance from a benchmark to a structure (i.e., building setbacks from property lines); buffers being designated spaces with restricted development and/or use. In coastal areas and along the shores of wetlands, rivers and lakes, setbacks and buffers are used in conjunction with other land use restrictions to (Simpson et al. 2012):

- protect human safety and well-being;
- reduce damage to nearshore property during extreme weather or as a result of changing water levels attributed to sea-level rise;
- protect biodiversity and sustain ecosystem services;
- protect significant cultural landscapes;
- protect important nearshore features (e.g., beaches and dunes, eroding cliffs, headlands; estuaries, wetlands);
- protect and/or enhance quality views and vistas;
- provide a buffer between marine and freshwater systems and coastal development, to allow shorelines to evolve, to expand or contract naturally, and/or to migrate inland;
- provide resources in support of natural processes such as erosion and sedimentation and prevent interference by hard armouring of shorelines;
- allow for the continuance of historic reserves and traditional public access to the shore;
- improve privacy for shoreline residents and users; and
- increase public ownership of the shore as well as participation in adaptation and restoration initiatives.

Setbacks and buffers can be employed by all levels of government and are generally enacted as a development policy or regulation, or as a zoning ordinance or bylaw. If well-designed and implemented, setbacks and buffers are a relatively low-cost to no-cost option for protecting shorelines and environments from human impacts, while advancing the benefits provided by natural features (i.e., attenuating impacts of higher water levels and wave energy, sequestering carbon). Setbacks and buffers are used in some Provinces and local jurisdictions to protect watercourses from development, including agriculture and industrial development. Setbacks and buffers can also be used to ensure there is sufficient area inland of a shoreline to allow for gradual migration of nearshore features such as beaches, dunes, wetlands and coastal forests.

SETBACK: a land management tool that requires development to be 'set back' a prescribed distance from a designated feature such as the high water high tide mark, the edge of a river bank, the seaward line of vegetation, or the crest of a dune formation. Inside the area prescribed by the setback, development can be banned or restricted according to an established set of criteria. Human use can also be limited by category, or time of the year. *(adapted from Simpson et al. 2012)*

BUFFER: a designated area of land in which construction and use is prohibited so as to protect the existing natural environment and to 'buffer' the effects of human society on valued adjacent ecosystems (e.g., beaches and dunes, wetlands, streams, forests).

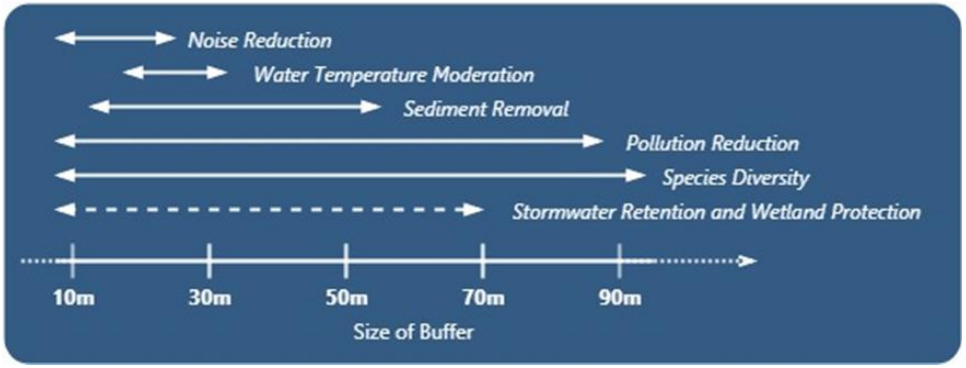


FIGURE 8-53: Sample buffer sizes for multiple goals *(adapted from Schreier 2014)*.

No setback or buffer can ensure safety from rising water or storm damage, especially in today's changing world.

Setbacks often use **benchmarks** to define their boundaries and/or the operating limits of restrictions for development or use. In marine coastal areas, setbacks generally fall into two broad categories (Figure 8-54):

- **Vertical setbacks** are intended to protect coastal infrastructure from flooding resulting from rising seas and higher storm surges and wave action. Vertical setbacks set a minimum height above an established sea level (e.g., higher high water plus projected storm surge) for the occupied floors of structures.
- **Horizontal setbacks** also protect coastal infrastructure but may be used to protect valued ecological and/or cultural assets, to ensure the rights of the Crown (e.g. access to the foreshore in harbours) or to ensure public rights of access. Horizontal setbacks can be more complicated as they are often based on a prescribed horizontal distance from a seaward benchmark that is used to define the area at greatest risk from coastal hazards (e.g. wave action, erosion, storm surges, and sea-level rise) and/or human development and use.

