Clean, Resilient Flood Technology Options in Canada

Prepared for Environment and Climate Change Canada by ACT (the Adaptation to Climate Change Team), Faculty of Environment, SFU

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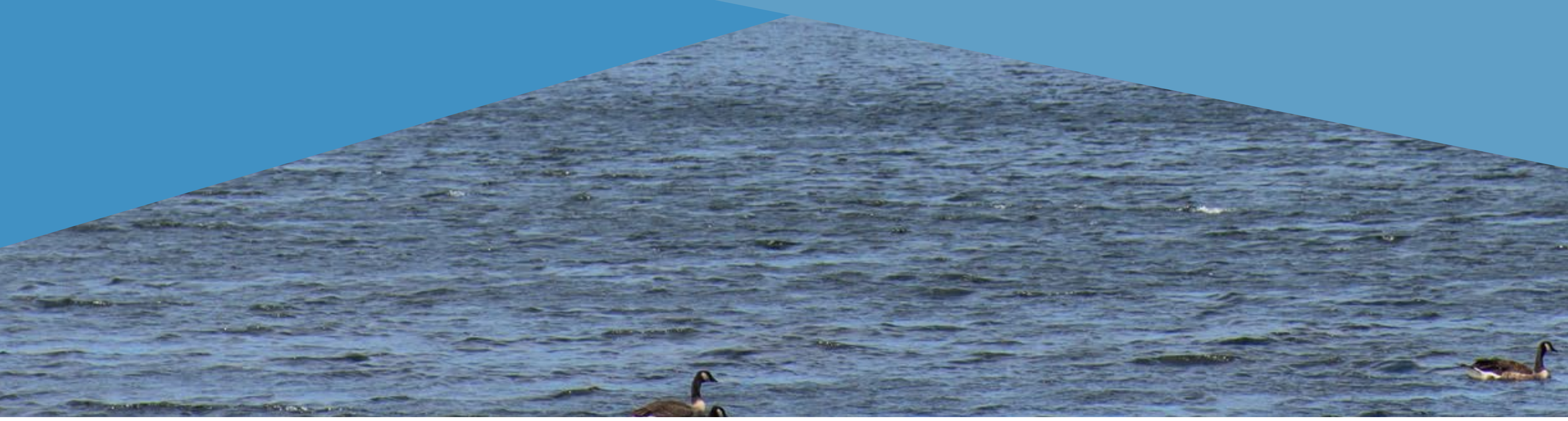

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Environment and Climate Change Canada

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The report was primarily written by **Andrew Marriott**, a graduate student in the School of Public Policy at SFU, under the supervision of **Deborah Harford**, Executive Director of ACT. Comments were also provided by **Dr. Alison Shaw**, Research Lead of ACT's Integrated Climate Action for BC Communities Initiative (ICABCCI), and **Jordan Brears,** Research Associate at ACT. ICABCCI produces action-oriented research and support to local governments in BC to adopt effective and streamlined approaches to climate action, emphasising the synthesis of adaptation and mitigation strategies under the umbrella of low carbon resilience (LCR).

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EXECUTIVE SUMMARY

This project summarizes existing literature and information on promising existing and emerging clean technologies for climate change adaptation in Canada in the context of urban planning and water resource management, specifically in terms of their climate resilience and cost and implementation barriers for wider adoption. The research focuses on flooding as a costly, current, and growing threat in the context of both urban planning and water resource management, with substantial planning and responses already underway and much more work needed. Using this research and stakeholder interviews, the project identifies measurable policy recommendations that can contribute to reduction of climate vulnerability through the use of clean technologies and other resources, increasing Canada's low carbon resilience in a changing climate.

Flooding is a significant threat to human life, property, the environment, and the economy in Canada, costing billions of dollars in damages. Canada is warming twice as fast as the global average and increases in severity and frequency of extreme precipitation are projected to exacerbate urban flood risks, while coastal flood risks will increase due to sea level rise in many areas.

Adaptation largely takes place at the local level and tends to be highly context-dependent, based on local geography, leadership, capacity, and community values. Canadian communities have implemented a wide variety of plans aimed at building resilience to flooding, and forward-thinking cities are planning to lock in resilience for decades by building adaptable and modular infrastructure. However, local governments often lack sufficient resources to properly address the problem alone.

The insurance industry is unable to keep pace with the cost of flooding, leaving many Canadians uninsured or paying high rates for coverage even as they face personal losses related to flood damage that cannot be covered by financial remuneration. The costs associated with flooding can be significantly reduced if adaptation and mitigation options are pursued, with every dollar spent on adaptation estimated to save up to six dollars in future costs.

Adaptation and emissions reduction measures are both crucial to reducing the impacts of flooding for Canadians now and in the future. Integrating the often-siloed practices of climate change adaptation and mitigation – an approach known as low carbon resilience – has the potential to streamline resources, align policy goals to be aligned, and ensure that flood interventions do not themselves add to risk, for instance, through increased emissions. Choosing flood adaptation approaches that are both low carbon and climate resilient wherever possible is therefore essential.

> "Adaptation and emissions reduction measures are both crucial to reducing the impacts of flooding for Canadians

Clean technology is a pillar of the Pan Canadian Framework on Climate Change and is a key element in Canada's transition to a low-carbon economy. While flood adaptation solutions have rarely been characterized as 'clean,' emissions reductions is a growing area of focus, and flood adaptation technology is emerging within this field. Canadian companies are producing innovative clean solutions that address many different aspects of flooding, including smart technology pilot projects, innovative digital services, nature-based solutions, and low-impact development practices.

Several companies are producing market-ready products that can assist in understanding the risk associated with flooding and preventing damage from flooding. These include homeowner products such as valves, pumps, alarms, and barriers, which can build individual resilience for relatively low costs, and products for use at the city or regional level, including large-scale stormwater management systems, reusable and modular barriers, traditional engineering solutions, and nature-based solutions that mimic natural processes. Buildings can be designed to be flood resistant by using water-resistant materials and development practices, and houses can even be built on water where appropriate. Other products are being developed or exploring commercialization after successful trials. Some of the many services provided by Canadian companies include flood mapping, risk assessment, watershed management, infrastructure assessment, water management, smart rainwater harvesting, and wave visualisation. Cutting-edge work is also being done with natural asset valuation and creating risk profiles for city buildings.

This report presents three sets of criteria that examine the resilience of a potential category of flood technology, the costs and barriers to implementation, and the degree to which a technology can be classified as clean. These criteria are applied to each category of technology to determine to what degree it successfully meets the measures laid out. Each category of technology has applicability in situations where it is the most appropriate flood response or adaptation solution. At times, pipes will be the logical and most cost-effective solutions, while at other times use of perforated pavement or other low-impact development practices will be necessary. The local context is the dominant determination of what approach should be taken.

Several categories clearly meet the criteria for being 'clean' better than others. For instance, Nature-based Solutions (NbS) sequester carbon, reduce other emissions associated with stormwater management, and provide quantifiable co-benefits. All the homeowner-level products identified have benefits that clearly outweigh any marginal costs. Other solutions are often necessary but have drawbacks that should be considered, such as the emissions intensity of traditionally engineered stormwater runoff management. These, and other approaches, including flood-resistant building materials and design, or aquatic architecture, all need to be evaluated on the merits of specific project requirements.

The findings from this work identify several gaps in Canada's current flood management approach that can be addressed with strategic policy actions, including the fact that new companies require assistance with scaling up promising products to commercialization. Low-impact development practices and NbS should be mainstreamed and used wherever appropriate to replace or supplement other measures. Natural coastlines and areas providing flood resilience and other ecological services should be preserved and restored as much as possible. Direction on standards for adaptation should be provided on a regional level for practitioners. Significant, stable, sustained funding should be provided for low carbon resilience projects to support local governments, and flood adaptation should be incorporated into asset management and infrastructure renewal. Funding should be based on partnerships and collaboration and tied to stringent environmental standards that emphasise building low carbon resilience.

Further research into the growing potential for clean technology approaches currently emerging around the world as well as in Canada would be helpful to inform further development of this sector in Canada and increase Canadians' resilience to the growing risks of flooding and other climate change impacts.

1) INTRODUCTION

This report summarizes the results of research into existing literature and information regarding adaptation in Canada for urban planning and water resource management through the lens of options for resilient clean technology responses to flooding. It describes the context of climate change and the growing severity of flooding in Canada, and the need for emissions reductions to be considered as one of the primary means of preventing severe flooding. It further discusses what adaptation needs are prioritised across the country, the growing economic costs of flooding, and how Canadian communities and governments are responding to this threat.

Existing and promising adaptation technologies are identified, with a focus on potential interventions at the individual building, neighbourhood, and community scales, providing examples of Canadian producers and providers of these technologies. These results are framed within the context of clean technology, with the aim of supporting implementation of the innovation, clean technology, and jobs pillar of the Pan Canadian Framework on Clean Growth and Climate Change (PCF). The results of this study are intended to be used to inform governmental action on clean technologies for flood management by providing additional knowledge to assess the technological potential and vulnerabilities of these technologies.

A set of criteria with specific measures that can be used to evaluate technologies is proposed based on resilience, cost and implementation barriers, and to what degree the product or service under consideration is a 'clean' technology. Technologies with known climate vulnerabilities that outweigh their resilience benefits are identified and contrasted with other potential solutions. These criteria are used to determine which technologies can be considered the most commensurate with the clean growth goals of the Canadian Government.

This framing reflects the emerging focus on integrated climate action, or low carbon resilience (LCR), which is a lens that coordinates adaptation and mitigation strategies in planning, policy, and implementation processes.[1] LCR measures can have co-benefits for health, equity, biodiversity and community livability, and form an important part of Canada's progress towards a sustainable development pathway.

Finally, the report provides measurable policy recommendations for clean technology investment that are designed to reduce vulnerability to flooding, increase Canada's climate change resilience, and meet the adaptation objectives outlined in the PCF.

2) METHODOLOGY

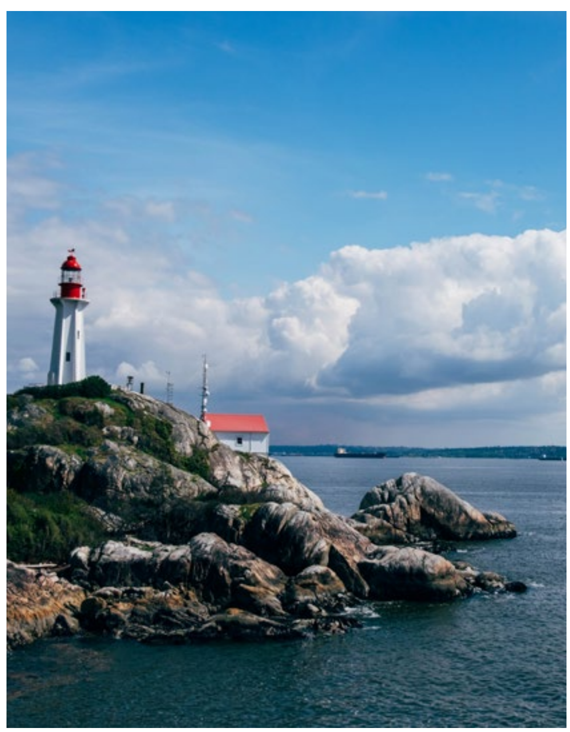
This report was conceived as a desk-based examination of the current state of Canada's flood adaptation landscape as a key aspect of urban planning and water resource management, and a review of clean flood technologies currently available or in development produced by Canadian individuals, companies, and organizations, enabling a deep dive into a crucial and costly area of current importance for Canadians. The results are intended to inform upcoming investment into clean technologies for climate resilience.

A literature review was conducted that synthesized resources including academic and grey literature, governmental and think tank reports, marketing materials, and publicly available web pages. These resources were used to inform the contextual basis of flooding in Canada and the flood adaptation landscape. Examples of the most promising new, existing, and emerging clean technologies and their providers were defined and scoped within Section 4 and contrasted with alternatives.

Phone and in-person interviews were conducted with six subject matter experts involved in different aspects of flood adaptation in Canada. Interviews were held with two engineers at large municipalities undertaking projects related to flood adaptation and a water resources engineer at a major engineering company focused on green infrastructure and low impact development. Additional interviews were held with the head of a well-known flood management consulting company, a director at a flood-focused adaptation think tank, and the owner of a start-up that has just launched an innovative flood visualisation product.

Criteria were developed to identify ways of evaluating what technologies were most closely aligned with the clean growth and adaptation goals of the Pan Canadian Framework on Clean Growth and Climate Change. These criteria emphasise potential barriers to implementation and to what extent technologies can be classified as environmentally friendly. An emphasis was placed on the resilience potential, costs, co-benefits, and implementation barriers surrounding these technologies; however, the degree to which they are 'clean' was also considered. Information collected during the research phase of the project was used to evaluate, at a high level, the efficacy of identified categories of technology in achieving the measures outlined in the criteria. However, given the location-specific nature of most flood adaptation projects, it is clear that technologies must be evaluated on a case-by-case basis depending on the unique conditions of each project.

Conclusions and policy recommendations reflect the perspectives and expertise shared by the experts interviewed as well as the research conclusions, identifying cross-cutting approaches that can benefit multiple objectives in the clean technology and adaptation sectors.



3) OVERVIEW: CLIMATE CHANGE ADAPTATION AND FLOOD TECHNOLOGY IN CANADA

a) Climate Change and Flooding in Canada

Floods are the most common and most significant hazard to human life, property, the economy, the environment, and water systems in Canada, with deep significance for both urban planning and water resources management. Climate change will exacerbate urban and coastal flooding in Canada, which is warming twice as fast as the global average, according to Canada's Changing Climate Report. Since 1948, Canada's average air temperature over land has increased 1.7 degrees Celsius, with this increasing to 2.3 degrees over Northern Canada.[2] Canada is expected to see increases in intensity and frequency of extreme precipitation that are projected to intensify urban flood risks, while coastal flood risks will increase due to sea level rise in many areas. Projected higher spring temperatures will also shift forward the timing of snowmelt-related flooding.[3]

Canada is vulnerable to many types of hazardous flooding across the country, given its vast and variable geography.[4] Due to the historical settlement patterns in Canada where cities were built around water bodies and flood plains, the most vulnerable areas are those that were first settled and farmed, leaving older Canadian cities particularly vulnerable. There are four primary geographic systems that contribute to different kinds of flooding in Canada: pluvial systems where flooding is caused by rain events, nival systems where peak flows result from snowmelt, mixed regimes that encompass both of these, and coastal flooding systems. Canada has all of these systems and they each have different characteristics due to climate change.

Pluvial regimes are seeing more frequent and intense precipitation and flooding events. Overland, or pluvial flooding, occurs when excess stormwater flows over ground that cannot absorb it quickly enough. This causes impacts including storm sewer and sanitary sewer back-ups when systems are overloaded, and discharge or back-up into basements and other areas, as well as moisture leakage in building foundations and basements.[5]

Effects on nival systems are more variable. Snowpack volumes may decrease; however, faster and more intense snowmelt may still increase the risk of freshet flooding as runoff is a primary cause of flooding. Rainfall on snowpack can increase the effects;[6] flooding caused by rapid snowmelt resulting in freshets that overwhelm downstream rivers and reservoirs could double by the end of this century, especially affecting areas in and downstream of the Rocky Mountains.[7] Riverine or fluvial flooding occurs when rivers and streams overflow their banks, often due to snow runoff or the convergence of this with precipitation events.

