Adaptation measures for floods, storm surges, and sea level rise

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CLIMATE CHANGE

Climate change is caused by an increase in the greenhouse gas concentration in the atmosphere. Since humans continue to emit greenhouse gases at an alarming rate, global warming is also most likely to continue. Nine out of the ten hottest years ever recorded happened since 2000. In Canada, July to September 2012 was the hottest period in 65 years (Environment Canada, 2012). These changes in the temperature will have an effect worldwide and for many years.

IMPACTS OF CLIMATE CHANGE

Coastal communities in New Brunswick are very vulnerable to climate change impacts. Many communities are already suffering effects from this phenomenon, among others during storm surges and due to the erosion along the coast. In New Brunswick, the erosion rate was 1.4 m per year from 1969 to 1981, but it has grown to 3.2 m per year from 1981 to 1990 (Vasseur, 2009). Rising sea levels, storm surges and floods are partly responsible for this erosion and the effect of these impacts will continue to worsen with climate change.

RISING SEA LEVEL

Rising sea levels vary from region to region, which leads to different impacts. Global warming is creating a thermal expansion of the oceans and melting sea ice (Environment Canada, 2006), which is contributing to the rising sea level. Another concern for Atlantic Provinces is that they have been slowly sinking for thousands of years (Environment Canada, 2006). Some studies show that a large part of New Brunswick's coast is very sensitive to rising sea levels (Natural Resources Canada, 2002). This sensitivity rests on geological features such as the type of rock and relief, as well as other factors like tide range and wave height (Natural Resources Canada, 2002). It is expected that in the next 100 years the sea level will rise 50 to 70 cm (Warren & Egginton, 2008).

STORM SURGE

A storm surge is when the level of the sea rises in coastal areas (Vasseur & Catto, 2008). The atmospheric pressure, winds, the Earth's rotation, the sea floor's configuration, and the tide (Wikipedia) influence this phenomenon. Strong storm surges during high tide cause flooding along the coast (Environment Canada, 2006). Combined with rising sea levels, storm surges have major impacts. During the past 20 years, a few storm surges have hit the New Brunswick coast, damaging ecosystems (cliffs, dunes, beaches, etc.) and numerous private properties and non-residential infrastructures (Environment Canada, 2006). As the sea level continues to rise, we will have stronger storm surges (Vasseur & Catto, 2008).

FLOODING

A flood is the overflow of a watercourse onto usually dry land (Wikipedia[2]). Heavy rainfall, rapid snowmelt, overflowing rivers, or storm surges can cause floods. The rising sea level and storm surges linked to climate change may increase the number and frequency of floods, as well as increase the size of the area flooded during violent storms and strong tides (Environment Canada, 2006).

Rising sea levels, storm surges, floods, and other factors tied to climate change may lead to other impacts along the coast, such as:

- Stronger waves near coastal areas (Environment Canada, 2006; Hill & Mate, 2011).
- Effects on tidal range, coastal currents, and the redistribution of soft sediments (Parlee, 2004).
- Decreased protection by sea ice, leading to both increased wave action and coastal erosion in winter (Environment Canada, 2006; Hill & Mate, 2011; Parlee, 2004).
- Increased coastal erosion (Natural Resources Canada, 2002).
- Accelerated coastal retreat, including dune and cliff erosion and breaching of coastal barriers (Environment Canada, 2006; Hill & Mate, 2011).
- Destabilization of coasts, particularly along the lowlands and coastlines composed of soft sediments (Parlee, 2004).
- Permanent submergence of some coastal sectors (Natural Resources Canada, 2002).
- Intrusion of salt water into rivers and coastal freshwater aquifers (Environment Canada, 2006; Hill & Mate, 2011).
- Damage to coastal infrastructure — roads, bridges, and wharves (Environment Canada, 2006; Hill & Mate, 2011).
- Impacts on bird and wildlife habitats (Environment Canada, 2006; Hill & Mate, 2011).
- Broad impacts on the coastal economy — tourism, business and properties (Environment Canada, 2006; Hill & Mate, 2011).
- Increased risk of disease (Natural Resources Canada, 2002).
- Effects on the population's health and security, emergency preparedness, material losses, and the insurance, construction, maintenance, and renovation of coastal infrastructures (Parlee, 2004).
- Increased risk of loss of life during floods (Natural Resources Canada, 2002).
- Changes in renewable and subsistence resources (e.g., fisheries) (Natural Resources Canada, 2002).
- Loss of architectural and cultural resources and treasures (Natural Resources Canada, 2002; Parlee, 2004).
- Forest dieback along watercourses caused by a rise in groundwater and salt-water intrusion (Parlee, 2004).