In many areas of the Canadian coast, the benchmarks established for coastal setbacks and coastal buffers are now moving, as sea levels rise, and storms become more intense. Vertical and horizontal setbacks established today cannot be depended upon to continue to protect all property and all activities as environmental conditions worsen at the shore. Property owners and coastal decision-makers must continually update their understanding of changing conditions to ensure that setbacks and buffers remain adequate to meet local challenges.

In the past vertical setbacks relied on benchmarks such as the historic records for local highest high water, and for the highest storm surges (e.g., 100-year storms) that had been recorded. As seas rise, and land subsides in some areas, vertical benchmarks may no longer provide long term security against flood and storm damage. Horizontal setbacks, and marine coastal and watercourse buffers, also use benchmarks (e.g., highest high water, top of beach, top of dune, edge of bank, edge of vegetation), all of which are now likely to be changing, even year to year. In some situations, depending on the objective, setbacks and buffers may use a combination of factors to designate benchmarks.

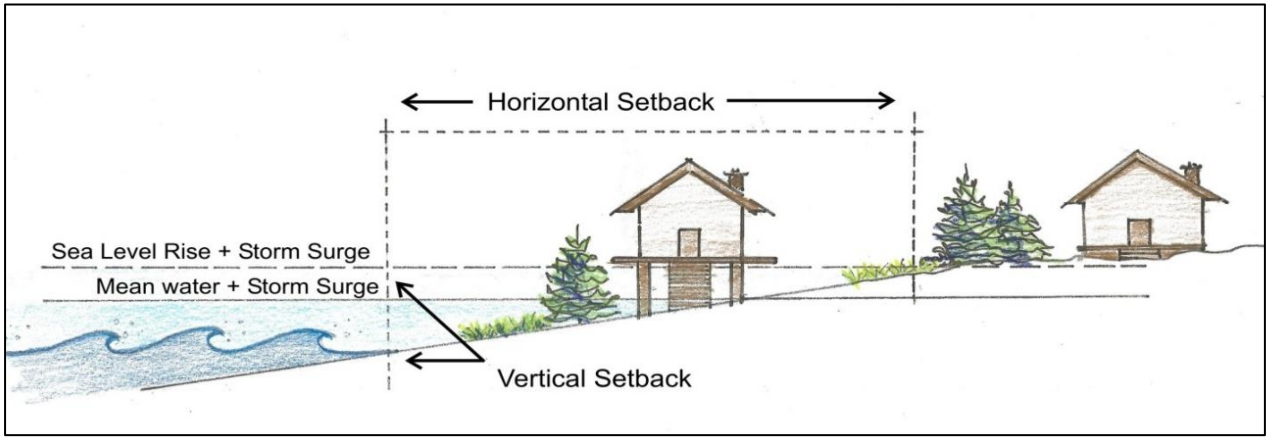


FIGURE 8-54: Vertical and horizontal setbacks on a marine coast *(Image Credit: C. Mercer Clarke)*

Coastlines are ever changing, shaped by wind, waves, tides and changing sea levels. The rules for property development and maintenance are designed to protect both the environment and the property owner.

Vertical and horizontal benchmarks can be used individually or in combination, resulting in a further delineation of setbacks described as follows (Figure 8-55):

1. A **vertical** setback based on a calculated minimum elevation above a permanently fixed sea-level benchmark (e.g. a fixed tidal benchmark, a surveyed point on the shore); or as
2. A **rolling vertical** setback based on a calculated minimum elevation above a sea-level benchmark whose position in the landscape may change over time.
3. A horizontal setback or buffer based on a specified distance landward of a permanently fixed benchmark (e.g. a fixed tidal benchmark, a surveyed point on the shore); or as
4. A **rolling horizontal** setback or buffer based on a specified distance landward of a coastal reference feature (e.g. seaward limit of vegetation, high water high tide, dune crest, shoreline), whose position in the landscape may change over time; or as
5. A **horizontal** setback or buffer based on a calculated distance (which uses dynamic, natural phenomenon) landward of a permanently fixed benchmark (e.g. a fixed tidal benchmark, a surveyed point on the shore); or as
6. A **rolling horizontal** setback or buffer based on a calculated distance (which uses dynamic, natural phenomenon) landward of a coastal reference feature (e.g. seaward limit of vegetation, high water high tide, dune crest, river bank, shoreline), whose position in the landscape may change over time.

Setbacks and buffers of any kind will be most effective when they are used as one of a mix of development planning and coastal management tools, and where the rules for application and enforcement have been carefully defined and agreed upon across all appropriate levels of government (Figure 8-56). Administration of setbacks and buffers, including the limitations under which exceptions may be considered, must work from established descriptions of prohibited and permitted work or activities, the conditions under which new development or alteration to existing structures may take place, and the restrictions on removal or alteration of existing vegetation and/or coastal features (Simpson et al., 2012).