Sea level rise will increase the vulnerability of many coastal communities to storm surges and erosion and render some areas uninhabitable, while loss of sea ice in Arctic and Atlantic Canada will increase the risk of erosion and other damages. In a high emissions scenario (e.g. RCP8.5), Canada could see some areas experience a rise of one metre by the end of the century, with significant economic impacts. For example, annual global losses could amount to more than 4% of global GDP, though this could be reduced to below 0.5% with effective mitigation and adaptation measures. China, India, and Canada are projected to experience the highest macroeconomic impacts among G20 countries if no further adaptation is completed.[8] All types of flooding threaten the risk of costly, disruptive damage.

> "Floods are the most common and most significant hazard to human life, property, the economy, the environment, and water systems in Canada

b) The Growing Severity and Cost of Flooding in Canada

Canada has experienced several severe urban flooding events in the last few decades, and they are becoming more costly and more frequent. In 1996, the Saguenay Flood was the first natural disaster in Canadian history with damages over $1 billion. The next year, the Red River flooded and caused an estimated $500 million in damage across Manitoba. Southern Alberta was inundated by rain in the spring of 2005 by three major storms in three weeks, that forced thousands of residents, including 2,000 in Calgary, to evacuate, and caused more than $400 million in damage. In May 2011, the Assiniboine River in southern Manitoba flooded and caused $1 billion in damage.[9] In 2013, the Bow River flooded after experiencing above-average rainfall and spring runoff; communities west of Calgary recorded hundreds of mm of rain while Calgary saw 68 mm of rain fall in 48 hours. Three thousand buildings in Calgary were flooded, tens of thousands of residents were evacuated, and damage was pegged as high as $6 billion.[10] Flooding in April and May 2017 in eastern Ontario and southwestern Quebec caused at least $200 million in insurable damages, with the true cost much greater. In 2019, the Ottawa River flooded again, at levels much higher than in 2017.

These events, and the fact that extreme precipitation-related urban flood risks and coastal flood risks are projected to increase in frequency and magnitude in many locations, as the Canadian population grows and many cities expand, have helped place a focus on the importance of proactive flood adaptation in order to preserve infrastructure and critical systems and prevent severe economic damage.

Due to the unprecedented and extremely costly nature of recent flooding in Canada, the insurance industry is facing significant challenges that will affect Canadians. Many insurance companies have previously assumed the risk to property from extreme weather is static and based their premiums on historical data and trends, but the risk is becoming greater. Insurance property and casualty payouts from extreme weather have more than doubled every five to ten years for almost four decades. Insurance payouts have averaged $1.8 billion per year from 2008 to 2017, more than four times the average of the previous twenty-five years.[11] Insurers are now starting to account for climate change as well as offering overland flood insurance, and this has resulted in a dramatic increase in premium rates or removal of coverage in high-risk areas.[12] As climate change advances and floods grow more severe, thousands of Canadians will be unable to acquire insurance on their homes or will have to pay prohibitively high premiums. Repeated flood damage can put homeowners under water on their mortgages, impact credit ratings of municipal bonds, and create lawsuits involving parties affected by flooding.[13]

Studies have shown that the financial damage associated with flooding can be significantly reduced if effective adaptation and mitigation options are pursued. Scenarios looking at keeping warming to a 2-degree Celsius temperature increase found that the localized cost of flooding would be several times cheaper than in a 4-degree scenario.[14] Research indicates that investments in adaptation and community resilience save up to $6 for every $1 spent.[15]

c) Adapting to Flooding in Canada

The prevalence, costliness and diversity of current and future flood risk requires Canadians to accelerate planning and implementation of flood responses through pro-active climate change adaptation planning. Municipalities control 60% of the public infrastructure in Canada and will have to deal directly with worsening climate impacts at the local level; they are on the front lines but have limited financial and jurisdictional capacity,[16] with some areas being disproportionately affected. Most adaptation initiatives are undertaken at the local or regional levels and the ability to adapt varies across populations, economic sectors, and regions.[17]

The methods of adaptation vary. The UN notes that adaptation technologies for flood management can exist to address hazards, with reservoirs, levees, and wetland being used to mitigate floods. These technologies can also address exposure and vulnerability, with flood warning systems and avoided or adapted development in floodplains.[18] There are many options and no one solution is perfect. Coastal areas, for example, can be protected with hard structures, such as dikes, seawalls, and tidal barriers, or soft structures like dune or wetland restoration or beach nourishment.[19] Each of these options carry their own difficulties and potentially significant trade-offs. There may be multiple competing options, and these are typically selected from using strategic structured decision-making approaches that take into account local context and values. Technologies may target one or more types of flooding, depending on the context.

Each flood response project entails a unique combination of historical risk and projected climate hazards, demographics and age/state of existing infrastructure (both grey and natural), adaptive capacity in terms of resources and leadership, community priorities and values, and urgency versus long-term thinking. Smart adaptation also requires responses to be considered in light of other climate change pressures and ways to achieve multiple co-benefits, rather than developing solutions for flooding alone. Each flood response project will therefore employ a unique combination of solutions and planning, and it is therefore difficult to identify one flood solution or technology that outranks another in all circumstances. Due to the key functions and specific scales of different technologies, it is also not possible to directly compare them – for instance, a pumping system cannot be compared to a sea wall or an early warning system, given their diverse applications.

This report presents examples of technologies designed to respond to flooding in Canada and proposes a set of criteria that can be used to assess resilience and sustainability of technology options in the context of the key adaptation needs being assessed for each project.

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d) Adaptation, Mitigation, Low Carbon Resilience, and Co-Benefits

Climate action involves both mitigation and adaptation. Mitigation involves the reduction of emissions while adaptation prepares for the impacts of climate change. Planning for these two goals has traditionally been done in silos, but there is a growing realization that there are major benefits to integrating them into a single approach known as low carbon resilience, or LCR. Integrating the two streams of climate action can streamline resources, align policy goals, and drive mutually beneficial opportunities.[20] This approach supports the transition towards a sustainable development pathway while creating co-benefits for human health, infrastructure, biodiversity, equity, and other priorities.

Reducing emissions is a key flood reduction approach. The Intergovernmental Panel on

Climate Change (IPCC) reports that there is high confidence that sea level rise will continue past 2100 and that slowing the rate of sea level rise provides a greater chance for adaptation.[21] Limiting global warming to a 1.5°C increase will limit human exposure to flooding overall, compared to a 2°C increase.[22]

Flood adaptation is costly and infrastructure-intensive and can also be highly emissions-intensive and environmentally damaging. As Canadians plan adaptation to flood risk, it is therefore essential that we consider solutions that are low carbon resilient and consider trade-offs as well as the potential to develop solutions that have multiple co-benefits in a changing climate. For instance, the **Municipal Natural Assets Initiative** has demonstrated that ecosystem-based flood responses have the potential to benefit both adaptation and mitigation and can offer financial advantages in terms of both avoided costs and reduction of pressure on ageing grey infrastructure, delaying replacement costs. They also often have further context-dependent social, economic, and environmental benefits, providing several of the co-benefits referred to earlier.[23]

> "Ecosystem-based flood responses have the potential to benefit both adaptation and mitigation and can offer financial advantages

e) Canadian Communities, Technologies, and Adaptation Strategies

Canadian industries, companies, governments, and individuals are devoting increasing efforts and funding to planning for the economic and social risks of flooding in response to the increase in severe events. The approach to flood risk in the last few decades has shifted from a viewpoint of 'flood defence' to 'flood management,' and from short-term reactive solutions to longer-term, flexible, and adaptive flood management policies.[24] Implementation, however, lags. Communities across the country are beginning to build flood adaptation projects and many have developed adaptation plans and strategies that include flood responses, but many of the most important projects are deferred into the future.

The response across Canada is varied depending on the geography and resources of each location. Ideas and strategies to address flooding may work in specific locations and be impractical or ill-advised elsewhere. Coastal cities, for example, have emphasised responses that aim to prevent or mitigate the effects of sea level rise, while other cities are facing more frequent fluvial and pluvial flooding.[25] Some cities, like Surrey, face threats from multiple types of flooding and have to tailor their response accordingly.[26] Other areas face more readily identifiable threats; the Red River Basin in Manitoba covers 13,000 km^2 and is so flat that major floods can spread over huge areas and cover vulnerable urban areas, spurring the construction of one of the most famous Canadian flood defences, the Red River floodway.[27] This sort of engineering is only appropriate in very specific circumstances where other solutions are impractical, or the consequences disastrous. A much smaller by-pass channel diverts potential floodwaters from Brampton, Ontario, but there is still significant flood risk in the downtown core; Brampton is an example of a Canadian city exploring adaptation strategies that could eliminate this risk and spur revitalization, addressing two key issues at once.[28]

Implementing flood prevention and recovery projects is crucial, but municipalities are often unprepared and lack the resources to prepare for, manage, and respond to large-scale flooding events. Money is often only spent in the aftermath of flooding. Billions of dollars have been spent across all levels of government in Alberta, for example, in the aftermath of the 2013 flooding that devastated Calgary.[29] Without preventing or mitigating flood damage, the financial costs of flooding could triple across Canada by 2030.[30] Being proactive and ensuring communities have the capacity to build before flooding occurs has the potential to save costs in the long run.

The federal Disaster Mitigation Adaptation Fund has provided several cities with the funding to begin building projects. Infrastructure Canada's Climate Lens acts in conjunction with this fund. It involves conducting a GHG mitigation assessment, requiring that an infrastructure project's anticipated emissions are measured, and a resilience assessment, which uses risk management to anticipate and adapt to climate change for projects over a certain cost threshold.[31] Saskatoon has accessed the fund to facilitate its Flood Control Strategy, which involves building infrastructure including dry ponds, underground storage, and additional piping in older neighbourhoods to improve their capacity to deal with stormwater.[32] The cities of Surrey and Delta, Metro Vancouver, and the Semiahmoo First Nation have collaborated on a joint submission to build resilience through both structural and nature-based infrastructure works, beginning with shovel-ready engineering projects.[33] This highlights the cross-boundary nature of flood adaptation and the need for jurisdictional cooperation.

The projected impacts of climate change and downstream flood impacts are based on complex models that have some degree of uncertainty based on assumptions about future trends. Some cities are therefore pursuing phased strategies to build in resilience to infrastructure projects by requiring that the products used are modular and able to be adapted as climate change challenges evolve in the future. For example, Surrey is proposing that an outdated sea dam be replaced with one that allows for pumping to be added in modules as sea levels rise and the rapid increase in pumping required in the future is realized. The gates can also be raised in concert with future increases in sea level rise. This type of adaptability ensures that projects will not need to be repeated in the future and lowers capital costs. By embedding this level of adaptability in the infrastructure they build, Surrey is attempting to build in resilience for up to a century.[34]

Other stakeholders have advanced context-specific products and services to provide Canadians with security against flooding, including through advance warning of extreme events. For example, **FloodNet** is a research network that advances collaboration between academics, government scientists, and end-users that aims to enhance flood forecasting and early warning systems.[35] Think tanks like the **Intact Centre on Adaptation**, in collaboration with the insurance industry, are providing guidance advancing expertise and innovative responses to flood risks for homeowners and commercial businesses.[36] These types of groups, along with private companies, are creating innovative technologies, products, and services to address flooding in Canada.

> "Canada's transition to a low-carbon economy requires the development of clean technologies that can advance adaptation to climate change while reducing emissions

f) Clean Technology and Flood Adaptation

Clean technology refers to any "process, product or service that reduces environmental impacts."[37] Canada's transition to a low-carbon economy requires the development of clean technologies that can advance adaptation to climate change while reducing emissions as much as possible. Environmental and clean technology activities totaled $66 billion in 2018, accounting for 3.2% of Canadian GDP, mainly driven by clean energy production and environmental goods and clean technology services. The sector employed an estimated 317,000 Canadians and exported $13.6 billion of goods in 2018.[38] Canada is investing in and promoting these technologies as part of an effort to meet increasing global demand and grow the domestic economy in ways that are beneficial for the country while advancing the goals of the Pan Canadian Framework on Clean Growth and Climate Change (PCF).

The PCF includes four pillars: pricing carbon pollution; complementary measures to further reduce emissions across the economy; measures to adapt to the impacts of climate change and build resilience; and actions to accelerate innovation, support clean technology, and create jobs.[39] The innovation, clean technology and jobs pillar emphasises early stage innovation, accelerating commercialization, fostering adoption, and strengthening collaboration.[40]

Many of the projects undertaken by cities are necessary defences against flooding, but their construction can entail environmental destruction or significant carbon emissions through the transportation of materials and the carbon embodied in the projects. The terminology of "clean technology" is not typically used within the adaptation approaches that have to do with flood solutions, since many of the projects and approaches described, especially traditional approaches, have not tended to see emissions reduction as a priority. Indeed, adaptation and mitigation have historically been approached in siloes, but this approach is becoming outdated, with the IPCC acknowledging the benefits of integration.[41] There is significant work underway in Canada to advance integrated climate action, or "low carbon resilience" (LCR).[42] The criteria outlined later in this report will help determine which of the identified technologies qualify as "clean" technology and explore the role for technological approaches that may not be classified as such.

Nonetheless, there are examples of clean technology being used for flood adaptation purposes in Canada and around the world. Aspects of the clean technology industry are beginning to partner with the insurance industry in some countries. Clean technology companies using emerging technologies like big data, the Internet of Things (IoT), mobile technology, AI, and sensors can more accurately quantify the risk exposure of insurance companies and create individual risk profiles. **FloodFlash**, a United Kingdom-based company, develops sensors that monitor floods. If the flooding is found to reach a pre-agreed water height, the policy pays out immediately. This provides more certainty to the insurer and the insured customer and allows for adaptive measures to be considered and used to reduce premiums.[43]

There are many other developing examples of clean technology that can be used for flood adaptation in Canada. Several of the companies and technologies outlined in the next section of this report, which is focused on Canadian flood adaptation products and services, collaborated on a stormwater technology pilot project in Collingwood, Ontario that aimed to develop a smarter way to overcome basement flooding, identify water management issues, and build resilience. The project installed the newly developed Internet-of-Things (IoT)-based product **SafeSump** in homeowners' basements, in conjunction with **RainGrid's** Stormwater Smartgrids, which connects rainwater barrels to a central server to manage household water levels. This was done in combination with the installation of low impact development features including rain gardens and permeable parking lots throughout the community. **Greenland Engineering Consultants** contributed its expertise in data collection, management, and analysis; the **Environment Network**, a local non-profit, held public consultations; and **Huronia Alarms**, a local alarm company, assisted in monitoring. The project's goal is to use the data acquired to divert sump pump drainage away from sanitary sewers and implement low impact development practices that reduce the town's carbon footprint.[44]

The project utilized existing expertise and a suite of cutting-edge flood prevention technologies to help reduce flood damage to property, reduce stormwater runoff and improve the ability to engage in evidence-based decision-making.[45] The project succeeded in reducing stormwater runoff by 69-100% for all sites analyzed.[46] This is one example of how clean technology can shape Canada's response to flooding; other Canadian examples of clean flood adaptation technologies are described in the next section.