The more the sea level rises and the more severe the storms become due to climate change, the more private properties, infrastructures, the economy, public safety, and habitats are in danger. Since nearly 60% of the New Brunswick population lives within 50 km of the coast and approximately 70% of the province's tourism is tied directly to the coastal experience (Hill & Mate, 2011), it is crucial to begin implementing adaptation measures to prepare for and limit the impacts of climate change. In general, with climate change, coastal communities already facing risks are even more exposed (New Zealand Climate Change Office [NZCCO], 2004).

ADAPTING TO CLIMATE CHANGE

"Adaptation refers to any activity that reduces the negative impacts of climate change and and/or positions us to take advantage of new opportunities that may be presented" (Warren & Egginton, 2008, p. 29). The goals of adaptation are to alleviate current impacts, reduce sensitivity and exposure to climate-related hazards, and increase resistance to stress factors (Warren & Egginton, 2008).

"[A]daptation to climate change is an ongoing and reiterative process that includes information development, awareness raising, planning, design, implementation and monitoring" (Stockholm Environment Institute, 2008, p. 38).

According to the Canadian Climate Impacts and Adaptation Research Network (C-CIARN, 2006), adaptation can be *proactive* (changes are brought before there are impacts) or *reactive* (measures are implemented after there are impacts). Adaptation measures are more often implemented after a natural disaster. They can be *spontaneous* or *planned*. In most cases, proactive and planned adaptation measures are less costly in the long term and more efficient than reactive adaptation.

Adaptation measures can be grouped in eight categories:

- *Supporting losses*: when a community cannot respond or when the cost of adaptation measures are judged as too expensive in relation to the risks or damages that occurred.
- *Sharing losses*: share losses between different systems or populations.
- *Changing the threat*: slowing the evolution of climate change by adopting mitigation measures.
- *Preventing the effects*: consider climate change when planning (e.g., changing agricultural and land-use practices).
- *Changing the use*: change, for example, the use of the land facing climatic risks.
- *Changing location*: move economic activities, infrastructures, or systems to locations subject to less climatic risks.
- *Carrying out research*: gain knowledge or develop technological innovations to support adaptation to climatic risks.
- *Educating, informing, and encouraging changes in behaviours*: knowledge dissemination through education and information campaigns (Stockholm Environment Institute, 2008).

In a process of sustainable adaptation, first those involved focus their efforts on adjusting policies, institutions, and attitudes that make it possible to establish the necessary conditions. Second, efforts transform into technological and infrastructural changes (Stockholm Environment Institute, 2008).

Before choosing the best adaptation measure to counter a climate change impact, identify the system's vulnerability and adaptation capacity. "[V]ulnerability refers to the degree to which a ***system*** [or a region, a community] is susceptible to, and unable to cope with, the adverse effects of climate change" (Environmental Panel on Climate Change, 2001a, in Warren & Egginton, 2008, p. 30). Vulnerability is a function of three elements (Füssel, 2007; IPCC, 1996; Polsky, Neff & Yarnal, 2007; Smit & Wandel, 2006; Turner, Kasperson, Matson, McCarthy, Carell & Christenson et al., 2003):

1. Exposure to risks caused by climate change.
2. A system's sensitivity to these risks.
3. A system's capacity to adapt to new conditions.

In order to better prepare to face climate change, the most vulnerable characteristics of a system are usually the first to be studied.

According to Warren and Egginton (2008), "adaptive capacity is defined as the 'potential, capability or ability of a system to adapt to climate change stimuli or their effects or impacts'" (Environmental Panel on Climate Change, 2001a, in Warren & Egginton, 2008, p. 32). By increasing adaptive capacity, the stress factors are reduced, including vulnerability to current and future climate.

Adaptation is carried out on several levels. Some measures are applied locally and others worldwide. Some measures are applied through the modification of technologies, policies, and behaviours. Adaptation may consist of, for example, promoting water conservation or recovery in regions where shortages are expected or preparing to face extreme weather events (violent storms, droughts, floods, etc.), by modifying building codes or reinforcing municipal infrastructures (C-CIARN, 2006).

"Evaluation of adaptation options can be based on criteria such as costs, benefits, efficiency, urgency, and implementability" (Smit et al., 2000, in Stockholm Environment Institute, 2008, p. 40).

There are several possible adaptation measures contributing to reducing climate change impacts. However, each case must be studied individually to implement the most appropriate adaptation measures to solve or improve problems in affected communities. The following are examples of adaptation measures that may be implemented in coastal communities in New Brunswick, whether through government authorities or individuals, to face rising sea levels, storm surges, and floods.