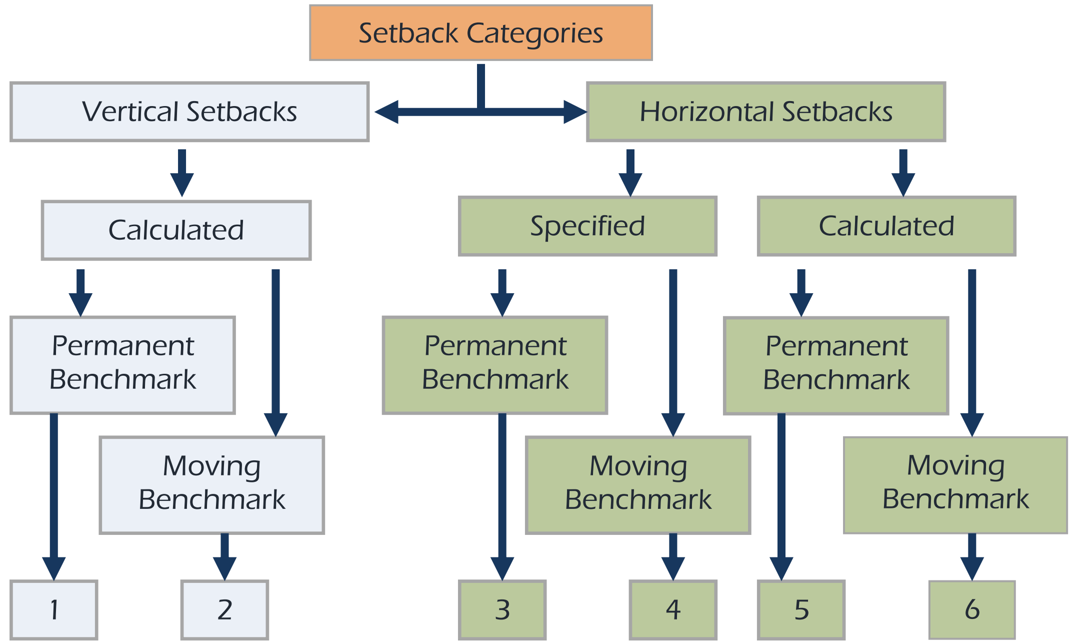


Figure 8-55: Setback categories as defined and illustrated by Mercer Clarke *(Simpson et al, 2012).*

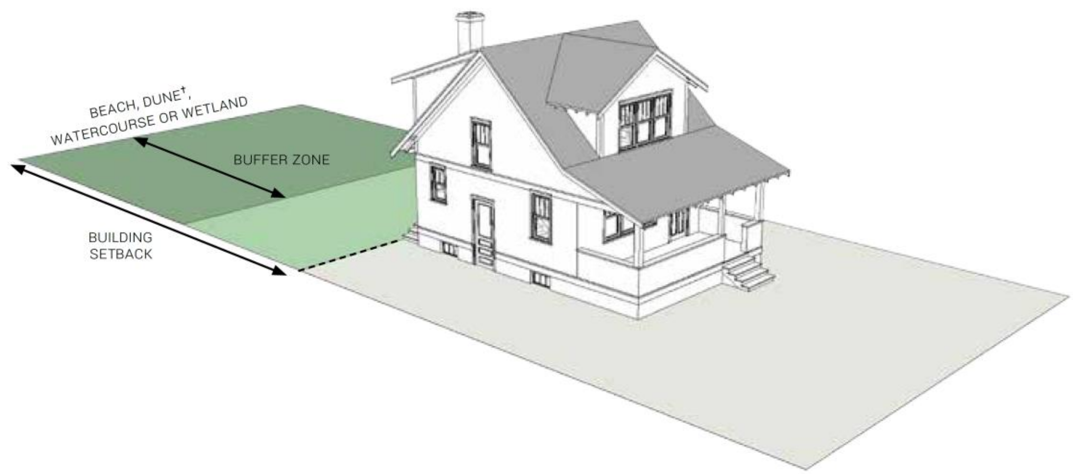


FIGURE 8-56: In Prince Edward Island, where the coastline can be threatened by erosion, development in areas that fall outside a municipality is overseen by the Province. Construction of new structures is governed both by a required Buffer established at the edge of the property to protect adjacent beaches, dunes, watercourses and wetlands, and by a Building Setback, which determines how close to the property line the foundation for a structure can be located. *(GOV/CAN/PEI 2016, used with permission).*

ROLLING EASEMENTS

Easements are generally legally binding agreements tied to property ownership. Easements can be attached to property deeds or enacted through special agreements. Property easements generally bind owners whether to some defined restriction in their use or development of their property (e.g., conservation easement) or provide a designated other with rights of access across their property (e.g., power and telecommunications distribution, shoreline access).