> "There is significant work underway in Canada to advance integrated climate action, or "low carbon resilience" (LCR)

4) CANADIAN FLOOD ADAPTATION PRODUCTS AND SERVICES

The adaptation landscape in Canada is evolving, with new products and services being constantly added. Innovative flood technology is being developed abroad and in Canada, with Canadian companies producing, piloting and delivering a range of flood products and services, many of which are relevant for adaptation to the exacerbated levels of flood risk being driven by climate change. This section outlines a range of Canadian examples and includes others that are being produced by international companies and hold promise for development here in Canada. This is not a complete list of technologies or sectors; examples of companies and products are used where appropriate and were selected based on identified sectors, publicly available information, and ties to Canada. Inclusion in this scan does not constitute an endorsement of a particular product or company.

It is important to note that there is a need for a constellation of these products and services as there are often overlapping applications and needs between their use, especially in the context of services. No one product or suite of products will offer a perfect solution in every context. The dynamics of flooding and the responses to it are location-specific and affected by different landscapes and geology, community values, and past choices in urban development. Clean technology approaches may have to be combined with traditional solutions and their trade-offs to ensure that adaptation effectively builds resilience and protects Canadians from the impacts of flooding. A combination of public policy, collaboration between stakeholders, public engagement, and strategic technology choices are all vital to ensuring Canada is prepared to face the challenge of flood risks that are projected to intensify in a changing climate in ways that do not add to the risk, and where possible, benefit multiple priorities beyond reducing flooding.

Technologies range from large-scale engineered solutions at the community level, to neighbourhood interventions, to household products designed to increase individual defences from flooding. As noted, flood technology has rarely been characterized as 'clean technology;' some of the technologies described may increase vulnerabilities in other areas and would not be characterized as environmentally friendly. Nonetheless, many of the technologies reduce environmental strain or provide new and innovative solutions. This is especially prevalent with smart technologies and the variety of services offered by Canadian companies. Section 6 evaluates the technologies using criteria designed to assess benefits in terms of resilience, emissions, costs, and other priority considerations.

This section provides an overview of common flood adaptation technologies and services. It begins with the status quo and focuses on traditional engineered solutions that have historically been used to combat flooding. It contrasts these with more natural solutions and moves into manufactured products offered by Canadian companies. It finally describes the suite of innovative services, technical expertise, and software provided by Canadian companies and organizations.

Traditional Engineered Approaches

The traditional response to flooding in Canada has been to emphasise the development of permanent 'grey' infrastructure that may entail significant emissions or construction costs. These hard engineering measures, such as sea walls, dikes, locks, weirs, pipes and dams, and reservoirs control bodies and flows of water by limiting and restricting where water can go. These measures are often required due to built environment conditions, but as we move forward with sustainability and low carbon resilience in mind, they should increasingly be used with caution and in conjunction with other measures. For instance, they can mask vulnerabilities and promote development in at-risk areas, alter the natural environment in undesirable ways, deflect the problem elsewhere, need significant and costly maintenance, and be both emissions-intensive and difficult to adapt to changing conditions.[47] Given the range of climate actions needed and the financial limitations many communities face, contemporary flood protection projects should consider a variety of context-dependent responses that both lock in or accommodate development of long-term low carbon resilience while aiming to provide the widest suite of co-benefits possible.

Sea Walls, Barriers, and Other Engineered Structures

Historically, Canada has mitigated coastal flooding through large-scale grey infrastructure such as sea walls and dikes. Structures can be designed for either coastal or riverine flooding, as the characteristics of the flooding are very different. The onset, duration of flooding, potential for damage, and power of flooding are context-dependent, and structures have to be designed with specific adaptation goals in mind.

While these barriers are necessary in many contexts, they increasingly have to be tailored to cope better with adaptation to more severe storms, rising sea levels, and more frequent coastal flooding. Planning such projects raises numerous issues, including uncertainty as to sea level rise timing and extent; emissions intensity and embedded carbon in the constructed barriers; the potential for ecological damage; and ocean view and access issues for residents. Reinforcing these barriers as sea levels rise entails an increase in barrier height and ecological footprint and may create a false sense of security.[48]

Revetments are sloping structures that line rivers, reservoirs, and lakes in a similar manner to sea walls. Levees manage the movement of water by creating a raised barrier and are found in many different contexts. The possibility of failure exists, and these structures have limited adaptation potential.[49] Flood walls with built in gates are a permanent barrier that allows gates to be closed to provide protection along a pre-built perimeter. Other barriers can be permanently or temporarily installed and deployed as necessary.

Floodways can be constructed to convey water in areas vulnerable to flooding. The Red River Floodway in Winnipeg, built in 1968, is an excellent example of this approach. It is designed to divert water away from the city via a control gate that is raised in a flood event, causing the water to divert into the 47 km floodway that bypasses the city. Although it was a very expensive capital project, it is estimated to have prevented tens of billions of dollars in flood damage over its life.[50] It was able to divert most of the water in the 1997 Red River Flood away from the city. Floodways, however, are not a perfect solution and include trade-offs such as the potential flooding of upstream communities.

Engineered Stormwater Runoff Management (ESRM)

Stormwater has traditionally been dealt with through engineered solutions and drainage systems that transport water away from areas that may flood. Retention basins and stormwater

> "Flood protection projects should consider context-dependent responses that lock in long-term low carbon resilience while providing the widest suite of co-benefits possible

chambers can provide alternative mechanisms for managing runoff that do not attempt to mimic the natural hydrologic cycle in the way approaches such as green infrastructure strive to.

ESRM can capture and store stormwater using submerged chambers, often created out of concrete, polyethylene, or other materials, before discharging the water to the ground or collection systems. Geocellular storage is an engineering solution that provides underground water storage capacity and is used to delay and control the movement of water, with the goal of limiting the strain on existing sewer and drainage networks. This approach consists of a modular crate system in areas with low levels of permeability and water storage capacity.[51] These detention basins can be used in concert with ESRM to temporarily store water during heavy rainfall to limit the peak runoff rates and prevent localised flooding.

Several Canadian companies provide expertise in this area, such as **Armtec** and **Next Stormwater Solutions**. Reinforced concrete chambers can be used to ensure durability, resistance, and adequate load capacity.[52] Similar products made of high-density polyethylene or other materials are more lightweight and can be carried into position and used as detention or infiltration systems when other solutions are less appealing.[53]

The practices surrounding ESRM have evolved to convey stormwater in a more comprehensive way, moving from an initial focus on grading and drainage designed for common and frequent events only, to a focus on removing water from an area as quickly as possible using sewers and engineered waterways. From there, flow management for large events was introduced and streets, homes, and overland flow routes were designed to handle events that exceeded storm sewer capacity. ESRM introduced technologies that can capture pollutants and remove them from the system prior to discharge and treat the water as it passes through the system. Contemporarily, geomorphology and downstream erosion control attempts to address the increase in stormwater volume, while source control and low impact development attempt to deal with runoff at the source and mimic the hydrological cycle to the extent possible.

Retrofitting and Replacing Storm Sewers

Storm sewers have been designed based on historical rainfall and runoff patterns. With climate change affecting precipitation patterns and reducing confidence in the capacity of these systems to manage extreme weather events and flooding, it is important to consider ways they can be adapted. For instance, some portions of sewer systems can be underutilized while others are overtaxed during storms, leading to overflow. This can take place in storm sewers and combined sewers in which storm and sanitary flow are not separated.

Increasing the capacity of drainage pipes is a common consideration in the suite of options available at the time of retrofit and replacement, although other strategies focus on utilizing existing infrastructure more efficiently. Modification and expansion of these systems provides one way to alleviate the pressures that will come with climate change. Practices such as real time control, as opposed to passive operation, can prevent overflows in municipalities served by combined sewers by directing stormwater to underutilized areas using pumps, gates, and dams.[54]

It is inevitable that sewers will need to be retrofitted or replaced in some circumstances, as infrastructure ages and climate change affects the performance of existing built systems. Flooding is likely to increase because of these factors and modifying sewer systems can directly address these impacts. In a case like this, technologies like ESRM and green infrastructure are not competing nor mutually exclusive. They both provide different means, that can be layered in the local context, of achieving flood adaptation goals.

“Practices such as real time control, as opposed to passive operation, can prevent overflows

Sewer upgrades can be completed in concert with other practices like Low Impact Development and Nature-based Solutions (NbS), which aim to enhance ground infiltration of precipitation. By integrating these approaches, flooding can be addressed in a more complete and holistic manner using a suite of the best and most applicable technologies and approaches available.

Nature-based Solutions

This report outlines flood management options that are both clean and resilient to increasing impacts. The dominant narrative surrounding a "clean" response to the challenge of flooding in Canada utilizes NbS that attempt to use or engineer technologies that mimic or use natural processes or assets to provide resilience to flooding. Natural assets such as forests, aquifers, wetlands and foreshores can provide a clean technology alternative to traditional engineered infrastructure that allows communities to reduce vulnerability to climate change impacts and reduce emissions over time.[55] They provide ecosystem services including provisioning, regulating, and supporting the natural environment, and also provide cultural services while benefitting human health.[56]

Nature-based flood management aims to slow, store, disconnect, and filter floodwaters as they move along their course, reducing peak flood flows by recreating natural processes and infiltrating more water into the ground. Different types of NbS can be aimed at surface, fluvial and coastal flooding, though many have multiple applications. Interventions using NbS can take place at different scales, including large-scale approaches such as living dikes, foreshores, river and stream restoration, parks designed as stormwater amenities, and small-scale applications installed on individual properties or in neighbourhoods.

NbS can provide alternative solutions for newly built developments or communities by implementing nature-based designs from the ground up, but they can also potentially be used to address flooding in built-up areas where no flood control measures exist, and used as an alternative or addition to the retrofit of existing measures where appropriate.

> "Nature-based flood management aims to slow, store, disconnect, and filter floodwaters as they move along their course

Coastal Flooding and Natural Adaptation Strategies

The unique environment and long-term nature of coastal flooding provides specific challenges. The shoreline provides the first line of defence against coastal flooding. Hard engineered structures such as sea wells, levees, and dikes support a traditional approach focused on coastal defence. Emerging approaches attempt to use the natural environment and soft engineering measures to manage coastal processes in a dynamic manner and utilize a staged approach that can be adapted as necessary when climate conditions change.[57]

Naturalizing shorelines involves the restoration or re-creation of natural buffers to waterways and take on many forms. Shorelines have the potential to act as buffers for sea level rise as well as for storm surges and flooding. They provide services like wave attenuation, erosion protection, and other co-benefits.[58]

There are several other coastal strategies that can increase an area's flood resilience. Coastal nourishment involves the artificial addition of sand and sediment to a shoreline, with the goal of dissipating wave energy. This can take place through natural processes, but in built-up areas where natural processes have been interrupted, nourishment often needs to be manufactured. This approach can reduce erosion while protecting and creating natural habitats and recreational areas for human activity.[59]

Sand dunes are a natural coastal flood defence and their restoration can accumulate sand, stabilise the dunes, and reduce how far coastal floods can reach inland. These natural flood defences can be damaged by human activity and bear the brunt of wind, wave, and tidal forces that cause erosion. Planting beach grasses and limiting human activity can preserve these structures.

Coastal wetlands and salt marshes come in many forms but tend to be partially separated from the sea and submerged by tidal forces. They provide essential habitats for many species and reduce the crest height and velocity of waves, decreasing erosion and the extent to which water moves inland.[60] Mud flats are a form of coastal wetland that are created from the sediments deposited from rivers or by tides. They also help reduce wave energy, limit erosion, and provide critical habitat.[61] Wetlands can also store and slowly filter water during precipitation events.[62] Natural and artificial reefs and rip rap – rocks or large boulders placed along a coastline – also perform many of these same functions.

Surface Flooding and Low-Impact Development Strategies

Attenuation strategies use natural or artificial structures to reduce the velocity and turbidity of water, increasing the time it takes for water to move along the pathway and giving more opportunities for infiltration. This reduces erosion, results in less sediment being transported, increases habitat creation and assists with preserving biodiversity.[63]

Strategies that can help accomplish this goal include upland woodland planting, which increases infiltration and reduces runoff, and the creation of natural overground material dams from fallen trees or similar natural products that act as a buffer and obstruct, but do not stop, the flow of water.[64] Restoring riverbanks by planting trees and plants can held stabilize the riverbank and increase sediment capture, while adjusting the morphology of the river to more closely resemble its natural state reduces how fast flood waters move. Other strategies include the creation of overland sediment traps and the creation of riparian woodlands.

Climate change is causing existing drainage networks to exceed their capacities, leading to combined sewer overflows and flood damage. Incorporating sustainable drainage systems can reduce the volume and intensity of surface and overland flooding, which reduces the load on the drainage system. These drainage systems are designed to mimic natural processes and retrofitting hard and impermeable environments using sustainable drainage systems can turn them into more natural and more efficient stormwater solutions.

> "Sustainable drainage systems can reduce the volume and intensity of surface and overland flooding

There is a large suite of technologies and processes that encompass NbS and sustainable drainage systems. Many of these applications focus on improved infiltration rate of surfaces, including technologies such as rain gardens, swales, perforated pipes, infiltration trenches, and permeable pavement.[65] The effectiveness of these can be accurately measured and specific infiltration rates targeted, although this will vary based on the local adaptation context.[66] These strategies are often termed low-impact development.

Green roofs, for example are layers of vegetation on the tops of buildings that can replace traditional rooftops. They detain rainfall in a permeable surface to reduce pressure on drainage systems for frequent events. These roofs present numerous co-benefits such as increased biodiversity, air quality, and reduced energy demand.[67]

Rain gardens exist at the neighbourhood level and provide naturalized infiltration opportunities that minimize or slow the entry of rainfall into traditional stormwater systems or bodies of water. This can assist the efficiency of these systems while also benefiting biodiversity and human health.[68]

Strategies like the installation of permeable pavement improve infiltration rates, manage run-off, recharge groundwater, and can be constructed to meet specifically required infiltration rates and potential loads.[69] Bioretention cells or areas collect water run-off and have soils and vegetation designed to remove contaminants from run-off, and often located adjacent to impervious surfaces like roads. Swales are shallow ditches lined with vegetation running parallel to roads and paths. Filter strips can gently direct water run-off towards swales or work in concert with filter drains that use a gravel-filled channel to treat surface flows and remove sediments before conveying water through a perforated pipe.[70]

Low impact development often focuses on source control of rainwater. When geography permits, retention ponds and wetlands – traditionally used end-of-pipe ESRM techniques with applicability to NbS – can be used to control flow rates and treat run-off by allowing sediments to settle and nutrients to be absorbed. Wetlands provide a variety of ecological services as well and can be constructed, as the City of London in Ontario did when it created the Dingman Wetland in 2015. The wetland incorporates erosion control and expanded water storage within the floodplain during storm events, while providing permanent new fish and wildlife habitats.[71]

Many communities and companies are exploring nature-based solutions as potential parts of a holistic adaptation strategy. Several different companies, including but not limited to the **Greenland Group, Stantec Inc.**, and **Watercom Engineering Inc.** offer services in the management and design of drainage based on Low Impact Development systems and Nature-based Solutions.[72]

> "Many communities and companies are exploring nature-based solutions as potential parts of a holistic adaptation strategy

Manufactured Products

In addition to solutions that mimic natural solutions, there are many other adaptation strategies that involve physical products that prevent flood damage or alert individuals to flooding events. Most of these technologies attempt to reduce the environmental impact of flooding or improve the efficiency of traditional responses by innovating and modernizing existing approaches. This section provides a brief overview of Canadian products, companies, and services that have been identified as contributing to flood adaptation in Canada.