ADAPTATION MEASURES

INDIVIDUAL (BY FAMILY OR HOUSEHOLD)

- Moving computer equipment, important documents, and items of great personal value (diplomas or certificates, birth certificates, passports, last wills and testaments, photographs, acts of ownership, mortgage deeds, etc.) out of zones at risk of flooding, such as basements (New Brunswick Environment and Local Government Department, n.d.; Oostrom, Andersson-Sköld, Bormann, de Lange & van der Linden, 2011; Ouranos, 2010).
- Raising floor levels, electrical fittings and equipment (Bizikova, Neale, & Burton, 2008).
- Raising electrical outlets and panels at least 1 meter above the floor (Department for Environment, Food & Rural Affairs, n.d.; New Brunswick Environment and Local Government Department, n.d.).
- Knowing the location of electrical panels, water supply and gas lines, and how to shut them off (New Brunswick Environment and Local Government Department, n.d.).
- Shutting off the electricity to the house when it is flooded (Oostrom et al., 2011).
- Making sure the water heater is above possible flooding level (Association of British Insurers [ABI], 2004).
- Moving the washer and dryer to the first floor (ABI, 2004).
- Checking the insurance policies of homes to ensure that they are covered for damages caused by floods (Oostrom et al., 2011).
- Buying flood insurance (Oostrom et al., 2011; Ouranos, 2010).
- Preparing a list and photos of the most important possessions in the house in case of an insurance claim (New Brunswick Environment and Local Government Department, n.d.).
- Installing a sump pump in your home to pump the water outside (far from the foundation) faster than it comes in (Bizikova, Neale, & Burton, 2008; Oostrom et al., 2011).
- Purchasing protection barriers of the right dimension and ready to be put in place in doors and windows (Oostrom et al., 2011).
- Installing overhangs to prevent infiltration of heavy rain around doors and windows (Bizikova, Neale, & Burton, 2008).
- Adding silicone sealants around doors and windows to limit water seeping in (Oostrom et al., 2011).
- Sealing gaps around pipes, cables and joints between walls and door and window frames (Bizikova, Neale, & Burton, 2008).
- Constructing buildings from flood resilient materials that can withstand direct contact with floodwaters without sustaining significant damages (e.g., concrete, vinyl and ceramic tiles, pressure-treated timber, glass block, metal) (Bizikova, Neale, & Burton, 2008).
- Replacing doors, windows, skirting boards, and door and window frames by fiberglass, plastic, or other waterproof material (ABI, 2004).

- Replacing construction materials by water resistant materials (e.g., particle boards can be replaced by concrete or pressure treated wood, carpets by ceramic tiles, and wooden doors by plastic) (ABI, 2004; Oostrom et al., 2011).
- Installing or converting suspended floors to solid, flood resistant floors (Bizikova, Neale, & Burton, 2008).
- Replacing chipboard floors by pressure treated wood, which is more resilient to floods (ABI, 2004).
- Purchasing removable household products like air brick covers, panels to cover windows, sand bags, and flood skirts that temporarily protect properties during flooding events (Bizikova, Neale, & Burton, 2008).
- Replacing floor joists with pressure treated wood, which is more resilient to water. Wood tends to absorb water less, which allows floors to dry more quickly, reducing the risk of rot (ABI, 2004).
- Replacing mineral insulation within internal partition walls with closed cell insulation. Closed cell insulation is less likely to be damaged by a flood (ABI, 2004).
- Replacing chipboard or melamine kitchen/bathroom units with plastic units. Floods generally destroy chipboard units, which must then be thrown out (ABI, 2004).
- Installing a check valve in toilet drains to avoid water flowing in through these pipes (Oostrom et al., 2011).
- Using expandable/inflatable plugs to temporarily block pipes, drains, and toilets to prevent backflow (Bizikova, Neale, & Burton, 2008).
- Inserting one-way valves into drains and sewage pipes to prevent backflow (Bizikova, Neale, & Burton, 2008).
- Choosing construction techniques to reduce damages (e.g., by constructing buildings on pilings) or raising existing buildings on pilings (European Commission, n.d.; Oostrom et al., 2011; Vasseur & Catto, 2008) to live near the water without being affected by floods. The back of the house must be able to face a surplus of water.
- Raising houses particularly at risk of being flooded (Richardson, 2010).
- Knowing the usual water level and listening to weather forecasts (Oostrom et al., 2011).
- Learning about the transformations taking place in coastal areas and about what may happen in the future (New Zealand Ministry for the Environment, 2008).
- Constructing house foundations in a way that will protect them from floods (water resistant) or making sure that the first floor can be flooded thanks to water resistant materials and that fragile equipment is raised to higher ground (Oostrom et al., 2011).
- Having temporary measures of protecting houses: sand bags, small earthen levees, available materials nearby (Oostrom et al., 2011).
- By using permeable coating (instead of asphalt) around the house to help water infiltration into the ground. The water could be stored in a reservoir, and then slowly percolate down into the soil (Bizikova, Neale, & Burton, 2008; Oostrom et al., 2011).