As sea levels rise and shorelines erode, traditional pubic access and use of the shore between high water and low water is also being eroded, and important coastal features such as beaches, dunes and wetlands are either caught in the squeeze between new mean water levels and development or have limited opportunities to continue to migrate inland as shorelines change.

A rolling easement is a legal instrument established to ensure that as water levels rise, and shorelines migrate, shoreline vegetation (e.g., salt marshes, wetlands) could also migrate and still be protected from development pressures (Figure 8-57). Benchmarks that describe the boundaries of the easement are tied to an attribute of the shoreline that is known to be moving (e.g., highest high-water mark, mean sea level, top of beach, edge of dunes, edge of wetland). As these features change the area included within the easement also changes, generally moving further inland.

While gaining increasing attention in recent times, rolling easements are not a new tool for land management, having already been used in Texas (1944), South Carolina (1988) and more recently in California 2009 (Bailey 2010). A rolling easement essentially returns ownership and management of land to the Crown, protecting public rights of access, and bringing the acquired property under potentially new restrictions for construction, renovation or even repair. Once an existing property falls within the easement, the rights of the owners and the value of their asset change significantly. Over time, easement restrictions can keep property owners from constructing shoreline defence measures, adding to existing structures, or repairing damage from storms, and may eventually require their homes or other structures to be demolished or removed from the site. Generally rolling easements do not prevent private use of the property until hazards render occupation or use unsafe.

Even where they are not referred to as rolling easements, many setbacks and buffers whose boundaries move with changing conditions (i.e. as the benchmark locations change) may perform similar functions. However, unless the setback or buffer is clearly described as intending to manage a migration of the shoreline, property owners may have heightened expectations for compensation from governments as their land and their activities are subsumed within the setback/buffer. Where coastal setbacks are rolling easements, the community intent to pursue migration instead of shoreline protection becomes a more viable option for planning and management.

ROLLING EASEMENT: a legal instrument that allows publicly owned land, and/or land use and development restrictions, to migrate inland as sea levels rise, shorelines erode and beaches and wetlands retreat. Rolling easements, like coastal setbacks, are measured against a coastal benchmark (e.g., highest high water, dune crest or edge of vegetation). Because these benchmarks are expected to move dynamically with the physical changes in coastal geomorphology, the easement is said to "roll".

THIS LAND IS YOUR LAND, THIS LAND IS MY LAND

In much of Canada, waterfront property owners hold title to land above the normal high-water mark, a benchmark that has been somewhat stable over the centuries, unless the land in question is subject to vertical movement (subsidence) or erosion. The Crown in Canada generally owns land between the normal high-water mark and the normal low water mark, which is why we have public access to beaches during periods of ebbing tide. There can be some exceptions (e.g., water lot rights) to these basic assumptions. In areas of the country where water levels are falling (i.e., some of the Great Lakes shorelines), questions are arising as to who now holds title to the land that is emerging. In areas of the country where shorelines are being eroded and mean water levels are rising, property owners are losing significant proportions of the land that historically formed part of their property. When rolling easements are keyed to those changes in shoreline features, conflicts can arise over the (evolving) rights of property owners, especially where land owners seek compensation for land already lost and/or included into a rolling easement.