Reusable Flood Barriers and Sandbag Alternatives

The traditional rapid response to flooding has been to place sandbag barriers where flooding is expected. Sandbags require significant amount of labour to fill and the sand often ends up in the landfill after the flood has passed, creating waste. Several Canadian companies have created reusable barriers that can be deployed when flooding is expected to occur, and some can even be deployed while submerged in water. These barriers provide an attractive alternative to traditional responses like sandbags. These alternative barriers are, for the most part, lightweight, reusable, and require less labour and time to set up. They can be stored when not in use, used on a variety of surfaces, and the rapid ability to deploy the barriers makes them ideal for responding quickly and effectively to flooding events.

Such products can provide an effective, efficient response to flooding that is adaptable, but do not constitute a permanent solution. There are still labour costs to set up the barriers and emissions involved in the production, transportation, and installation of these barriers. Barriers of this type can be placed at the individual building scale or put in place to protect an entire neighbourhood, depending on the product used and location it is applied.

There is some variation in the construction of these barriers and the methods used to hold back water in a flood. **Flood Control Canada's** INERO barriers emphasise durability and are made up of modular aluminum sections almost two metres high that interlock with supports to create a curve-able, fixed barrier covered with a polyethylene film and anchored by sandbags.[73] It is a rigid structure that can be put together quickly.

Other barriers, such as Quebec-based **MegaSecur's** Water-Gate water dams, are lightweight, self-locking, and modular dams, that use the weight of the incoming floodwater to deploy and gain stability without the need for sandbags.[74] The flexibility of the PVC barrier allows for a variety of configurations and barriers can be stored pre-joined in crates.

This type of technology is currently manufactured by several Canadian companies. In addition to the two companies described above, **Rapid Barrier Systems Inc.**[75] and **Barricade Environmental Inc.**, both based in Alberta, the **Layfield Group**,[76] based in British Columbia, and **Ark Flood and Dam Resources**,[77] based in Saskatchewan, are among the companies that produce similar products. **Eco Fox Solutions** is also developing a rapid deployment system for community and structural flood protection, emphasising portability.[78]

Alarms, Sensors, Valves, Pumps and Homeowner Products

Many Canadian companies are focused on providing expertise and products that reduce the flood risk borne by individual homeowners. Three of the primary examples of technologies homeowners can invest in to mitigate flooding potential are backflow prevention valves, sump pumps, and alarms. Backflow prevention valves prevent water from entering a home when combined sewers overflow due to capacity issues, while sump pumps work in tandem with a pit that collects floodwater that is then pumped out of the pit and away from the building, ensuring the basement stays dry. Alarms placed in areas where flooding first occurs can provide a means of alerting property owners before the damage becomes unmanageable. New variations of these products include innovative features like real-time alerts and data, integration with other products, and autonomous operation.

These products entail some emissions in their production, transport, installation, and use, but the benefits provided outweigh these costs. There are potential methods of reducing these emissions, such as de-carbonizing the power grid or limiting the depth of new basements to reduce the amount of pumping required when they do flood.

Backflow valves are one of the cheapest and most effective means that a homeowner can protect their property from flooding.[79] They prevent sewage backup into basements by being placed directly into the sewer and automatically closing if sewage backs up from the main system. They are manufactured by a number of Canadian companies, including **Mainline Backflow Products Inc.**, which has several variations of the products and was founded in 1997.[80]

Alert Labs, founded in Kitchener in 2015, offers a suite of water management products that work together, including the Flowie water flow sensor, Shuttie automatic shut-off valve, and the Floodie flood sensor. This company uses IoT technology to build products and has partnered with the cities of Guelph and Welland to help customers monitor and reduce their water usage and prevent flooding, contributing to Canada's green building industry. The products will send alerts to a customer's phone or computer and, depending on the configuration, can shut off water valves automatically if an anomaly is detected.[81] The Sumpie, installed on a sump pump, can also help monitor water levels and the maintenance requirements of the pump.[82]

As sump pumps become more important, Canadian companies like **Safe Sump** are focused on updating and modernizing old designs to ensure they include fail-safes, real-time notifications on a homeowner's phone, and autonomous

> “
> Many Canadian companies are focused on providing expertise and products that reduce the flood risk borne by individual homeowners

operation.[83] These pumps leverage Internet of Things technology. A pilot project using Safe Sump has just been completed in Collingwood, Ontario, and commercialization of these pumps is the next step for the company.[84] This project involved the collaboration of several partners and other companies with the community.

Several companies have developed or are developing alarms that can be placed in households or commercial buildings so that water leaks or flooding can be detected early on and dealt with before it becomes a significant problem. Smart metering devices provided by several companies can help control the flow of water and reduce the potential for flooding by investigating how much water is typically flowing through a system. Some of these products, like the **Alert Labs** Floodie, work in tandem with other products and detect leaks while minimizing damage from temperature changes.[85] **Eddy Solutions** also provides several sensor products that identify leaks and measure the flow of water. These include the Eddy IQ, which provides automatic meter reading and advanced metering infrastructure, uses behavioural learning capabilities to learn a customer's water usage patterns, and has remote and automatic shutoff capabilities. Eddy H20 Sensors monitor an area for the presence of water as well as temperature and humidity. The Eddy Link and Eddy Valve integrate with each other to provide shutoff capabilities and identify real-time water usage and issues.[86]

While some of these technologies require another proprietary product to work, researchers at the University of Waterloo are attempting to miniaturize and mass-product low-cost versions of alarms to increase the usage of these valuable tools.[87] Professors **Norman Zhou** and **George Shaker** have developed a battery-free self-powering sensor housed in a box that is only three square centimetres. The device, utilizing IoT technology, sends an alert about flooding to smartphones via wireless radio and relay nodes. The professors estimate that because of the lack of a battery and related circuitry, the sensor can be commercially produced for less than one dollar each.[88] Due to the prohibitive cost, lack of knowledge, or other factors, many property owners do not install any sensors or enough sensors to be able to immediately detect leaks. The much lower cost of these sensors provides a potential means to correct this. The researchers have applied for patents and are exploring commercialization under the newly created moniker **AquaSensing**.[89]

> "Water-resistant materials prevent damage, are easier to clean, and easier to dry

Flood-resistant Building Materials and Design

As the scale of flooding and the need to rebuild after flooding events becomes more urgent, many companies and individuals are looking at alternative solutions. Flood proofing can involve either wet flood proofing – where water is allowed to enter and leave the building – or dry flood proofing – where water is diverted away or prevented from entering the building. Builders working in areas with high risk of flood are focusing on using building materials that are resistant to water damage in flooding. These can include concrete, brick, aluminum, and other materials.[90]

Some companies produce fiberglass replacements for drywall that are highly mold resistant and protect against moisture. These solutions are not as cheap or readily available as traditional products like drywall, but they provide a mechanism to prevent repeat flood damage as flooding events become more common. Water-resistant materials prevent damage, are easier to clean, and easier to dry. This sector of the flood adaptation landscape is rapidly evolving and changing dramatically as new companies present products.

Dry-proofing measures can include products and strategies that aim to restrict water entry. These include temporary deployable barriers that protect gaps in buildings such as doorways, self-closing flood barriers, and flood doors designed to prevent flooding. **Aquobex**, a British company, makes several variations of these products.[91]

Wet-proofing, by contrast, assumes that water will infiltrate the building and attempts to design highly recoverable buildings that will not see permanent damage or expensive repairs. Either water-compatible or sacrificial building materials are used, pumps are installed that can help remove floodwaters, and vulnerable property is removed from the potential floodable areas.[92]

Low-Carbon Concrete

Traditional engineered solutions are often carbon-intensive and come with significant environmental costs, but as these solutions will continue to be an essential measure in some areas, they should be made as low-carbon and resilient as possible. Practices that can accomplish this include land grading for efficient drainage, decarbonizing the power supply, and utilizing less plastics and concrete in their development.

Concrete is an ubiquitous building material that makes up many of the roads, buildings, and structures in Canada, and entails significant emissions in its production. There is 60 Mt of concrete produced in Canada annually and the Canadian cement industry emits 8 Mt of CO2 per year.[93] Development of less carbon-intensive concrete is an important emerging technology and is beginning to be adopted in Canadian projects. It uses supplementary materials to partially replace cement, and uses CO2 to activate the strength of the concrete and permanently sequester CO2 in the concrete as calcium-carbonate crystals, resulting in up to 75% fewer emissions per concrete block produced.[94] **CarbonCure Technology**,[95] **Carbicrete Technology**,[96] and **Carboclave Technology**[97] are all Canadian companies focused on this cutting-edge clean technology.

> "Development of less carbon-intensive concrete is an important emerging technology

Aquatic and Flood-resistant Architecture

Several Canadian and international companies are examining the feasibility of creating houses and buildings specifically architecturally designed to reduce damage from flooding. By using these technologies, the producers aim to continue being able to build on flood plains. These measures can include using materials that are not easily damaged by water such as waterproof insultation, concrete walls, stone and metal, placing critical parts of buildings above where water will reach, or placing flood mitigation fail-safes in essential parts of infrastructure. Some companies are also looking at the feasibility of aquatic architecture, or houses designed for communities on water, although these are not commercialized in Canada; pilot examples are emerging in other countries.[98]

Floating homes have started to be considered a feasible option for new development in areas vulnerable to flooding or faced with other constraints. These homes must be situated in an area sheltered from severe wave action, debris, or wind loading. They are not appropriate in every context but can be used to provide new opportunities for development.[99] Such homes exist in Canada, including in several locations across Metro Vancouver, and are built on a concrete pad filled with dense Styrofoam, moored in a marina. Proponents of these homes view them as a potential response to rising sea levels and coastal flooding, allowing waterfront space to be used in a responsible way.[100]

Software Modeling, Mapping, and Risk Assessment Services

Flood modelling allows Canadian governments, companies, and citizens to explore the consequences and potential for past, present, and future flood events and strategically prepare in advance. Credible data is crucial for informed decision-making on investment and flood management strategies.[101]

Many Canadian companies provide engineering and consulting services to help customers understand the context and risks they face from flooding. This information can help engineers and decision-makers analyze flooding tendencies and facilitate the development and design of responsible urban and natural drainage and adaptation strategies. These services can include stormwater management, hydraulics modelling, GIS mapping, flood mapping, natural asset valuation, and public engagement advice. There are many practitioners in Canada that provide flood hazard assessments and risk management analyses that are based on this computer modelling and evaluation of specific local risks. These services are highly context-specific, driven by the demands of a project and must be evaluated on that basis. Clients will determine what they want, and their evaluation of the solutions needed may differ from what experts might consider an ideal approach.

There has been a significant increase in the demand for information about ecosystem goods and services. Groups of companies like the **Greenland Group** are using proprietary online technologies to create information systems to evaluate and manage watersheds and assess river ecosystems.[102] Greenland has developed a cloud-based flood forecasting, control, and floodplain mapping system known as the Internet Science and Watershed Management System (ISWMS) that uses IoT technology and can identify real-time solutions and be used anywhere in the world. **Geosapiens** has developed the E-NUNDATION web platform, which provides predictive flood risk mapping by assessing the impacts of flooding. It innovatively focuses on the specific, quantifiable risk borne by people, businesses, and critical infrastructure and is positioned as a valuable decision-making tool to support effective flood risk management.[103]

There are several companies focused on water utilities and implementing smart technology. **Waterlix Inc**. utilizes geo-AI solutions to identify active leakage areas and identify vulnerable water mains or sewer pipes using consequence of failure analysis.[104] It can forecast water demand and predict or simulate the flood risk of an area. Additionally, **inField Solutions Inc**. has developed the inField Water iQ platform, a smart water management platform. It detects leaks and flooding, automatically notifies stakeholders, remotely shuts off water, and dispatches a plumber to resolve the issue.[105] It is usable in both residential and commercial buildings. **RainGrid Inc**. uses AI and IoT technology to manage their Stormwater Smartgrid, which are distributed networks of residential rain harvesting cisterns, coupled with a controller and centralized app. These cisterns act as a dispersed stormwater retention system and can capture up to 90% of annual roof runoff. They feature remote monitoring and control. The grid allows water to be released as required and can replace piped stormwater infrastructure.

Some companies, such as **Computational Hydraulics International**, have expertise that involves licensing software for stormwater management and wastewater or watershed modeling. This allows engineers to analyze flooding and facilitate responsible drainage design and planning in both urban and natural settings.[106]

Other businesses, like **Northwest Hydraulics Consultants** are recognizing that stormwater management require an integrated approach to water quality, flood control, channel stability, and aquatic resource protection. This approach can

"Credible data is crucial for informed decision-making on investment and flood management strategies

involve striking a balance between reducing flood risk and conserving natural floodplain function.[107]

Canadian companies and practitioners are innovating and delivering new services and processes that help Canadian communities gain the knowledge and expertise necessary to build resilience to flooding and understand the potential linkages between clean technology and flood adaptation. The **Intact Centre on Climate Adaptation** is creating matrices that practitioners can use to assess their own risk to physical impacts like flood, fire, and windstorms. These matrices are viewed by the Centre as potentially transferable to any industry sector.[108] The Intact Centre also provides flood protection training for home inspectors, real estate agents, and insurance brokers to increase knowledge uptake about basement flooding among industry professionals and homeowners.[109]

3D Wave Design, an Indigenous-owned company based in Nova Scotia, has just launched a product that uses Lidar to create a photo-realistic 3D model of a location that can be manipulated using sliders to simulate different severities of sea level rise and storm surges.[110] This creates a visualisation of the effects of climate change using a technical animation based on accurate data, and can be accessed on a mobile phone. This allows decision-makers, citizens, and stakeholders more easily grasp how sea level rise and storm surges will affect their communities. Improving climate risk communication using site-specific and feature-specific visualisations will enhance understanding, collaboration, and buy-in for engaging in adaptation. 3D Wave design has already begun partnering with municipalities and First Nations.

