Flood Adaptation

Good Practices for Southern Alberta

THE RESILIENCE INSTITUTE

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The Resilience Institute

The Resilience Institute (TRI) is a charitable organization that addresses climate change and sustainability through education and research. TRI is a hands-on organization that develops resilience building initiatives with partners and communities. TRI's focus is on advancing the capacity of communities to respond to climate change impacts by delivering education, conducting applied research, and through weaving knowledge systems for effective and relevant adaptation strategies.

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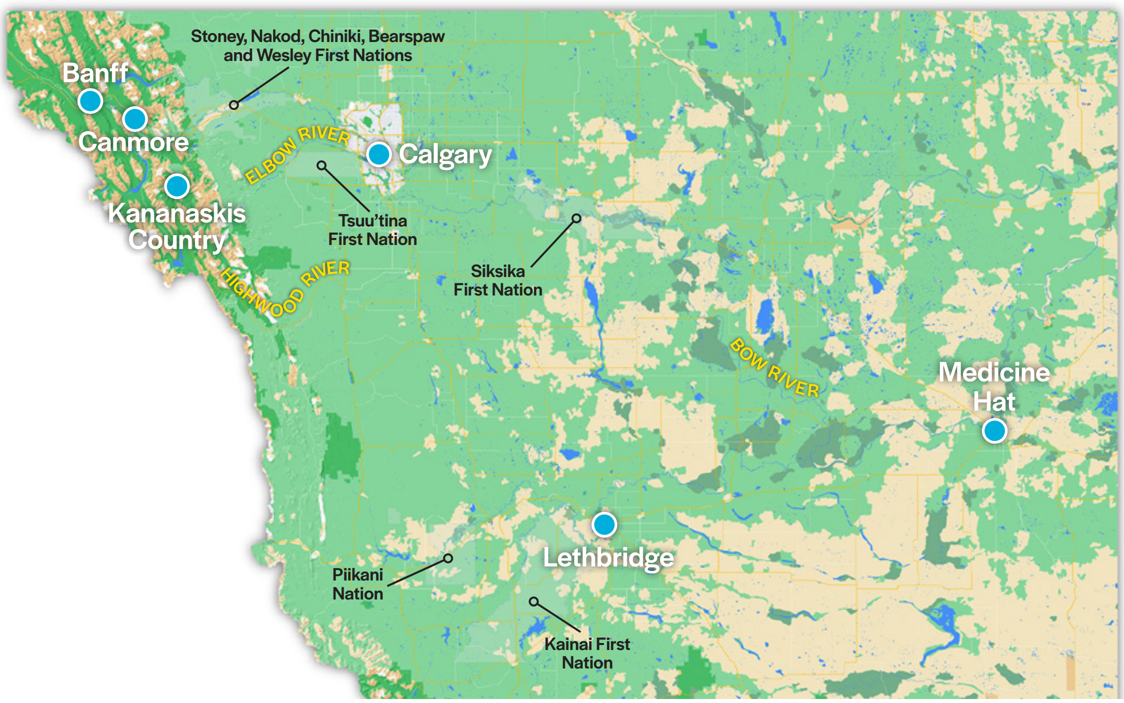
Table of Contents



Kananaskis Country

Executive Summary

'Flood Adaptation – Good Practices for Southern Alberta' looks at what it means to be resilient in the context of climate change and extreme flood events.

In this report a range of structural and non-structural flood mitigation measures is presented, with a discussion of the strengths and weakness of each method in the context of climate change. Structural methods of flood mitigation protect a specified area from floodwater damage by using hard infrastructure such as dams, levees, retention walls, river channels, and sediment management structures. Non-structural methods focus on adopting systems and practices that promote flood adaptation and community resilience. This includes green infrastructure and social methods. Green infrastructure refers to protecting and/or restoring wetlands, increasing vegetation cover, and increasing green spaces, natural drainage, and permeable surfaces. Social methods refer to strategic planning, zoning, building bylaws, insurance, and public education.

Flood adaptation in Southern Alberta means adopting new behaviours and infrastructure that will limit damage from flood events while accommodating changes in the environment and weather patterns. The overarching goal is to create resilient communities – communities that tolerate change, reorganize, and renew following natural disasters in a timely and efficient manner. Increasingly, the sole use of structural methods of flood mitigation is seen as ineffective over the long term, as infrastructure tends to be designed to parameters that are increasingly becoming obsolete in the face of climate change uncertainties. To achieve resilient, flood-adapted communities, The Resilience Institute suggests three areas of focus: watershed-level collaborative planning, green infrastructure, and public education.

The overarching goal is to create resilient communities – communities that tolerate change, reorganize, and renew following natural disasters in a timely and efficient manner.