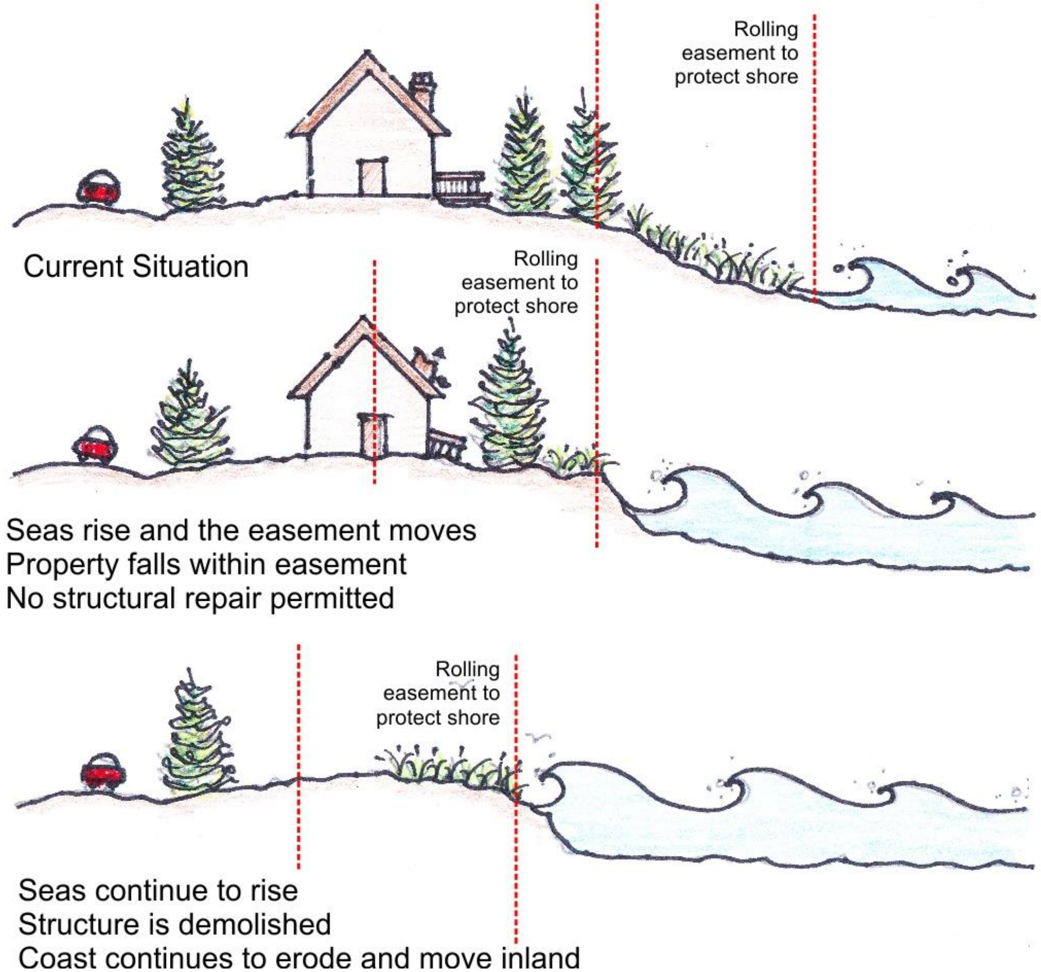


FIGURE 8-57: When governments implement rolling easements, existing structures and uses may be located in close proximity to the initial easement boundaries. Rolling easements clearly present the government's intention to move those boundaries as the line of shore changes. Easements require property owners to recognize that their property rights may be affected, and that eventually will be subsumed within the easement. In the case depicted, no repairs are permitted for structural damage due to environmental impacts. In some situations, repairs of any kind may be banned. Structures deteriorate, and when it is determined they are no longer safe, or that there are threats to human safety and well-being, authorities may revoke occupancy permits or permits for other uses *(Image Credit: C. Mercer Clarke)*.

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RESOURCES ON THE WEB

ATLANTIC CLIMATE ADAPTATION SOLUTIONS ASSOCIATION (ACASA): COASTAL COMMUNITY ADAPTATION TOOLKIT

https://atlanticadaptation.ca/

The Atlantic Climate Adaptation Solutions (ACASA) Project is a partnership among the provincial governments of Newfoundland and Labrador, Nova Scotia, Prince Edward Island, and New Brunswick, and regional stakeholders including non-profits, tribal governments, and industry. ACASA applied for and received a grant from Natural Resources Canada (NRCan) as part of the Regional Adaptation Collaborative (RAC) Program to build a collaborative effort to address regional climate change impacts. This site primarily provides access to ACASA's projects, publications, and other research outputs that help Atlantic Canadians better prepare for, and adapt to, climate change.

AUSTRALIAN NATIONAL CLIMATE CHANGE ADAPTATION RESEARCH FACILITY (NCCARF) COASTADAPT TOOL:

https://www.nccarf.edu.au/CoastAdapt-beta-release

CoastAdapt is an online coastal climate risk management framework developed by NCCARF to support adaptation to coastal climate change and sea-level rise. It has been released as a beta trial version so that potential users may provide feedback on its usefulness. CoastAdapt includes tools and information on the science of climate change, risks, effective response options, and likely costs of action. It makes use of national data sets and research outputs developed over the past 5 years by Australian scientific organisations and includes clear guidance on good practice and links to case studies. A final version will be released in early 2017.

CANADIAN EXTREME WATER LEVEL ADAPTATION TOOL (CAN-EWLAT)

http://www.bio.gc.ca/science/data-donnees/can-ewlat/index-en.php

The Bedford Institute of Oceanography is home to this science based planning tool for climate change adaptation of coastal infrastructure related to future water-level extremes and changes in wave climate. The tool includes two main components: 1) vertical allowance and 2) wave climate. CAN-EWLAT was developed primarily for DFO Small Craft Harbours (SCH) locations, but it should prove useful for coastal planners dealing with infrastructure along Canada's ocean coastlines.