- Directing downspouts to drain water away from the house to encourage infiltration in the ground instead of the house (Bizikova, Neale, & Burton, 2008). In fact, heavy rainfall often accompanies storm surges.
- Digging shallow ditches to allow water to seep into the ground on site or to be transported through pipes. Ditches can be covered by a permeable surface like grass or rocks (Oostrom et al., 2011).
- Planning house lots to slow water or keep it away from vulnerable structures, for example, by adding vegetation, ditches, slopes, and walls (Bizikova, Neale, & Burton, 2008 ; NZCCO, 2004 ; Oostrom et al., 2011).
- Constructing buildings on the most elevated piece of land (NZCCO, 2004).
- Supporting programs meant to protect the coastal areas in a region (New Zealand Ministry for the Environment, 2008).
- Being aware of flood risks when purchasing a property (New Zealand Ministry for the Environment, 2008).
- Having a non-perishable food reserve (New Brunswick Environment and Local Government Department, n.d.).
- Planning to have replacement batteries for all current equipment (New Brunswick Environment and Local Government Department, n.d.).
- Abandoning affected structures located too close to the shore, or only installing temporary structures or structures that can be sacrificed (Ouranos, 2010; San Francisco Planning and Urban Research Association [SPUR], 2011).
- Relocating houses that are more at risk of flooding to higher grounds (Richardson, 2010) possibly with the government's financial support (Apine, 2011; SPUR, 2011).

According to Aubé and Kocyla (2012), water and sewer check valves should be compulsory, as well as protecting water wells against water infiltration and contamination, and an expert's certification that buildings, wells, and septic tanks are flood resistant.

INFRASTRUCTURES

- Adopting inspection procedures and a maintenance schedule of infrastructures and buildings (Ouranos, 2010).
- Stabilizing coastal infrastructures at high risk of deteriorating (Ouranos, 2010).
- Relocating coastal infrastructures to areas not at risk of erosion and/or flooding (Environment Canada, 2006; Ouranos, 2010).
- Locating essential facilities (fire stations, hospitals, power plants, water treatment plants, etc.) as well as new infrastructures to areas not at risk of flooding (NZCCO, 2004).
- Protecting or relocating existing infrastructure and critical facilities. Only allowing the expansion or renovation of facilities in coastal hazard areas if measures to reduce risks are taken (constructing protection barriers, elevating existing facilities above flooding levels, relocating high-risk facilities) (NZCCO, 2004).

- Ensuring a high level of monitoring of the wastewater treatment system; raising or modifying the system if necessary (Richardson, 2010).
- Improving the stormwater management system to control floodwaters (Best Management Practices) (Dalton, Riley, Richards, & Daigle, 2009).
- Widening rainwater and sewer system pipes to increase drainage capacity (Bizikova, Neale, & Burton, 2008).
- Developing separate drainage systems for surface and foul water so surface water can directly return to watercourses, reducing water treatment efforts (Bizikova, Neale, & Burton, 2008).
- Identifying and prioritizing areas vulnerable to climate change (Chouinard, Gauvin, & Tartibu, 2011).
- Evaluating the infrastructures' resistance to storms and extreme weather (Vasseur & Catto, 2008).
- Incorporating infrastructure adaptation into the planning, maintenance, and replacement of new and existing infrastructures (Bizikova, Neale, & Burton, 2008).
- Making sure that new constructions can face predicted impacts of climate change (Bizikova, Neale, & Burton, 2008; Department for Environment, Food & Rural Affairs, n.d.; NZCCO, 2004).
- Constructing apartment buildings so that the lower floors can be flooded without too much damage (e.g., fitness centre, meeting rooms). Living areas should be more elevated (NZCCO, 2004).
- Replacing fixed walkways by removable ones (Environment Canada, 2006).
- Designing buildings that are easily disassembled and that their uses can easily change over time (Bizikova, Neale, & Burton, 2008).
- Demolishing and replacing unsafe structures (Bizikova, Neale, & Burton, 2008).
- Relocating existing structures and residents when economically feasible (Vasseur & Catto, 2008).

ROADS

- Giving priority to repairing roads broken by heavy rainfall or flooding (Richardson, 2010).
- Abandoning old roads in favour of new ones located further inland (Chouinard, Gauvin, & Tartibu, 2011; Dalton, Riley, Richards, & Daigle, 2009).
- Raising roads (Chouinard, Gauvin, & Tartibu, 2011; Environment Canada, 2006; Richardson, 2010).
- Making sure that primary roads are located outside at-risk areas and that secondary roads are placed perpendicular to the coast (NZCCO, 2004).
- Increasing depressions to keep water from accumulating on roads (Bizikova, Neale, & Burton, 2008).

BOATS & MARINAS

- Increasing the strength of building materials and providing equipment that elevates small boats above the water level during storms to protect them from wind and waves (Needham, Brown, & Carter, 2012).
- Providing machinery, ramps, and multiple marina access points to enable fishermen to quickly remove boats from the water, and perhaps transport them inland (Needham, Brown, & Carter, 2012).
- Raising port structures (anchorage, wharves) and offshore structures to protect them from strong waves (Environment Canada, 2006).
- Repairing and modifying broken wharves after major storms (Environment Canada, 2006).
- Using flood-resistant construction materials (waterproofing materials, waterproof joints, strong foundations) (Environment Canada, 2006).