There are several other processes and services being developed in Canada that have the potential for increased use and scalability. Two of the most promising are outlined below:

> "Improving climate risk communication using site-specific and feature-specific visualisations will enhance understanding, collaboration, and buy-in

City-Wide Flood-Risk Profiles

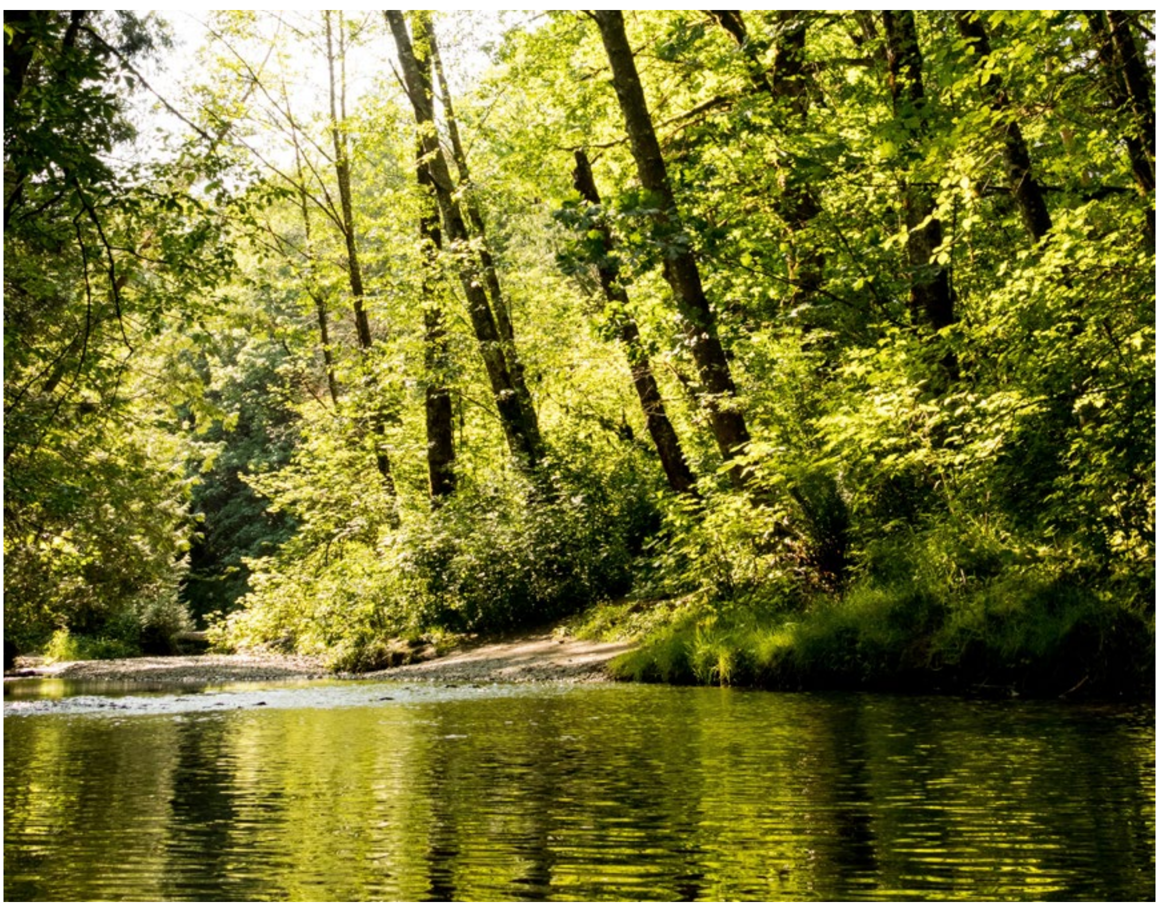
Hiran Sandanayake, Senior Water Resources Engineer for the City of Ottawa, has developed a framework for creating a City-Wide Flood Risk Profile by leveraging existing GIS information and modeling programs to create proxies that allow the risk of flooding to be measured effectively.[111] This was done for every building in the City of Ottawa in only two years and would have taken at least 80 years to complete using traditional mapping approaches. While some neighbourhoods had been studied in detail and the risk of flooding from sources including sanitary sewers, storm sewers, river (fluvial), and overland flooding was well known, other neighbourhoods lacked this comprehensive data. By using modeling proxies when this information was not available and riverine flood mapping as a conservative indicator of risk potential, the city-wide flood risk profile was able to fill in gaps that exist in the understanding of the city's risk, level of service, and asset performance. It can be thought of as an asset management tool with potential applicability to other cities, contingent on understanding their local flooding hazards, information gaps, geographic context, and available resources. Once communities are armed with knowledge about the risks they face, they are able to create effective policies and choose how best to adapt to flooding.

Natural Asset Valuation

Since natural assets provide essential but largely invisible services to communities, there is a bias towards devaluing ecosystem components such as forests, wetlands, or aquifers, or representing their value as zero. Many communities are moving towards placing an explicit value on the natural assets they control as part of their municipal asset management and investment planning. Doing so, using several techniques, can help them understand the value of the ecosystem services they access, including flood mitigation, and understand how changes affect community welfare.[112]

Canadian organizations, such as the **Municipal Natural Assets Initiative** (MNAI), provide scientific, economic, and municipal expertise to support local governments in creating a valuation and inventory of natural assets in their financial planning.[113] The MNAI has partnered with almost a dozen communities to determine what economic value is derived from their natural assets in terms of avoided flood damage costs.

Including natural assets as climate-resistant infrastructure is a leading-edge approach that emphasises the sustainability and environment value of these assets. The valuation of these assets shows that they can provide equivalent stormwater management to traditional grey infrastructure, their value can increase over time, and communities are very interested in learning more about this work.[114] There is significant international interest in this valuation work in other jurisdictions and there is an opportunity to expand, scale up, and export this expertise.



5) CRITERIA FOR TECHNOLOGY SELECTION

Since the adaptation responses demanded by flooding are generally context-specific, it is not be possible to evaluate specific technological responses on a general basis. Instead, it is important to ask specific screening questions and apply criteria to potential solutions based on the specific circumstances and desired outcomes for flood projects. This creates a decision-making framework for individual projects that can inform how best to approach the contextual reality.

a) Criteria for Resilience of Flood Technologies

Criteria should first be created to establish whether a technology is vulnerable to the impacts of climate change. Many technologies adopted as short-term band-aid solutions will eventually be overwhelmed, while long-term solutions that do not have resilience locked in will may be rendered obsolete as climate impacts worsen.

Building resilience is defined here as an action that reduces risk and vulnerability to the impacts of flooding. It can also involve the identification of potential strategy alignments and co-benefits. Scale can refer to whether a technology is applicable at the building, neighbourhood, or community level. **There are specific questions within these criteria that should be addressed, summarized in the following table:**

Broad Category	Criteria	Measure(s)
Effectiveness: Does it build resilience?	• Does this technology improve resilience to flooding? At what scale? • Is this technology designed as a long-term solution or will it have a shorter lifespan and need to be replaced with other solutions as conditions change? • If it is not a long-term solution, is it fulfilling a specific niche or need (e.g. emergency barriers)?	• Effectiveness of technology to mitigate expected flooding impacts or improve recovery from flooding • Required lifespan of a technology under projected scenario (e.g. different IPCC pathways) • Ability to address niche or specific need
Future-proofing: Is it resilient?	• Is this technology vulnerable to climate change or weather-related effects? • Is this technology adaptable, modular, or flexible? Will it become vulnerable or obsolete in the future? • Is the technology maladaptive in any way? Does it increase vulnerabilities elsewhere?	• Effectiveness in variable temperatures, rainfall patterns, extreme weather, etc. • Level of adaptability to changing climate conditions • Does it increase vulnerabilities elsewhere and to what extent?

These criteria should be used to initially determine how much a proposed technological solution would, at a high level, achieve project-specific flood adaptation goals. Once these questions have been answered, it is important to review other considerations, including cost and implementation barriers. Specific barriers for implementation will exist in different localities based on social, economic, and environmental constraints and the goals of an adaptation project. Some initially high costs may be justified based on long-term benefits and some initially attractive solutions may prove untenable to some stakeholders.

b) Criteria for Barriers to Implementation

Some technologies will have few tangible barriers, such as the widespread implementation of back-up valves and alarms to alert homeowners of basement flooding, although uptake of these options is currently still limited. Others, such as large-scale engineering projects, will have significant capital costs and less clear benefits in the long-term given the potential for extremes in a changing climate. **Suggested questions to establish barriers can be summarized as follows:**

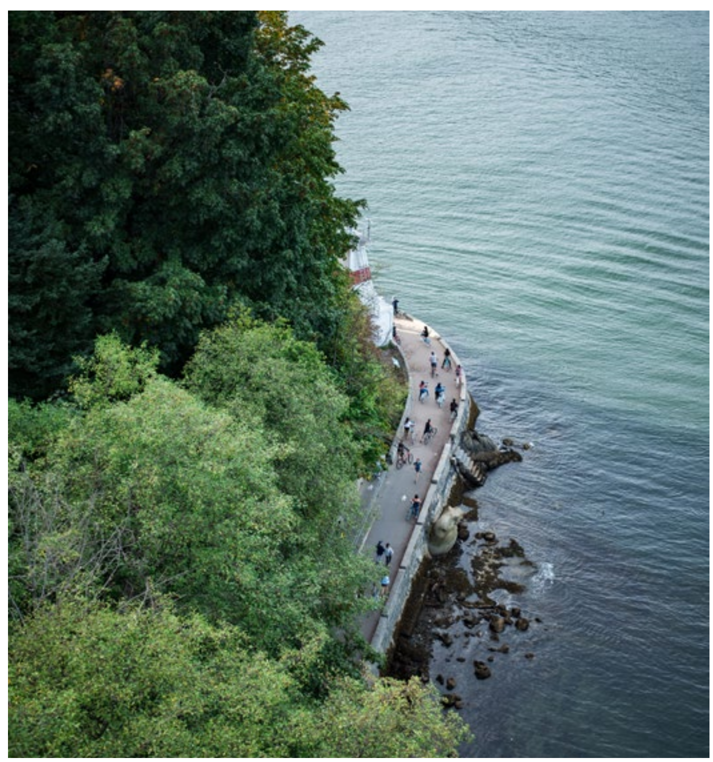
Broad Category	Criteria	Measure(s)
Cost	• How much does this technology cost to implement in the short-term • What maintenance, storage, operational, replacement, or other lifecycle costs are associated with this technology?	• Initial investment cost in $CAD; incremental cost less incremental revenue • Operation and maintenance costs entailed over lifespan beyond initial implementation (Whole Life Cost)
Feasibility/Cost Effectiveness	• Is this technology scalable in a significant way? Has it been tested at a large scale or in a particular context? • Is there a business case present for implementing this technology in this particular context? • Does this technology provide a cost-effective way of creating context-specific resilience to floods?	• Level of general applicability to different contexts or large-scale adoption • Context-derived justification for implementation • Cost of technology vs. outcome generated
Ease of Implementation	• Is this technology easy to implement? Does it require significant licensing, approval, environmental assessments, etc.? • Is the technology in compliance with local environmental standards? • Is there a skills requirement to install, operate, or maintain this technology?	• Level of difficulty applying the technology on an effective scale • Yes or no • Level of specialized skills required for installation, operation, or maintenance
Stakeholder Acceptability	• Does the public accept this as a viable solution? Do local decision-makers? • Does the technology serve cultural and community priorities and values?	• Level of public support determined through surveys, open houses, buy-in from decision-makers, etc. • Added benefits for residents of the community; level of protection of cultural heritage
Fairness/Equity	• Does this technology entail costs to some that are incommensurate with the benefits? (e.g. high capital costs for homeowners, depreciated property values, mandatory evacuation) • Does the technology provide benefits for vulnerable populations?	• Analysis of the costs, benefits, and trade-offs of the application of the technology on individuals and the wider public • Context-specific analysis of benefits provided

c) Clean Technology Criteria

Finally, criteria should be used to determine which technologies are the "cleanest" and provide the widest range of co-benefits. They should also aim to fulfill the adaptation objectives in the Pan Canadian Framework for Clean Growth and Climate Change.

While it is acknowledged that many necessary technologies will not have these co-benefits and will still need to be pursued, these criteria should remain as aspirational goals when choosing adaptation measures:

Broad Category	Criteria	Measure(s)
Clean Technology Criteria	• Does this technology have positive or negative effects on ecosystems or biodiversity?	• E.g. habitat destroyed or created, specific effects on ecosystems and the natural environment
	• Does this technology protect and improve human health and well-being? Does it create co-benefits?	• E.g. toxicity and other harmful effects; recreation benefits such as those provided by parks
	• Does this technology create significantly more GHG emissions, have no net effect, or reduce them?	• E.g. GHG emissions embodied in materials and involved in implementation, maintenance, and replacement; ability to monitor or track GHG emissions; reinforcement of the circular economy



6) ANALYSIS OF TECHNOLOGY OPTIONS

Many of the criteria and measures outlined in the previous section are highly context dependent. This means that any evaluation of these criteria must be done at the project level, where detailed contextual information can be acquired. The level of stakeholder acceptability, for instance, would vary based on location and specific project attributes.

All of the technologies included here have some degree of adaptation potential, but many differ on the mitigative benefits they provide. For simplicity's sake, the technology categories are evaluated here at a high level, using colour coding. Red indicates high costs potentially incommensurate with the benefits a technology provides and therefore imply that it should be used with caution. Yellow means that a technology has trade-offs and it may not be the ideal approach in a specific context. Green indicates that the benefits provided by a technology are significant and should be considered for context-dependent implementation. Grey means that a technology cannot be evaluated, either due to a lack of information, inapplicability to the criteria under consideration, or an inability to measure performance.

This evaluation of categories of technology is based on the informed judgment of the researcher. The context- and company-specific implementation of these technologies creates a potential confound with these evaluations; any final determination of what technology to use should be done on a project-by-project basis and embedded in local needs and desired outcomes.

The first set of criteria considers flood resilience, examining the effectiveness and sustainability of technological responses:

Technology	Effectiveness			Future-proofing		
	Does this technology improve resilience to flooding? At what scale?	Is this technology designed as a long-term solution or will it have a shorter lifespan and need to be replaced as conditions change?	If it is not a long-term solution, is it fulfilling a specific niche or need (e.g. emergency barriers)?	Is this technology resilient or is it vulnerable to climate change or weather-related effects?	Is this technology adaptable, modular, or flexible? Will it become vulnerable or obsolete in the future?	Is the technology maladaptive in any way? Does it increase vulnerabilities elsewhere?
NbS: Coastal strategies						
NbS: Foreshore, river, or stream remediation						
NbS: Stormwater management						
Engineered barriers						
Engineered stormwater storage						
Storm sewer expansion/ retrofit						
Portable barri-ers & sandbag alts.						
Alarms						
Shut-off valves						
Sump pumps						
Smart-metering devices						
Flood-resistant building design						
Aquatic architecture						

Analysis:

Nature-based Solutions (NbS) focused on coastal adaptation are indicative of a shift from an attitude of coastal defence towards coastal management – meaning that there is a recognition that reactive engineered coastal defences are largely unsustainable. NbS are dynamic and deliver wide ecological benefits.[115] They can be modified as conditions changed and are adaptable and able to be designed to context-specific specifications.

Foreshore, river, and stream remediation can help restore the environment to its natural state, reducing the speed water run-off travels and creating a natural barrier against storm protection and flooding.

Sustainable drainage systems that manage stormwater through mimicking natural processes cause minimal or no long-term damage, are environmentally beneficial and are often more flexible that engineered structures. Climate change is causing increases in rainfall intensity, duration, and volume. Existing drainage networks, engineered to historical specifications, are now often exceeding their designed capacity.