CITY OF KITCHENER STORMWATER MANAGEMENT:

https://www.kitchener.ca/en/livinginkitchener/StormwaterManagement.asp

Managing stormwater at your home or business. The site provides useful information on how to reduce stormwater runoff to municipal systems, as well as a program for municipal tax credits for participating property owners.

CLIMATE CHANGE VULNERABILITY ASSESSMENT TOOL FOR COASTAL HABITATS:

http://www.ccvatch.com/

The CCVATCH is designed to be used by land managers, decision-makers, and researchers who are tasked with developing conservation, management, and restoration plans and policies for coastal habitats. This tool will help coastal land managers to identify habitats that are likely to be affected by climate change, and the ways in which they will be affected, in order to make better decisions about habitat management and restoration.

COASTAL CITIES AT RISK:

http://coastalcitiesatrisk.org/wordpress/

In 2011, the International Development Research Centre (IDRC) together with the Canadian Institutes of Health Research (CIHR), the Natural Sciences and Engineering Research Council of Canada (NSERC), and the Social Sciences and Humanities Research Council of Canada (SSHRC) awarded a total of $12.5 million dollars to five research teams under the International Research Initiative on Adaptation to Climate Change (IRIACC). The objective of the Coastal Cities at Risk (CCaR): Building Adaptive Capacity for Managing Climate Change in Coastal Megacities Program is to develop the knowledge base and enhance the capacity of mega-cities to successfully adapt to and cope with risks posed by the effects of climate change, including sea level rise, in the context of urban growth and development.

ENVIRONMENT AND CLIMATE CHANGE CANADA: FLOOD MANAGEMENT SITES

REDUCING FLOOD DAMAGE;

https://ec.gc.ca/eau-water/default.asp?lang=En&n=72FDC156-1

CANADIAN HURRICANE CENTRE:

http://www.ec.gc.ca/ouragans-hurricanes/default.asp?lang=En&n=DA74FE64-1

FLOODS:

http://www.getprepared.gc.ca/cnt/hzd/flds-en.aspx

FLOODING IN NEWFOUNDLAND:

http://www.env.gov.nl.ca/env/waterres/flooding/flooding.html

Information on flood occurrence and risk in Newfoundland and Labrador

FLOODPLAINS BY DESIGN:

http://www.floodplainsbydesign.org/

Working with those who know the land and waters best, the Floodplains by Design partnership of the State of Washington is carrying out integrated projects that improve flood protection for towns and farms, restore salmon habitats, improve water quality, and enhance outdoor recreation.

FRASER BASIN COUNCIL: REGIONAL ADAPTATION BCRAC

http://www.fraserbasin.bc.ca/ccaq_bcrac.html

Public and private sector leaders in BC are seeing the need to assess climate change impacts at the regional and local level to protect communities, safeguard economic activity and sustain environmental health. Backing these efforts is the BC Regional Adaptation Collaborative (BC RAC) program, part of a national strategy on climate adaptation.

GEORGETOWN CLIMATE CENTER: ADAPTATION CLEARING HOUSE

http://www.adaptationclearinghouse.org/

An online database and networking site that serves policymakers and others who are working to help communities adapt to climate change

GOVERNMENT OF CANADA: PUBLIC SAFETY CANADA: NATIONAL DISASTER MITIGATION PROGRAM

https://www.publicsafety.gc.ca/cnt/mrgnc-mngmnt/dsstr-prvntn-mtgtn/ndmp/index-en.aspx

GREEN SHORES:

http://stewardshipcentrebc.ca/Green_shores/

Green Shores provides options and tools for a wide range of planning, design and construction professionals who are interested in minimizing the environmental impacts of their projects in a cost effective manner. For home owners and communities, the stories, resources and examples presented here can inspire you to make choices that will be beneficial to everyone in the long term.

NATIONAL DISASTER MITIGATION PROGRAM (NDMP) CANADA

http://www.publicsafety.gc.ca/cnt/mrgnc-mngmnt/dsstr-prvntn-mtgtn/ndmp/index-en.aspx

The NDMP fills a critical gap in Canada's ability to effectively mitigate, prepare for, respond to, and recover from, flood-related events by building a body of knowledge on flood risks in Canada, and investing in foundational flood mitigation activities.

NORTHEAST REGIONIONAL OCEAN COUNCIL (NROC)

http://northeastoceancouncil.org/marshmigration/

Make Way for Marshes: Guidance on Using Models of Tidal Marsh Migration to Support Community Resilience to Sea Level Rise covers the entire modeling lifecycle from developing a modeling approach and working with data to communicating modeling results. The guidance was developed through expert interviews, a regional workshop of practitioners and scientists, and a scientific and technical literature review. While some of the information pertains specifically to NROC's region of interest in the northeastern United States, the report is also intended as a useful resource for modeling of marsh migration in other regions.