ECOSYSTEMS

- Planning space on each side of the river for overflow, with a buffer zone of grasses, trees, or shrubs (Department for Environment, Food & Rural Affairs, n.d.).
- Allowing rivers to expand into side channels and wetland areas (Bizikova, Neale, & Burton, 2008).
- Having flood plains near watercourses so they can empty into them during floods and be released during dryer periods (Department for Environment, Food & Rural Affairs, n.d.).
- Recreate functional flood plains (Bizikova, Neale, & Burton, 2008).
- Updating criteria and standards promoting the protection of wetlands (Ouranos, 2010).
- Increasing natural resilience (e.g., restoring coastal dunes, renewing wetlands) (Environment Canada, 2006).
- Restoring and/or creating wetlands (Climate Change Impacts and Adaptation Directorate : Natural Resources Canada, 2002; Environment Canada, 2006; European Commission, n.d.).
- Protecting, preserving, reclaiming, and restoring critical areas (e.g., restoring dunes and wetlands as they provide protection from storm surges) (Bizikova, Neale, & Burton, 2008).
- Preserving wetlands to retain runoff, reduce spring floods, and increase water flow during summer (Vasseur & Catto, 2008).
- Preserving lands to manage current and future risks of flooding (Bizikova, Neale, & Burton, 2008).
- Establishing and protecting open spaces in urban areas, such as woodlands, trees in streets, fields, parks, outdoor sports facilities, community gardens, and private gardens to attenuate water flow and decrease flash flooding (Bizikova, Neale, & Burton, 2008).

- Paying particular attention to the size and biodiversity of species, and to where vegetation is planted (Bizikova, Neale, & Burton, 2008).
- Helping species survive by reducing habitat fragmentation or destruction, over-exploitation, eutrophication, acidification, pollution, and the introduction of invasive or exotic species, among others (Bizikova, Neale, & Burton, 2008).
- Reserving a buffer or setback area in which wetlands can migrate between developed land and today's shoreline (SPUR, 2011).
- Adding vegetation in coastal areas to absorb the energy of waves during storms in order to reduce erosion and provide a habitat for fauna (Bizikova, Neale, & Burton, 2008).
- Switching from traditional agriculture to salt-resistant crops (Climate Change Impacts and Adaptation Directorate : Natural Resources Canada, 2002).
- Preparing detailed maps highlighting areas potentially at risk of floods (Richardson, 2010).

COASTAL AREAS

- Establishing guidelines for erosion control structures on municipal and private properties (Aubé & Kocyla, 2012).
- Developing intervention scenarios for setting up protection structures (riprap, beach development and nourishment, groins, reconstruction of adjacent dunes) along the city's shoreline and the gradual withdrawal of buildings and roads (Apine, 2011).
- Implementing shoreline protection measures for low-lying coastal areas and beach cliffs in order to protect existing infrastructures and developments. Examples of such measures: breakwaters, riprap, rock walls, gabions, wood walls or block partitions, concrete blocks, angled fences, sand fences; vegetation like beach grass or conifers, additional sand, restoration of salt marshes, reshaping cliffs to reduce erosion (Chouinard, Gauvin, & Tartibu, 2011; Davies, 2011; Environment Canada, 2006; Oostrom et al., 2011; Ouranos, 2010; Paulin, 2009; Richardson, 2010; Vasseur & Catto, 2008).
- Constructing and restoring groins to stabilise the coast (Environment Canada, 2006; Vasseur & Catto, 2008).
- Establishing a second shoreline protection measure behind the first (Bizikova, Neale, & Burton, 2008).
- Constructing permanent protection measures as well as pumping systems (Bizikova, Neale, & Burton, 2008).
- Taking advantage of permanent structures, such as walls, berms, and parking lots (NZCCO, 2004).
- Widening of watercourses by dredging (Bizikova, Neale, & Burton, 2008).
- Building structures to protect at-risk tourist sites (Vasseur & Catto, 2008).
- Ensuring the maintenance of protection structures (Committee on Climate Change Impacts and Adaptation Research, n.d.).