Engineered barriers often lack adaptability and can have negative effects on adjacent ecosystems, leading flood water to be forwarded to surrounding areas.[116] These structures, especially older ones already existing, are vulnerable to changes in climate and are often not designed to adequate flooding specifications.

Engineered stormwater storage has a built-in capacity that can be difficult to expand without significant capital investment, although it may also be the easiest and most cost-effective method of building resilience. Expanding the capacity of existing sewer systems alone fails to reduce the rate that water moves through the system, shifting the problem elsewhere and causing negative effects further down the system.[117] Processes like real-time control can help prevent this, but a cleaner and more long-term solution may be to supplement the existing drainage network with sustainable drainage systems.

Sandbags are a commonly used measure to prevent water from entering a specific area, but they have significant drawbacks. They are prone to leakage, require expertise to assemble correctly, and are usually one-time use. They are inadaptable and disposable.[118] Portable barriers and perimeter protection provide undeniable benefits as an alternative, but they are not a catch-all solution. These barriers can push the problem to another location, such as an unprotected property, and are vulnerable to groundwater flooding and flooding from behind. They can be overtopped in significant flooding events and cannot prevent the most severe flooding, necessitating other flood resilience measures in a building or community.[119] Nonetheless, modern designs produced by Canadian companies are modular and flexible enough to provide an attractive alternative to sandbags.

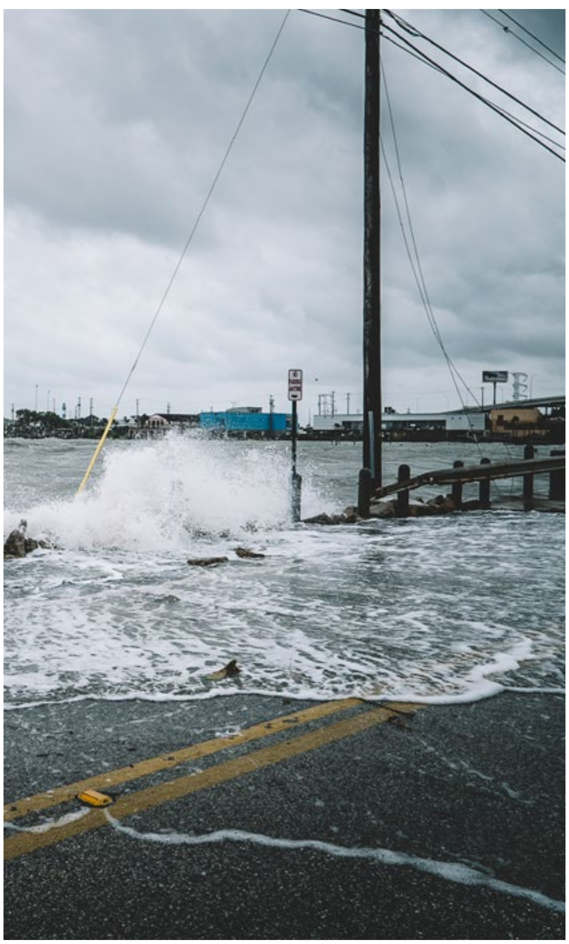
Alarms and smart metering systems are an easy method of increasing awareness and reactiveness to flooding events and have very limited drawbacks, but they are not a solution by themselves. Shut-off valves provide an easy and resilient solution to preventing the backflow of sewage and flood water. The drawbacks for these valves are limited and they should be implemented wherever possible.

Sump pump systems remove flood water from a building and can prevent widespread flooding or limit the rate flood waters rise in a property. They are a crucial flood defence for property owners and prevent worst-case flood damage, but do not last forever and can fail without warning.

Flood-resistance measures in building design – where a building is dry-proofed or wet-proofed – can provide a means of building resilience against flooding. Emphasising the recoverability of buildings after they flood accepts that there will be some flood damage, but creates the conditions for a less lengthy, invasive, and expensive recovery after flooding. Allowing water to enter a building reduces the hydrostatic load on the structure, provides a safety net if barriers or other measures prove ineffective, and is an attractive option in areas that are already built-up or prone to flooding.[120]

Aquatic architecture is an attractive alternative in areas where building space is limited, and cities require densification. Rather than building static structures on floodplains, houses can be built and moored on the water in a manner that builds resilience to flooding. In this way, it fulfills a niche, but these structures can be vulnerable to storms and, due to their proximity to water bodies, can contribute to pollution.

The next set of criteria examines cost and implementation barriers, focusing on factors that may inhibit the uptake of promising technologies. There is no absolute measure for what constitutes a "high" cost since each cost-benefit analysis, as defined by the incremental revenues less the incremental expenditures, will vary based on contextual information. In this exercise, if there are significant trade-offs with implementing a technology or the benefits are not viewed as offsetting the cost, a technology category may be characterized as high cost. Stakeholder acceptability, fairness and equity, and aspects of feasibility and ease of implementation are not evaluated due to the fact that context for projects would be required in order to make valid determinations.



	Effectiveness		Future-proofing		Ease of Implementation	
Technology	How much does this technology cost to implement in the short-term?	What maintenance, storage, operational, replacement, or other lifecycle costs are associated with this technology?	Is this technology scalable in a significant way? Has it been tested at a large scale?	Does this technology provide a cost-effective way of creating context-specific resilience to floods?	Is this technology easy to implement? Does it require significant licensing, approval, assessments, etc.?	Is there a skills requirement to install, operate, or maintain this technology?
NbS: Coastal strategies	Yellow	Green	Yellow	Yellow	Yellow	Yellow
NbS: Foreshore, river, or stream remediation	Yellow	Green	Green	Yellow	Yellow	Yellow
NbS: Stormwater management	Yellow	Green	Green	Yellow	Yellow	Yellow
Engineered barriers	Red	Red	Green	Red	Yellow	Yellow
Engineered stormwater storage	Yellow	Yellow	Green	Yellow	Yellow	Red
Storm sewer expansion	Red	Yellow	Green	Yellow	Yellow	Red
Portable barriers & sandbag alts.	Green	Green	Green	Green	Yellow	Yellow
Alarms	Green	Green	Green	Green	Green	Green
Shut-off valves	Green	Green	Green	Green	Green	Yellow
Sump pumps	Green	Yellow	Green	Green	Green	Yellow
Smart-metering devices	Green	Yellow	Green	Green	Green	Green
Flood-resistant building design	Yellow	Yellow	Green	Green	Yellow	Yellow
Aquatic architecture	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow

Analysis:

Nature-based Solutions (NbS) provide co-benefits for the environment and human population in a manner other technologies and products cannot. The ecosystem services they provide often outweigh the construction costs and the added mitigation benefits mean they are a more holistic product than those that focus solely on strengthening grey infrastructure approaches. These solutions are often implemented as part of pilot projects and lack standardization and true expansion of scale. Reducing the implementation barriers that affect these technologies has the potential to mainstream their use and contribute to a low-carbon, green economy. The co-benefits these solutions provide can include recreation areas, green spaces, increased biodiversity, enhanced property values, and additional liveability in communities.[121] The implementation and maintenance costs of NbS are extremely variable and depend on local conditions and adaptation goals. Practices like beach nourishment can replenish these areas and increase flood resilience, but there are concerns over how much the practice costs as well as the emissions profile of projects such as trucking in large quantities of sand. For example, the United States spends $150 million annually on beach nourishment and control of shoreline erosion. Nonetheless, the value of coastal wetlands and beaches tends to far outweigh this cost.[122] River and stream restoration can help regulate water absorption, slow the overland flow rate, and recharge groundwater, and the avoided costs of flood damage often outweigh the initial construction costs.[123] Nature-based stormwater management solutions can occasionally be blocked by contaminants whose removal requires additional maintenance.[124]

Engineered barriers can require reinforcement and repair and increases in height and the amount of space they occupy. The adaptation potential for these structures is limited; they have a limited lifespan and significant capital costs to construct. They can result in environmental destruction, limit citizen access to areas, and impart a false sense of security. The lack of flexibility surrounding these solutions explains why they have been deemed high cost in the criteria analysis. At the same time, however, they provide a predictable and accessible solution that has been utilized around the world.

When the choice must be made about whether to choose between a nature-based solution or an engineered solution, one of the primary considerations that decision-makers focus on is that of cost. As this report has repeatedly highlighted, there is no “best” solution in absolute terms; the trade-offs of each potential flood response must be grounded in the specific contexts of a project’s location and goals. There is a growing consensus that even within specific projects there is no need to choose between one or the other. [125] Saltmarshes, for example, can have their effectiveness bolstered by constructing breakwaters or artificially elevating the foreshore.[126]

There are many examples of NbS providing a cost-effective alternative to traditional engineering, but there are still some concerns over the rigorousness of evaluations. This uncertainty is one of the reasons NbS were classified in these criteria as having trade-offs in cost to consider. They can be harder to predict and cost than engineered or grey infrastructure. Benefits like food and water security, carbon sequestration, biodiversity health, and recreation opportunities are difficult to monetize and are often not accounted for,[127] sometimes leading to underestimation of the benefits of these solutions.

Engineered solutions can be implemented in a manner where there is relative certainty about time, scale, and type of benefits provided, but NbS offer more flexibility and additional benefits that can be realized in the future. Although they may have significant upfront costs, the benefits have been found to outweigh the costs of implementation and maintenance in diverse contexts including flood risk reduction along coasts and in river catchments.[128]

There are many Canadian examples of projects in which NbS were chosen due to their favourable cost when compared to engineered solutions. In 2016, the Town of Gibsons in British Columbia partnered with the Municipal Natural Assets Initiative to undertake a study of the stormwater ponds in their community and to quantify whether they had sufficient capacity during a 100-year storm event. The study concluded that these natural assets provided stormwater services that would have cost $3.5-4 million if an engineered solution were chosen, as well as numerous additional community benefits, justifying the cost of rehabilitating the wetland.[129]

West Coast Environmental Law commissioned a report to examine the Boundary Bay Living Dike concept, a project at the junction of Surrey, Delta, and White Rock in the BC Lower Mainland. The cost and efficacy of raising a traditionally engineered dike was compared and contrasted with a nature-based alternative to address 1 m of sea level rise, providing flexible and adaptable storm and wave protection while supporting and sustaining offshore ecosystems like salt marshes and eelgrass meadows. The report found that gradually building a living dike over 30 years would cost $175-250 million, whereas raising the standard dike that presently exists would cost at least $250 million.[130]

The manufactured products available in Canada are more straightforward in evaluating implementation costs. Since many of these products are geared towards preventing or mitigating basement flooding, which has an average household cost of $43,000,[131] it is easier to analyze the benefits provided.

Sandbags require significant amounts of labour to be filled and assembled and are generally a reactive last resort to prevent damage.[132] They are one-time use and must be properly disposed of, requiring additional costs every time they are used. Portable barriers that serve the same function as sandbags have a higher up-front cost, but much lower labour costs and are almost universally reusable. MegaSecur's Water-Gate barrier can cost several thousand dollars for the highest and longest 50-foot section, but the product can have a useful life of 20-25 years.[133] The primary maintenance requirement is storage and transportation when not in use. They may require some specialized instruction or expertise to put together.

Alarm systems and smart-metering devices are simple and low-cost additions to a building that can drastically improve its resilience insofar as they can immediately inform property owners of flooding events and allow them to take action. These products have a range of costs depending on the provider and functionality but are all very inexpensive relative to the benefits they provide. If commercialization is successful for a company like AquaSensing, this cost could be further lowered.

Shut-off valves are low-cost and require minimal maintenance, but they should be easily accessible so that they can be examined for blockages and should be installed and tested by a trained professional.[134] These products can cost up to a few hundred dollars each, but are most cost-effective when installed in newly constructed buildings.[135] The cost to retrofit may be slightly more, but these are still low-cost considering the financial damage basement flooding can do.

Sump pumps are relatively low-cost compared to other interventions but require an initial investment and ongoing maintenance. Pumping systems should be regularly inspected, as many traditional pump systems have to be replaced after several years and do not incorporate fail-safes.[136]

Canadian innovations including new pump designs and monitoring systems are helping to rectify this. SafeSump's most advanced system, that includes multiple pumps and a failsafe, has an introductory price of $600.[137]

Flood-resistant building design may entail an upfront cost if a home is being retrofitted, but if properly practiced, it can significantly reduce the cost borne by a property owner faced with flooding, especially in areas with repeat damage. The techniques are somewhat specialized, but not out of reach, and result in less damaged waste from flooding that must be disposed of. Dry proofing or wet proofing a home provides obvious flood-protection benefits but retrofitting a building to meet these goals comes with potentially significant costs. Depending on the scale of the work, dry proofing a home has an average cost of several thousand dollars.[138]

Aquatic architecture and float homes are generally cheaper than traditional real estate, primarily due to there being no land in the purchase price. There are examples of this type of architecture throughout Canada, but zoning issues and limited uptake beyond land-stressed areas like Metro Vancouver have resulted in its potential not being fully explored.

	Clean Technology Criteria		
Technology	Does this technology have positive, negative, or negligible effects on ecosystems or biodiversity?	Does this technology protect and improve human health and well-being? Does it create co-benefits?	Does this technology create significantly more GHG emissions, have no net effect, or reduce them?
NbS: Coastal strategies			
NbS: Foreshore, river, or stream remediation			
NbS: Stormwater management			
Engineered barriers			
Engineered stormwater storage			
Storm sewer expansion			
Portable barriers & sandbag alternatives			
Alarms			
Shut-off valves			
Sump pumps			
Smart-metering devices			
Flood-resistant building design			
Aquatic architecture			

The final set of criteria examines which of these categories of technology can be considered to be the 'cleanest':

Analysis:

The Government of Canada defines a clean technology as any "process, product or service that reduces environmental impacts."[139] Despite this very broad definition, it is difficult to measurably determine whether many technologies would fall into this category. In certain cases, such as with the household and manufactured products identified in this report, it is difficult to categorize them as being clean or not clean without extensive exploration of their product lifecycle and case studies on their use. Their effects on biodiversity are difficult, if not impossible, to measure and it is not possible to definitively say whether they contribute positively or negatively to emissions. The only exception to this is portable barriers, as described below.

Nature-based Solutions (NbS) clearly constitute a 'clean' technology insofar as they reduce environmental impacts compared to other comparable technologies like engineered structures, but they also act as carbon sinks and contribute to climate change mitigation.[140] NbS can act as a carbon dioxide removal option that is more readily available and implementable than other technologies like direct air capture or carbon capture and storage. Simple approaches like the restoration and proper management of forests can sequester carbon, protect biodiversity, and, if done correctly, assist with flood abatement in cities and communities downstream.[141]

There are, however, some concerns regarding the maintenance of NbS. Practices like beach nourishment can replenish these areas and preserve flood resilience, but there are worries over how often this has to be done and the carbon emissions that may be entailed in transporting the sand.[142] At some point, it is possible that NbS reach a saturation point where the ecosystem is at an equilibrium and sequestration is balanced by emissions.[143]

Sustainable drainage systems, depending on the design, can improve habitats, limit erosion, and reduce the flow velocity of water run-off.[144] Most of these systems are designed to improve infiltration of stormwater runoff and contribute to groundwater recharge. These low-impact development practices can improve the filtration of contaminants in runoff, removing primary pollutants close to the source. Since they can potentially reduce the necessity of other, more heavily engineered, carbon-intensive solutions that would convey the water to more central processing facilities, these approaches can be considered clean. It should be cautioned, however, that this technology can be difficult to implement in urban areas since the complex existing infrastructure and lack of standardization may provide barriers.