ONTARIO MINISTRY OF TRANSPORTATION: HYDROLOGIC COMPUTATION TOOLS

http://www.mto.gov.on.ca/english/publications/drainage/hydrology/section10.shtml

The site provides access to a number of inline tools helpful to estimating riverine flows during precipitation events.

RAIN COMMUNITY SOLUTIONS:

http://www.raincommunitysolutions.ca/en/roads-and-runoff/

A site that assists communities in managing rain where it falls to save money, reduce flood risk and protect water.

REUTERS NEWS 2016: WATERS EDGE THE CRISIS OF RISING SEA LEVELS.

http://www.reuters.com/investigates/special-report/waters-edge-the-crisis-of-rising-sea-levels/

A news service review story on the effect of rising water levels in North America and globally and some of the challenges as well as the innovative new approaches to preparing for change.

TURN BACK THE TIDE:

http://www.turnbackthetide.ca/

An initiative of the Government of Newfoundland and Labrador, Turn Back the Tide seeks to provide tools and resources to assist in building solutions to emerging challenges.

UNIVERSITY OF BRITISH COLUMBIA: STORMWATER MANAGEMENT VIDEO SERIES:

http://mlws.landfood.ubc.ca/videos/

The Master of Land and Water Systems program at the University have produced a series of videos that introduce the emergence of innovative designs and approaches to urban stormwater management. The series focuses on stormwater management at three different scales.

USA/ACE NORTH ATLATIC COAST COMPREHENSIVE STUDY REPORT:
RISK MANAGEMENT STRATEGIES FOR COASTAL COMMUNITIES

http://www.nad.usace.army.mil/CompStudy/

The US Army Corps of Engineers recently completed a report detailing the results of a two-year study to address coastal storm and flood risk to vulnerable populations, property, ecosystems, and infrastructure affected by Hurricane Sandy in the United States' North Atlantic region. The North Atlantic Coast Comprehensive Study is designed to help local communities better understand changing flood risks associated with climate change and to provide tools to help those communities better prepare for future flood risks.

USA/FEMA:

http://www.fema.gov/climate-change

This USA government website provides a range of information about climate change and links to related tools and documents. The page is intended for anyone interested in learning more about our resources and other USA government resources to support climate preparedness and resilience.

USA/EPA URBAN DESIGN TOOLS FOR LOW IMPACT DEVELOPMENT WEBSITE:

http://www.lid-stormwater.net/

The site provides watershed managers and other decision-makers with information on tools and techniques for Low Impact Development approaches that can be used to meet regulatory and receiving water protection guidelines for urban development, re-development and retrofit projects.

USA/NOAA/ OFFICE FOR COASTAL MANAGEMENT/DIGITAL COAST:

https://coast.noaa.gov/digitalcoast/

This NOAA-sponsored website is focused on helping communities address coastal issues and has become one of the most-used resources in the coastal management community. The dynamic Digital Coast Partnership, whose members represent the website's primary user groups, keeps the effort focused on customer needs.

CANADIAN READINESS AND RESPONSE RESOURCES

PUBLIC SAFETY CANADA:

http://www.publicsafety.gc.ca/cnt/mrgnc-mngmnt/index-en.aspx

A range of websites from different organizations all intended to better aid Canadians in readying and responding to disaster situations:

PUBLIC WEATHER ALERTS:

https://weather.gc.ca/warnings/index_e.html

EMERGENCY MANAGEMENT FRAMEWORK FOR CANADA:

https://www.publicsafety.gc.ca/cnt/rsrcs/pblctns/mrgnc-mngmnt-frmwrk/index-eng.aspx

DISASTER ASSISTANCE PROGRAMS:

https://www.publicsafety.gc.ca/cnt/mrgnc-mngmnt/rcvr-dsstrs/dsstr-ssstnc-prgrms/index-eng.aspx

FINANCIAL ASSISTANCE ARRANGEMENTS:

https://www.publicsafety.gc.ca/cnt/mrgnc-mngmnt/rcvr-dsstrs/dsstr-fnncl-ssstnc-rrngmnts/index-eng.aspx

GET PREPARED:

http://www.getprepared.gc.ca/index-eng.aspx

STORM PREPAREDNESS: Taking Action against Hurricane Hazards:

http://www.ec.gc.ca/ouragans-hurricanes/default.asp?lang=En&n=5BD95EA0-1

EMERGENCY KITS:

http://www.getprepared.gc.ca/cnt/kts/index-en.aspx

CANADIAN RED CROSS DISASTER PREPAREDNESS KIT:

https://products.redcross.ca/product/459/canadian-red-cross-disaster-preparedness-kit?gclid=CMv6wo_OhMsCFZeEaQodM_gE_g