- Implementing integrated coastal zone management to avoid destructive activities in these areas (Bizikova, Neale, & Burton, 2008; Committee on Climate Change Impacts and Adaptation Research, n.d.; Environment Canada, 2006).
- Identifying compulsory setback zones (Environment Canada, 2006).
- Redesignating and rezoning land in coastal hazard areas for uses more consistent with the risk (NZCCO, 2004).
- Identifying or modifying the zoning in coastal hazard areas to protect them or use them as open spaces (parks, playgrounds, agriculture, etc.) (NZCCO, 2004).
- Ensuring the strict application of laws along the coast (Environment Canada, 2006).
- Developing a best practices guide for coastal areas (Environment Canada, 2006).
- Identifying coastal sensitivity with maps (Environment Canada, 2006).
- Re-vegetating coastal areas with salt-resistant species, reforesting, and naturalizing shorelines (Bizikova, Neale, & Burton, 2008; Ouranos, 2010).
- Recharging beaches (e.g., installing sand fences) and planting grasses on dunes (e.g., beach grass) to increase the coast's resistance to erosion and storms (Arkell, Darch, & McEntee, 2007; Environment Canada, 2006).
- Recharging beaches by adding sand (Climate Change Impacts and Adaptation Directorate : Natural Resources Canada, 2002; Davies, 2011; Environment Canada, 2006; European Commission, n.d.).
- Controlling and/or forbidding the removal of beach sediments from rivers and along the coast (Climate Change Impacts and Adaptation Directorate : Natural Resources Canada, 2002; Committee on Climate Change Impacts and Adaptation Research, n.d.).
- Advocating for the sustainable use of the coast (Environment Canada, 2006).
- Evaluating the stress of tourism in coastal areas to recognize the risk of erosion and modification of beach sediments (Vasseur & Catto, 2008).

PREPARING & PLANNING

EMERGENCY-RESPONSE PLAN

- Writing and implementing federal and provincial laws concerning the preparation of emergency measures and mitigation (Environment Canada, 2006).
- Creating government organizations responsible for emergency management (Environment Canada, 2006).
- Creating organizations for disaster prevention (Committee on Climate Change Impacts and Adaptation Research, n.d.).
- Elaborating plans to manage emergencies and local mitigation policies (Environment Canada, 2006; NZCCO, 2004).
- Providing government financial support to research on the development of preparations in case of catastrophes (Environment Canada, 2006).
- Developing training programs on how to prepare for emergencies (Environment Canada, 2006).

- Identifying the measures to implement in case of emergencies and the resources needed to respond to extreme weather; planning for evacuations (NZCCO, 2004; Transports Canada, 2003; Vasseur & Catto, 2008).
- Identifying emergency shelters in case of floods (Environment Canada, 2006).
- Identifying and preparing emergency shelters for residents that must be evacuated (European Commission, n.d.; NZCCO, 2004).
- Planning a space to where floodwater can be directed and stored (controlling floods/levees) (Dalton, Riley, Richards, & Daigle, 2009).
- Deviating the flow of floodwater away from vulnerable areas (Bizikova, Neale, & Burton, 2008).
- Having multifunctional zones that can be flooded: areas that can be flooded without affecting their main function too much until the water has seeped into the ground (e.g., open spaces, parks, soccer fields) (Oostrom et al., 2011).
- Reinforcing and repairing existing breakwaters (Environment Canada, 2006).
- Planning an alternative source of energy for times of crisis (Dalton, Riley, Richards, & Daigle, 2009; Ouranos, 2010).
- Raising power plants to higher ground (Environment Canada, 2006).
- Finding alternative sources of drinking water and of storing water (Dalton, Riley, Richards, & Daigle, 2009).
- Building a recovery plan that is part of the emergency measures (NZCCO, 2004; Oostrom et al., 2011; Ouranos, 2010).
- Identifying replacement facilities in case of destruction (NZCCO, 2004).
- Ensuring that drainage infrastructures can face heavy rainfall (Catto & Hickman, 2004; Vasseur & Catto, 2008).
- Developing a plan to manage health and security problems linked to the flooding of community access roads during storm surges (Environment Canada, 2006).
- Developing emergency-response plans to intervene in isolated areas during storms (Richardson, 2010).
- Implementing warning systems in case of extreme weather events and making sure that the entire population in warned (Bizikova, Neale, & Burton, 2008; Climate Change Impacts and Adaptation Directorate : Natural Resources Canada, 2002; Environment Canada, 2006; European Commission, n.d.; NZCCO, 2004; Oostrom et al., 2011).
- Improving monitoring systems (in the long term and in real time) (Committee on Climate Change Impacts and Adaptation Research, n.d.).
- Making sure that residents benefit from an effective evacuation plan (Oostrom et al., 2011).
- Ensuring monitoring, inspection, and maintenance of watercourses to limit the presence of debris, plants, etc. that could hinder the normal flow of water after an event (Oostrom et al., 2011).
- Having a plan for objects that float after an event (Oostrom et al., 2011).
- Identifying the role of each government jurisdiction in the face of problems (Chouinard, Gauvin, & Tartibu, 2011).
- Developing agreements and procedures with owners and residents to ensure access to emergency shelters (NZCCO, 2004).