The co-benefits provided by NbS are one of the aspects that sets this suite of technologies apart from its competitors. These co-benefits can positively affect human health and well-being, ecosystems and biodiversity, provide amenities for human use, improve energy and water efficiency, and provide adaptation against climate change and flooding. [145] The mitigative benefits provided by these solutions can help build in low carbon resilience. This clean approach helps lower the chances of flooding occurring while providing sustainable protection.

Engineered barriers and stormwater storage entail significant embodied carbon emissions in their construction and replacement, especially those made of concrete. Land has to be excavated, pipes laid, barriers raised, and habitats and city systems interrupted for these solutions to work, meaning for instance that tailpipe emissions from idling traffic in busy or disrupted work areas may also increase. Although they may be necessary, there are significant environmental trade-offs that have to be considered; by the standards explored in the report, they cannot be considered a "clean" technology.

Even a technology like *sandbags* can contaminate local ecosystems if it is not properly disposed of or if it must be taken to a landfill after use.[146] Relative to sandbags, portable reusable barriers provide good value and fewer environmental costs because they can be reused and do not leach contaminants into environments.

Most of the manufactured products – *alarms, sensors, pumps, portable barriers, and similar products* – have minimal emissions that are associated with the construction, transportation, and power consumption of the products. Products like smart meters can even help passively reduce water usage, preserving water resources and lowering emissions associated with their processing.

Flood-resistant building design and aquatic architecture are interesting cases in that there is an identifiable need for these products and design concepts, but they might not be considered clean technologies. Depending on placement, aquatic architecture may displace water habitats and has the potential to pollute waterways, but also provides recreational benefits to residents and is adaptable to changing conditions. Flood-resistant design may prevent further damage and minimize future costs, but building to relevant specifications requires either reconstruction, significant renovations, or occasional replacement of water-damaged materials, creating emissions as damaged materials are replaced.

Analysis of Technology Options: Summary

This analysis illustrates that all technologies under consideration have costs, benefits, and trade-offs that must be considered. **The results are summarized in the following matrix:**

	Criteria	Technology Category												
		NbS: Coastal Strategies	NbS: Foreshore or waterway remediation	NbS: Stormwater	Engineered barriers	Engineered stormwater storage	Storm sewer	Portable barriers	Alarms	Shut-off valves	Sump pumps	Smart-metering devices	Flood resistant building design	Aquatic architecture
Effectiveness:	Does this technology improve resilience to flooding? At what scale?	Green	Green	Green	Green	Yellow	Yellow	Yellow	Yellow	Green	Green	Green	Green	Green
	Is this technology designed as a long-term solution or will it have a shorter lifespan and need to be replaced as conditions change?	Yellow	Green	Green	Yellow	Yellow	Yellow	Red	Yellow	Green	Yellow	Green	Green	Green
	If it is not a long-term solution, is it fulfilling a specific niche or need? (e.g. emergency barriers)							Green						Yellow
Future-proofing	Is this technology resilient or is it vulnerable to climate change or weather-related effects?	Green	Green	Green	Red	Yellow	Yellow	Yellow	Green	Green	Green	Green	Yellow	Yellow
	Is this technology adaptable, modular, or flexible? Will it become vulnerable or obsolete in the future?	Green	Green	Green	Red	Yellow	Yellow	Green	Green	Green	Yellow	Green	Green	Yellow
	Is the technology maladaptive in any way? Does it increase vulnerabilities elsewhere?	Green	Green	Green	Red	Yellow	Yellow	Yellow	Green	Green	Green	Green	Yellow	Yellow
Cost	How much does this technology cost to implement in the short-term?	Yellow	Yellow	Yellow	Red	Yellow	Red	Green	Green	Green	Green	Green	Yellow	Yellow
	What maintenance, storage, operational, replacement, or other lifecycle costs are associated with this technology?	Yellow	Yellow	Yellow	Red	Yellow	Yellow	Green	Green	Green	Yellow	Yellow	Yellow	Yellow
Feasibility/ Cost Effectivenes	Is this technology scalable in a significant way? Has it been tested at a large scale?	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Yellow
	Does this technology provide a cost-effective way of creating context-specific resilience to floods?	Yellow	Green	Green	Red	Yellow	Yellow	Green	Green	Green	Green	Green	Green	Yellow
Ease of Implementation	Is this technology easy to implement? Does it require significant licensing, approval, assessments, etc.?	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Green	Green	Green	Green	Green	Yellow	Yellow
	Is there a skills requirement to install, operate, or maintain this technology?	Yellow	Yellow	Yellow	Yellow	Red	Red	Yellow	Green	Yellow	Yellow	Green	Yellow	Yellow
Clean Technology Criteria	Does this technology have positive, negative, or negligible effects on ecosystems or biodiversity?	Green	Green	Green	Red	Yellow	Yellow						Yellow	Yellow
	Does this technology protect and improve human health and well-being? Does it create co-benefits?	Green	Green	Green	Yellow	Yellow	Yellow	Red	Red	Yellow	Yellow	Green	Yellow	Yellow
	Does this technology create significantly more GHG emissions, have no net effect, or reduce them?	Yellow	Green	Green	Red	Yellow	Yellow	Yellow					Yellow	Yellow

These results indicate that all the products under consideration build resilience by reducing risk and vulnerability, but there are significant differences in how the categories of technologies are evaluated based on the other criteria. Several of the technologies – including all of those thought of as traditional engineering solutions – have trade-offs to consider regarding the adaptability, resilience, and lifespan of the products. These solutions are often inadaptable or entail large costs for adaptation.

Nature-based solutions are distinguished by their ability to provide co-benefits and reduce emissions while still protecting areas from the effects of flooding. They have questions that need to be answered surrounding costs, maintenance, and implementation, but these barriers should be able to be overcome relatively easily. Doing so will allow this clean technology to be implemented where appropriate.

The manufactured products considered, especially those designed for use at the individual building level, have minimal drawbacks and should be implemented wherever practical. They provide cost-effective means of building resilience in a way that is, on the surface, easy to implement, scalable, and feasible. There are few reasons property owners should not install most of these technologies, as the benefits greatly outweigh the costs and the products will likely pay for themselves. Alarms can provide a cheap and easy means of being made aware of flooding, valves can cheaply prevent some kinds of flood damage, and pumps can save basements from severe damage. Smart-metering devices can help reduce and make homeowners more aware of their water usage and potential for flooding. Niche products like portable barriers that replace sandbags are an excellent stop-gap solution during flooding events but should not be relied on permanently or as a replacement for other products and practices.

In addition to the products evaluated, most of the services offered by Canadian companies can be considered clean technology, as there are no or very few emissions associated with their use. They are applicable in a wide variety of Canadian contexts and provide a means of understanding what other technologies, clean or otherwise, can be implemented in a specific area.

7) POLICY RECOMMENDATIONS

Flooding is one of the most significant climate change impacts for Canada. Interviews with experts working on flood adaptation on the ground have been instructive in contributing to the development of tangible, feasible, and useful policy recommendations. These experts work within cities, engineering and consulting companies, and think tanks, often dealing with the federal government, all levels of stakeholders, and context-specific flooding issues. Most respondents indicated that there is no one-size-fits-all solution and that appropriate technological and policy responses are determined by many factors; however, several concrete policy recommendations were identified during the research and the expert interviews. Several of the recommendations are actionable by the federal government, while some are best left to partner jurisdictions like cities and provinces. These are nonetheless included here because flood adaptation is cross-jurisdictional in nature and requires a response at every level of government.

1. Provide support to emerging Canadian flood technology companies for the commercialization, scaling, and marketing of promising products and services.

Many of the companies identified in this report are small in scale and rarely more than a few years old. Several are exploring commercialization but have not brought their products to market yet. The Smart Prosperity Institute has indicated that Canada performs comparatively well in the early stages of clean innovation, especially in research and development, but that it lags behind other countries in commercialization and market deployment.[147]

Aiding with commercializing, marketing, and exporting these products can help build Canada's clean tech sector and reinforce made-in-Canada solutions for flood adaptation. Government departments like the Clean Growth Hub at Infrastructure Canada already aid individuals and companies focused on research, development, and demonstration. Businesses attempting to grow, however, must turn to the Business Development Bank of Canada or Export Development Canada for assistance in commercialization. The Strategic Innovation Fund focuses on large-scale projects with a requested financial contribution of over $10 million.

Providing more direct support to smaller enterprises will help eliminate this gap in Canada's clean tech landscape. Access to capital and programming should be provided to companies and industries developing and commercializing products in priority areas, such as flood adaptation, without constraints on project size. Additionally, federal taxes and regulatory policies should be designed to incentivize the adoption of transformative clean technologies.

Finally, services provided by Canadian companies should not be discounted from consideration in measures like this. Services such as software solutions, modelling, risk assessment, watershed management, and asset evaluation, are all aspects of a clean technology response to flooding in Canada.

2. Mainstream Nature-based Solutions, Green Infrastructure, and Low Impact Development for flood adaptation.

Natural assets are a potential solution that is often treated as a cure-all for flood adaptation. While this overstates their applicability and they are often context-specific, mainstreaming the use of these approaches will ensure that resilience is increased in an environmentally friendly and incremental way. These solutions are often done as pilot projects or one-offs instead of being incorporated into a business-as-usual framework where they are utilized as a matter of course. By emphasising they should be used wherever feasible and practical, they will be viewed as an effective measure instead of as a fad. ACT supports the following recommendations that were submitted to the Prime Minister on May 20, 2020 by a coalition of professional associations, research bodies, local governments, and philanthropic foundation in a document entitled "Natural Infrastructure is an Integral Part of Green Recovery":

a. Get money moving: Expedite funding to: 1) projects that are “shovel-ready” and “shovel-worthy”; and 2) to readiness assessments and other early stage support to create an ongoing pipeline of fundable projects. Benefits include immediate jobs and support for local supply chains. Indigenous peoples must be engaged in all projects impacting their traditional territories, consistent with the principles of free, prior and informed consent as set out in the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP).

b. Keep money moving: Modify existing programs, such as the Disaster Mitigation and Adaptation Fund (DMAF) and the Investing in Canada Infrastructure Program (ICIP) to address current barriers for natural infrastructure projects. Concurrently, continue to fund ongoing monitoring, measurement and evaluation of initial “shovel-ready” projects.

c. Sustained support: Enable integrated policy, programs and legislation over the longer-term, including the establishment of a dedicated natural infrastructure fund. [148]

Additionally, it should be emphasised that in preparation for this "early stage support", governments should proactively begin funding adaptation research including academic studies, feasibility studies, and other scoping work. This will provide the necessary background and justification for communities, non-profits, and other stakeholders to propose formal infrastructure projects in the future.

3. Tie the federal post COVID-19 recovery and stimulus response to criteria that lock in low carbon resilience.

The recovery from the COVID-19 pandemic represents a once in a lifetime chance to target economic stimulus for recovery focused on building in low carbon resilience to the impacts of climate change. Funding for local governments and industry should be linked to the criteria advanced in this report to ensure that we lock in low carbon resilience, not emissions and climate risk, for decades to come. Tying funding streams designed to support local governments through the Federation of Canadian Municipalities (FCM), and development through Infrastructure Canada, to how stakeholders plan to provide adaptive and mitigative benefits at the same time is an opportunity to increase co-benefits and ensure that projects aimed at increasing flood resilience do not have maladaptive aspects nor contribute to climate change. Effective policies that have strict regulation or incentives attached to financing – for example applying a climate lens – have the potential to result in transformational changes. Specific examples include:

a. The recapitalization of FCM's Municipal Climate Innovation Program should require that all funding for local government climate action planning be positioned to enable proponents to consider low carbon resilience (LCR) and co-benefits, rather than separate adaptation and mitigation streams, and tools and resources be made available to help all local governments including small, remote and rural communities achieve this.

b. The federal First Adapt program, which is designed to help Indigenous communities plan for adaptation, should be expanded to include funding for planning for LCR as well as implementation, plus resources for communications and capacity building developed in partnership with Indigenous communities.

c. The Infrastructure Canada (IC) Climate Lens should be expanded to require proponents applying for IC funding to consider LCR over the lifetime of all projects, instead of only large projects with a budget of over $10 million, and provide detailed tools and resources as well as guidance on how this should be planned and implemented.

d. Federal funding designed to help the private sector rebound from the pandemic should be tied to LCR criteria, at the minimum requiring companies to ensure they do not increase emissions, vulnerability and ecological damage through how the funding is spent, even if there is a need to demonstrate trade-offs in terms of these calculations. Examples of existing international standards with similar goals include the Task Force on Climate Related Financial Disclosures.

e. Intersectionality means that vulnerable and marginalized populations experience more damaging effects from both climate impacts and the costs of shifting to a decarbonized world. The federal government should develop funding streams and resources designed to facilitate a Just Transition, in contexts with potential employment or livelihood loss due to decarbonization or adaptation to climate change impacts.

4. Provide region-specific climate change and adaptation standards for practitioners to use when designing infrastructure.

Climate models and data can be complex and difficult to understand. Practitioners implementing adaptation solutions on the ground are usually not climate scientists and do not have the technical expertise to use and manipulate the models. The Canadian Centre for Climate Services is a highly useful resource that is helping to translate and apply climate data; however, it would also be useful to provide region-specific standards for individuals and organizations to adhere to in local projects. Projects will have to be built to specific standards in regions facing different climate impacts. Practitioners should be able to know before a project gets underway what impacts they must build to; for instance, a sustainable drainage project in southern Ontario will have to be able to handle a different sized storm event or infiltration level than a project in British Columbia. Having this knowledge readily accessible and standardized will make projects more efficient and more context driven.

For example, Infrastructure Canada could provide centralized tools and standards on how to incorporate increasing heat, sea level rise, and precipitation projections into designs for both retrofits and new infrastructure. This would help to guide developers and ensure a cohesive and proportionate response across regions. As many of these projects will be carried out by public sector organizations, the federal government could provide specific support to the provinces and territories for development of both mapping and updated codes and standards.

5. Collaborate with the insurance industry and design programs for homeowners to reduce their flood risk.

Homeowners and insurance companies bear a large proportion of the costs that come with severe flooding. There are several technological solutions outlined in this report that can substantially reduce the risk homeowners face from flooding, but there has been limited uptake from Canadians. The government should focus on communicating the risk from being unprepared for flooding and the rewards from adopting technologies like basement pumping systems, alarms, shut-off valves, and other interventions. There is opportunity for collaboration with the insurance industry to create programs that alleviate financial risk for both homeowners and industry, while potentially providing relief against rising insurance premiums.

The federal government has previously provided tools like funding, grants, and tax incentives for homeowners to install energy-efficient appliances or retrofit their homes. Similar programs that subsidize the uptake of flood protection technologies have the potential to be an important investment and lower future taxpayer liabilities stemming from flooding events.