ST. JOHN AMBULANCE EMERGENCY EVACUATION KITS:

https://www.sja.ca/English/Safety-Tips-and-Resources/Pages/Emergency%20Preparedness/Types%20of%20Emergency%20Kits/Emergency-Kits.aspx

SPCA EMERGENCY PREPAREDNESS FOR PETS:

http://www.ontariospca.ca/what-we-do/investigations/emergency-prepardness-for-pets.html

VIDEOS

BC ADAPTS: ADAPTING TO CLIMATE CHANGE ON THE BRITISH COLUMBIA COAST

https://www.youtube.com/watch?v=jEekmRWWMLc&list=PLbER4Sxdn0R4RKkJN5sKGzM0CdkOjUQs1

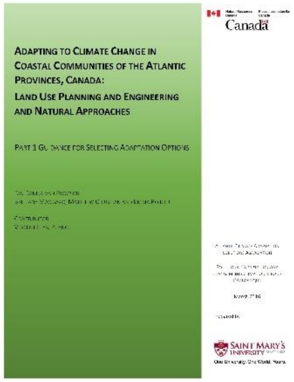
A series of fourteen YouTube videos that provide an introduction to living with climate change on the BC Coast, with special attention to three subject areas: coastal flood management; rainwater management, and water conservation.

DUCKS UNLIMITED CANADA: WEATHERING THE STORM

https://www.youtube.com/watch?v=jKmSKmNSGBI&feature=youtu.be

While solutions to climate change can be costly, working with nature is one of the simplest and most cost-effective actions we can take. This video helps to better understand the relationship between wetlands and flooding in Ontario

KEY REPORTS AND BOOKS



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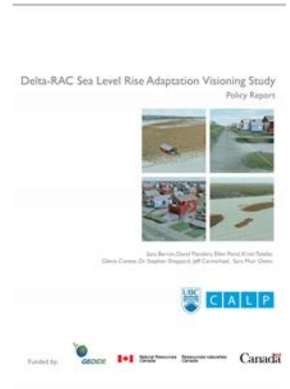

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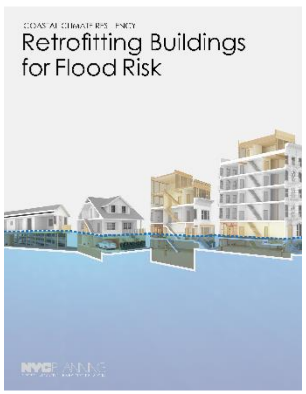

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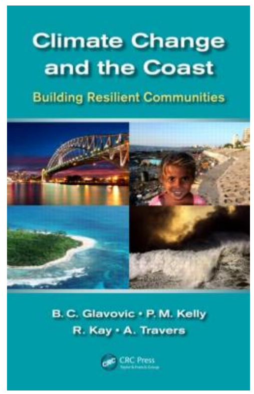

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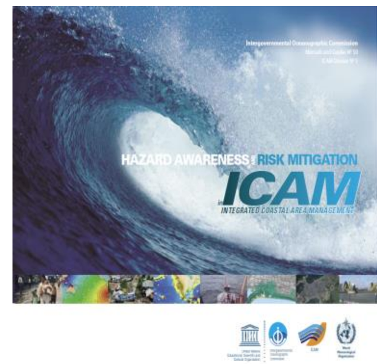

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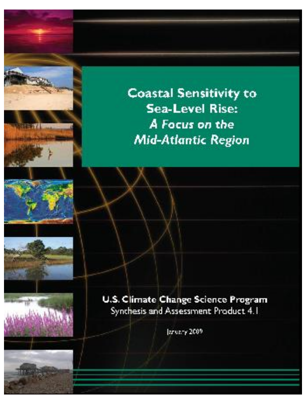

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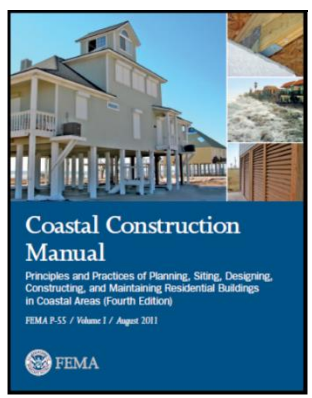

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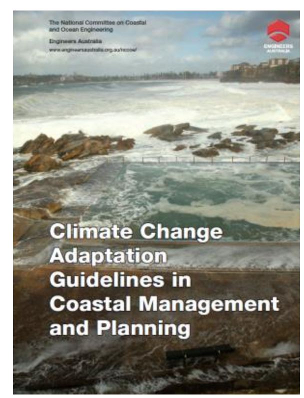

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