- Providing those responsible for emergency measures knowledge on possible flooding and erosion risks (Aubé & Kocyla, 2012).
- Starting an exchange group involving planners, engineers, decision-makers, affected residents, etc. (Chouinard, Gauvin, & Tartibu, 2011).

PRODUCTION OF MATERIAL FOR PREDICTING IMPACTS

- Producing maps that identify the areas the most at risk of flooding (during storm surges or heavy rainfall) and erosion (Aubé & Kocyla, 2012; Bizikova, Neale, & Burton, 2008; Environment Canada, 2006; Oostrom et al., 2011).
- Acquiring and updating geographic data in areas threatened by storm surges (Environment Canada, 2006).
- Mapping the areas the most at risk based on the locations where flooding has already happened and identifying their causes (bad maintenance, lack of drainage capacity, etc.); distributing these maps to all those affected (Committee on Climate Change Impacts and Adaptation Research, n.d.; Ouranos, 2010).
- Obtaining data on future sea-level rise and storm surges, as well as a database of at-risk infrastructures (roads, buildings, parking lots, wharves, aircraft runways, gas stations, protection structures, etc.) according to different flood scenarios (Aubé & Kocyla, 2012; Leon, Hamel, Forman, & Stori, 2012; Richardson, 2010; Vasseur & Catto, 2008).
- Financially supporting research on coastal risk factors (Environment Canada, 2006).
- Identifying specific coastal areas at high risk of suffering impacts as well as the probable duration of impacts to identify intervention needs (the loss of homes linked to erosion leads to the need to find short to medium-term housing, flooding living areas necessitates temporary shelters, etc.) (NZCCO, 2004).

PLANS & LAWS

- Developing policies to face the following impacts: localized floods, erosion, decreased drinking water during droughts, power failures, sewage and stormwater backup, overloaded wastewater treatment plants, health problems (Dalton, Riley, Richards, & Daigle, 2009).
- Planning land use by taking into consideration the impacts of climate change (Aubé & Kocyla, 2012; Bizikova, Neale, & Burton, 2008; Environment Canada, 2006).
- Regulating drainage systems of new developments to give them the capacity to support the expected increase in heavy rainfall throughout the infrastructures' lifetime (Ouranos, 2010).
- Revising standards and criteria of design plans for underground structures (Ouranos, 2010).
- Regulating by using maps of areas at risk of erosion or flooding to define what structures are allowed and/or are forbidden in order to limit development in

problem areas, and prohibiting any new construction (Aubé & Kocyla, 2012; Apine, 2011; Davies, 2011; NZCCO, 2004; Richardson, 2010).

- Avoiding risks by prohibiting inappropriate development (avoiding constructions of great value and with high occupancy rates) on vulnerable coastal lands (Bizikova, Neale, & Burton, 2008; Environment Canada, 2006; NZCCO, 2004; Ouranos, 2010).
- Modifying development plans to include setback areas where no new construction and expansion of existing buildings will be allowed (Aubé & Kocyla, 2012 ; Bizikova, Neale, & Burton, 2008; European Commission, n.d.).
- Modifying zoning to encourage land use with few constructions on vulnerable lands or only allowing structures that must be located on the shoreline (e.g., wharves, fish processing plants, public access, and reserves) (Environment Canada, 2006; Vasseur & Catto, 2008).
- Prohibiting new construction on flood plains to reduce damages linked to flooding (Vasseur & Catto, 2008).
- Developing requirements for structures to be located along the coast, such as mitigation and emergency measures (NZCCO, 2004).
- Identifying the undeveloped lands along the coast, like protected areas, used to reduce the impacts of the rising sea level and storms (Environment Canada, 2006).
- Using lowlands for less financially profitable projects (e.g., parks instead of inhabited areas) (Environment Canada, 2006).
- Integrating an accommodation zone for conditional use to the development plan. This area should correspond to a flood-prone area determined according to storm surge scenarios according to the following conditions (table below).

FOR EXISTING BUILDINGS	FOR NEW BUILDINGS
- Changing the use of a building to a use said to be "strategic" should not be permitted (e.g., hospital, senior citizens' homes, fire stations, schools).	- "Strategic" use should not be allowed.
- Expanding buildings should only be allowed under conditions that would depend on the planned additional area.	- The first floor of a living area should be above flood level.
- Expanding buildings should be done vertically.	- Networks (water, electricity, etc.) and mechanical systems should have to be located above flood levels; otherwise they should be protected against water infiltration.
- Other conditions should be defined according to expansion percentage categories (the greater the expansion, the more the conditions should liken those of new buildings).	- Expert certification that a building can resist floods should be required.
- Above a certain expansion percentage, conditions for new buildings should apply.	

(Aubé & Kocyla, 2012)

- Requiring that new constructions can be easily moved (NZCCO, 2004).
- Requiring a minimum height for the first floor (NZCCO, 2004).