Similarly, the Insurance Bureau of Canada and Public Safety Canada commissioned a report on flooding and high-risk residential properties,[149] which outlined several options to transfer the burden of property risk from post-disaster government response programs to private sector insurance programs. One option is to create a high-risk flood insurance pool by placing levies on municipal taxes or relying on government contributions. This would provide high-risk insurance to ineligible Canadians or those who cannot afford flood insurance due to high premiums. This can be done in concert with de-risking approaches and subsidization of flood management technologies.

6. Develop new certifications and immigration programs for professionals to ensure Canada has the expertise necessary to combat flooding.

The scale of current and future flood risk in Canada is not yet fully understood, especially as comprehensive flood maps illustrating the changing extent of flood zones in a changing climate are not yet available for the whole country. According to our interviewees, experts have expressed the idea that there is a generational gap caused by a previous government's lack of direction that has resulted in a lack of mid-career expertise between a cohort of young professionals and late-career individuals.

Expediting immigration of highly qualified personnel is one of the goals of the Pan Canadian Framework on Clean Growth and Climate Change. Professionals focused on water resource management and flooding have been identified by experts as an important category that is lacking in home-grown expertise. Immigration, Refugees and Citizenship Canada should prioritise the immigration of water professionals with significant experience from around the world so that they can work in Canada and help the country manage the flooding-related aspects of climate change. While the federal government can focus on immigration, provincial governments can emphasise the development of skilled professionals in Canada. Experts have suggested that to help fill this skills gap, professional certification programs should be created at post-secondary institutions across Canada. Programs in Integrated Watershed Management, for example, already exist at schools such as McGill University and the Southern Alberta Institute of Technology.

7. Ensure there is significant, stable, long-term funding for adaptation projects in Canada.

The flood management sector requires stable, long-term federal funding so that business and organizations in the sector have a predictable and consistent environment to work in. There is a need to recognize the urgency of adaptation, and the wide range of projected climate change impacts that require strategic, multi-beneficial responses. Initiatives dedicated to collecting data, creating flood maps, conducting risk assessments, and creating tangible plans to increase community resilience need sustained support to be effective. Programs like the Disaster Mitigation and Adaptation Fund (DMAF) have a limit of $2 billion in funding for all projects, meaning that projects are competing for the same pot of funding, and all projects must be completed by 2027-28. Given the decades of work that will be necessitated as Canada moves to a low carbon economy and adapts to the effects of climate change, funding for planning, management and innovation should be increased and stabilized with long-term guarantees. Programs like the DMAF should likewise have predictable and consistent funding and project goals so that work can be done to keep communities safe as efficiently and proactively as possible. A coherent, collaborative approach to resourcing communities across regions would help them to work with each other towards mutually beneficial goals that have multiple co-benefits. Adaptation projects should be evaluated on their merits and not against one another.

8. Facilitate data sharing with practitioners and the public and continue supporting the expansion of open data.

Experts have noted that data is often difficult to find or requires significant delays dealing with departments to access, especially with priority issues like flood mapping and modelling. Ensuring the accessibility of government-provided data is important. Emphasising open data, as the federal government is already doing with climate data through the Canadian Centre for Climate Services, would spur innovation and the continued development of new flood adaptation technologies. The private sector, if provided with the necessary data in a clear and accessible way, would be able to fill in technological gaps and help develop the clean technology landscape in Canada. The Open Government Portal is a useful resource, for instance, but can be cumbersome to use. Government data related to flooding should be centralized in a portal adjacent to or within the Portal, including comprehensive national flood mapping incorporating climate projections, region-specific information, active floods, historical data, and other information relevant to professionals and industry.

Experts have also expressed a desire to have standardized and accessible information wherever possible. This includes resources such as flood maps and modeling, which should be open and standardized so that experts can spend time using them rather than finding and interpreting them. Utilization of standard or transferable modelling services would achieve this aim. An additional area suggested by experts is to explore having provincial governments update their municipal road and sewer Standards and Detail drawings; this would allow for province-wide standardization of needed products and materials to mainstream approaches like NbS and Low Impact Development. Creating standardizations in things like supply, materials, specifications, and requirements can all contribute to effective mainstreaming of new and clean technologies.

9. Incorporate flood adaptation into asset management and infrastructure renewal.

Although this is not done exclusively at the federal level, it is important that communities' adaptation strategies are being incorporated into asset management, especially at the municipal level. Given the limited resources cities often possess, it is important to be as efficient as possible and look for synergies in strategic investments. When outdated infrastructure or assets need to be replaced, it is therefore useful to evaluate whether climate goals can be met by introducing more up to date and environmentally friendly technologies. Kitchener, for example, incorporates Low Impact Development practices into its road renewal program. Surrey is substituting obsolete infrastructure with modular and modern replacements that are flexible in a changing climate. Redevelopment should be designed to lock in resilience rather than risking compounding vulnerabilities. Building standards and other regulations should be updated to ensure that new infrastructure and retrofits consider low carbon resilience. Infrastructure Canada's Climate Lens is an example of a useful tool to drive such practices that could be scaled up and resourced more extensively so that local governments have more information about how to use it and how to integrate adaptation and mitigation effectively across the board; research into additional key resources that could be adapted for this goal would be useful.

10. Scale up the pace of implementation of national standards for adaptation.

There are already some standards created by the Canadian Standards Association (CSA) in place that are intended to increase adaptation to flooding events. These include CSA Z800,[150] guidelines on basement flood protection and risk reduction, and CSA W204,[151] flood resilient design for new residential communities. Other policies are currently being developed, and CSA is working on updating standards, but the implementation of these policies on the ground needs to be scaled up and these guidance materials need to be referenced in relevant policies. Guidelines should also focus on non-structural measures such as leak detection and the building materials used instead of solely being focused on structural measures.

11. Facilitate collaboration and partnerships among ministries and diverse stakeholders, including the public.

Flooding crosses jurisdictional boundaries and requires input from numerous professional sectors, and diverse stakeholders need to address the issue in a collaborative way. The Disaster Mitigation and Adaptation Fund could help related organizations, such as private companies, separate municipalities, and government ministries, collaborate on specific projects and encourage further collaboration. This is important in order to create partnerships rather than having multiple stakeholders all working on the same project separately.

Experts have also noted that federal ministries often do not communicate effectively amongst themselves and tend to work on projects in a siloed manner incommensurate with a cohesive approach. It is therefore important to establish new bodies and communications tools dedicated to harmonization between departments and ministries as well as between different levels of government and professional sectors.

In order to incentivize low carbon resilient development, the federal government should update the Pan Canadian Framework on Clean Growth and Climate Change to actively integrate the four pillars of the framework, beginning to move the country away from the siloed narratives for adaptation, mitigation and clean growth and towards strategic planning that has multiple co-benefits for all pillars.

The public has a significant stake in how flood adaptation is pursued in communities. Climate risk assessments must be guided by the values of each community. Involving stakeholders in discussions surrounding what adaptation will look like can also assist with greater acceptance and public uptake of strategies aimed at increasing resilience. Funding requirements should therefore also include communications and engagement, and new funding should be made available to support co-creation of solutions with local experts as well as ensure that voices that may be marginalized have a seat at the table.

8) FURTHER RESEARCH NEEDED

Experts have identified gaps in how data is developed and acquired, and the suite of technologies available in Canada, for urban planning and water resource management. ***More work is required on clean, resilient technology options that can help build low carbon resilience in a wide variety of contexts.***

While the flood adaptation technology sector is rapidly growing, there are numerous examples of technology being imported; for example, cities have had to procure fish-friendly pumps from companies in Europe to adhere to Canadian environmental standards.[152] This suggests that there is potential for growth in the Canadian sector that might benefit from investment. Given the breadth of climate impacts, from drought to flood, for instance, and exacerbating underlying conditions such as issues of social justice, endangered species, and ageing infrastructure, the most rewarding investments will respond to more than one challenge. ***A more comprehensive scan of multi-beneficial clean technologies for climate resilience across the board that can be produced in Canada would be a useful next step.***

As noted in the report, this investigation and evaluation of the usefulness and effectiveness of the wide range of technologies available must be done in a context-specific manner so that the best possible solutions can be pursued at the local level. The threat of flooding is growing faster than the infrastructure budgets of cities and their capacity to address the problem. Further discussion is required about ways to further leverage the power and capacity of the federal and provincial governments to provide the resources required at the local level to adapt to increasingly severe flooding and other climate impacts. ***Research into effective collaborative mechanisms would be useful as would case studies of existing multi-beneficial responses already being explored at the local level in Canada.***

In some cases, the risks of flooding may become so great that relocation may become the only option; worse yet, without proper preparation, both short and long-term displacement may also occur. ***The federal government should invest in development of resources, data, and policy planning for flood-driven human mobility, and at a broader scale, climate change displacement.***

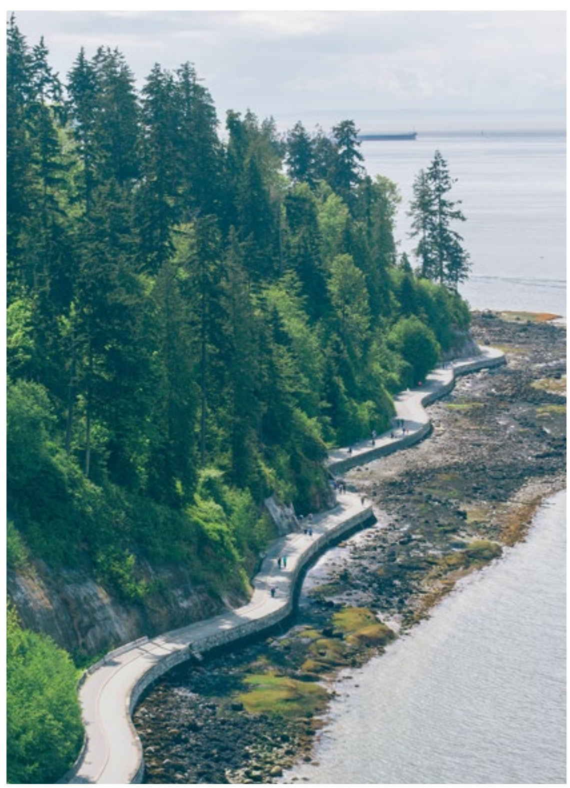
There is currently no central hub for accessing and investigating flood adaptation technologies in Canada; identifying them requires research into individual companies and analysis by climate-focused organizations. Canadian companies in this sector often do not directly refer to climate adaptation as a primary goal, with the result that clean adaptation-designated technology products are often difficult to identify. However, flood technologies have numerous applications for adaptation, and as decarbonization emerges as a global priority and trend, an increasing number of flood-related products in Canada are beginning to reflect the definition of "clean, resilient" technology. ***Further detailed investigation in collaboration with flood managers and other experts would provide grounded, detailed insights into development and communication of resources needed to advance best practices.***

9) CONCLUSION

There are many promising existing and emerging clean technologies for climate change adaptation in the context of urban planning and water resource management in Canada, and their resilience and affordability are becoming better understood. It is clear that use of clean technologies and other resources can increase Canada's low carbon resilience in a changing climate, and it is crucial that we advance action in this area given that climate change is a costly, current, and growing threat.

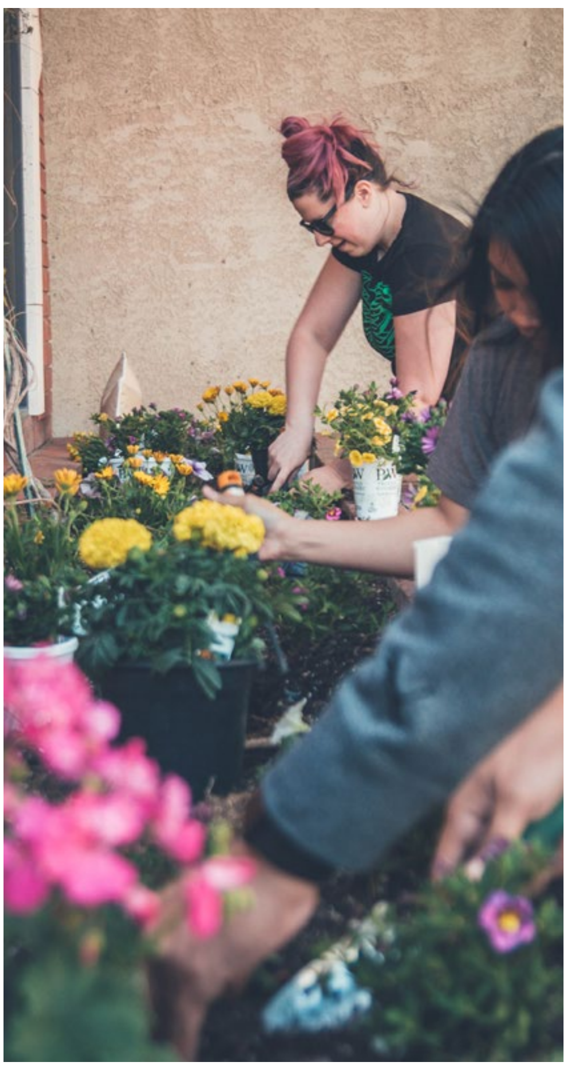
Adaptation to flooding in Canada is an imperative. Canada faces the prospect of more frequent and severe flooding with significant economic and social costs that will increase in the future. By reducing emissions, Canada helps to reduce the risks; however, some effects of climate change are inescapable. Temperatures will increase, sea levels will rise, and flooding will become more common. Responses need to be effective, evidence-based, and flexible. To adapt effectively to climate change, responses must also be both low carbon and resilient.

There is a growing recognition that the linkages between adaptation, which is designed to increase resilience, and emissions reduction need to be addressed in a cohesive way. It no longer makes sense to address these two areas separately. Some adaptive actions, such as use of concrete in construction of seawalls designed to guard against sea level rise, may entail the release of significant emissions. Likewise, efforts to reduce emissions may create new vulnerabilities to climate events.



By accounting for "low carbon resilience", or LCR, in an integrated approach to the two streams of action, the trade-offs, linkages, and co-benefits can be more accurately and effectively examined, with outcomes that address multiple co-benefits. For instance, NbS are a useful flood response that can help reduce vulnerability to climate impacts while also reducing emissions and benefiting human health and biodiversity.[153] Focusing on clean, resilient technologies can also help advance multiple sustainable policy goals.

This report outlines clean technology options that are resilient to the increasing impacts of climate change and provide the widest suite of co-benefits. A suite of technological, regulatory, and economic policies and solutions is required to effectively build resilience to flooding in Canada. No one technology is entirely superior to the others, due to the intricacies of the local contexts in which climate change impacts occur; however, the results of this project illustrate that clean technologies that reduce emissions, build in resilience in a flexible manner, and offer co-benefits are part of a vibrant, emerging sector in Canada with potential for expansion.



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ACT Adaptation to Climate Change Team

ACT (the Adaptation to Climate Change Team) in the Faculty of Environment at SFU brings leading experts from around the world together with industry, community, and government decision-makers to explore the risks posed by top-of-mind climate change issues and to identify opportunities for sustainable adaptation.

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