- Requiring professional services when developing protection measures for existing developments (NZCCO, 2004).
- Adopting regulations to better control the development of areas already at risk (Ouranos, 2010).
- Including floods and storm surges in the Building Code and require strict conformity to building standards (Bizikova, Neale, & Burton, 2008; Environment Canada, 2006).
- Establishing a permanent committee composed of the municipal council and citizens to deal with issues of climate change adaptation (Aubé & Kocyla, 2012).

EDUCATION & RAISING AWARENESS

- Implementing an awareness-raising and training program for the personnel on climate change issues (Bizikova, Neale, & Burton, 2008; Ouranos, 2010).
- Developing a communication plan to disseminate information on climate change to citizens (Ouranos, 2010).
- Transmit information to the population: emergency-response plans, measures for areas at risk of flooding and erosion. This information can be transmitted during public meetings, through newspapers, on the radio, on the Internet, etc. (Aubé & Kocyla, 2012).
- Developing and implementing an education and awareness-raising program for the public to stimulate people's participation in preventing disasters. Such programs can discourage developments along the coast (Bizikova, Neale, & Burton, 2008; Committee on Climate Change Impacts and Adaptation Research, n.d.; Environment Canada, 2006; NZCCO, 2004; Oostrom et al., 2011; Vasseur & Catto, 2008).
- Publishing documents on catastrophe management for the private sector and for communities (including children) (Environment Canada, 2006).

INSURANCE & INCENTIVES

- Establishing a national program for residential flood insurance (Committee on Climate Change Impacts and Adaptation Research, n.d.; Environment Canada, 2006).
- Planning reserve funds (e.g., for relocating residents) (Ouranos, 2010).
- Moving from existing neighbourhoods or at-risk communities (Bizikova, Neale, & Burton, 2008; NZCCO, 2004).
- Developing a program of the "Buy me out" type in which the government buys at-risk properties (Chouinard, Gauvin, & Tartibu, 2011).
- Buying coastal hazard areas with government funds in order to protect them or use them as undeveloped open spaces (NZCCO, 2004).
- Reducing or eliminating the costs of construction permits for structures elevated at least 2 feet above the ground (Leon, Hamel, Forman, & Stori, 2012).

- Offering financial compensation to farmers who allow their farmland to be flooded (Bizikova, Neale, & Burton, 2008).
- Using incentives or other financial measures to encourage flood prevention (e.g., reducing residential tax rates by eliminating application fees, permit fees, and inspection fees) (NZCCO, 2004).
- Planning funds and grant programs for post-disaster restoration (Committee on Climate Change Impacts and Adaptation Research, n.d.).

Before choosing the adaptation measures to implement, a vulnerability analysis of the community must be carried out (UNFCCC, 2007). The most vulnerable features are preferably the first to be studied and implemented.

Some obstacles must also be overcome for a community to implement adaptation measures (Leary, Kulkani, & Seipt, 2007).

- Some stakeholders or decision-makers may think that climate change poses less risk than other dangers and are therefore not a priority.
- Knowledge of the options that will reduce climate risks and of the means to implement them can be limited.
- Uncertainty about the future can make it difficult to know what to do or when to do it.
- Irreversible consequences of some actions can delay choices until uncertainty is resolved.

All of these obstacles can limit adaptation. However, it is important for communities to adapt now because climate change can already be felt and will continue to do so. Here is what can be done to facilitate adaptation (Leary Kulkani, & Seipt, 2007):

- *Create conditions for adaptation*: raising awareness, informing and communicating, decreasing uncertainty, attributing financial resources, improving the state of natural resources, encouraging with incentives/discounts, etc.
- *Integrate adaptation to development*: current and future impacts of climate change threaten development. Adaptation measures can reduce these threats.
- *Increase awareness and knowledge*: gather data on climate history and on the future, as well as the impacts and causes of vulnerability. Develop programs to improve, interpret, communicate, and implement knowledge in order to manage climate risks.
- *Reinforce institutions*: community organizations, farmer associations, local government agencies, etc. who exercise the appropriate functions and enable adaptation. These institutions share knowledge, human and animal labour, equipment and food reserves; mobilize resources for community projects and public works; control the land and water use, etc.
- *Protect natural resources*: in developing countries, people's survival, economic activity, and revenues depend on natural resources. Often human pressures and climate and environmental variations influence these resources. When natural

resources are in poor condition, these resources and those who depend on them become more vulnerable to climate change impacts.

- *Provide financial support*: the poor are particularly vulnerable to climate change. Various organizations have funds, but they are very limited.
- *Involve those who are directly affected*: by involving those affected, and therefore the beneficiaries, successful adaptation is more likely. In this way, adaptation responds to local needs, use traditional knowledge and expertise, and enables citizens to own their options.
- *Use area-specific strategies*: adaptation must be specific to each area. The characteristics of local context should always shape the approach and practices that will work best.

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