High River

Introduction

The term ‘climate change’ in this report refers to global warming driven by human emissions of greenhouse gases, primarily carbon dioxide and methane, and the resulting large-scale shifts in weather patterns. Fossil fuel burning, largely coal, oil, and natural gas, is the main source of greenhouse gas emissions, with additional contributions from agriculture, deforestation, and manufacturing. The World Meteorological Organization (WMO) has reported that the years from 2011 to 2020 formed the warmest decade on record, and that this is a continuation of a persistent long-term climate change trend. Globally, the warmest six years on record (from 1880 to today) have all been since 2015, with 2016, 2019 and 2020 being the top three. The human cause of recent climate change is not disputed by any scientific body of international standing.

Climate change is affecting millions of people across Canada. The Prairie provinces, including Southern Alberta, have experienced the strongest warming to date across southern Canada, particularly in the winter months. Climate modeling indicates that in the future there will be significantly fewer cold days, higher maximum temperatures, and heavier rainfall events, particularly in the winter and spring. Warmer temperatures are increasing rates of evaporation and the atmosphere’s capacity for moisture retention, causing more intense storms and weather-related natural disasters. Analysis of rainfall data generated by climate models indicates that climate change will cause a significant shift in the intensity, duration, and frequency of rainfall events in Southern Alberta. These changes in climate patterns are predicted to increase the risk of overland flooding as rainfall becomes more intense. Floods will increasingly be generated by heavy rain or rain on snow, whereas historical flooding was more often the result of spring snowmelt. In Southern Alberta, the risk of mountain runoff flooding is particularly high for Alberta’s urban centres, given their proximity to the Rocky Mountains. (Sauchyn et al., 2020).

In Canada, flooding is the most common and most destructive natural hazard. Currently, the top five worst floods (in terms of damage to communities and cost to rebuild) have all taken place since 2010, with the 2013 Southern Alberta Floods causing the highest impacts (Canadian Freshwater Alliance, 2019). Climate change played a strong role in the 2013 Alberta floods, as these were driven by unusually strong jets of humid, unstable air that flowed up against the eastern slopes of the Rockies, triggering three days of heavy rains (Liu et al., 2016). The temperature was also several degrees warmer than normal during this extreme event, which meant that precipitation fell as rainfall rather than snow at high elevations in the mountains. This enabled rapid runoff rather than delayed melting of snow, contributing to flash flooding in the Bow, Elbow, and Highwood Rivers and numerous smaller river basins in Southern Alberta that feed into these systems.

This report ‘Flood Adaptation – Good Practices for Southern Alberta’ looks at what it means to be resilient in the context of climate change and extreme flood events. An overview of the strengths and weaknesses of flood mitigation measures is provided, followed by recommendations for flood adaptation good practices for Southern Alberta.

The Language of Resilience

In the last decade, climate change mitigation has become a fundamental goal embraced by world leaders around the globe. More recently, governments and environmental organizations have diversified their efforts, promoting both climate change mitigation and adaptation policies and programs. A combination of mitigation and adaptation practices is now seen as the best approach to minimize the effects of climate change on communities across Canada and the world.

Considering all points of view and ways of seeing, Albertans are in a strong position to create effective strategies for flood adaptation.

Considering all points of view and ways of seeing, Albertans are in a strong position to create effective strategies for flood adaptation. Accordingly, The Resilience Institute (TRI) is committed to inclusive language that brings people together. For the purposes of this report, TRI defines mitigation, adaptation, resilience, and good practices as follows:

Mitigation

The United Nations Framework Convention on Climate Change (UNFCCC) describes climate change mitigation as being a two-pronged approach, addressing both carbon emissions and carbon storage. Climate change mitigation is defined as decreasing the amount of greenhouse gas emissions released into the atmosphere by human activities, as well as reducing the current concentration of carbon dioxide by protecting and enhancing natural carbon sinks. For example, protecting or increasing forested areas. Collectively, efforts to reduce human caused emissions and enhance natural carbon sinks are referred to as 'mitigation'.

Mitigation policies and practices typically focus on transitioning from fossil fuel-based energy systems to clean, renewable energy, and balancing the release of greenhouse gases into the atmosphere with natural systems of capture and storage. Maintaining or augmenting natural systems of capture and storage is accomplished by stopping and reversing deforestation, rebuilding soils in agro-ecosystems, and restoring natural habitats.

Adaptation

The UNFCCC defines climate change adaption as 'adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts.'

Climate change adaptation looks at how to reduce the negative effects of the changing climate on human communities, and how to take advantage of any opportunities that arise. Policies and practices for adaptation vary depending on the specific climate change impact being addressed. In the context of flooding in Southern Alberta, adaptation means adopting new behaviours and infrastructure in order to accommodate changes in the environment, thereby limiting risk and damage.

Resilience

The United Nations defines resilience as the ability of a system, community, or society exposed to hazards to resist, absorb, accommodate, and recover from the effects of the hazard in a timely and efficient manner, including preservation and restoration of essential structures and functions.

In the context of flooding, Liao (2012) and Asrat (2015) explain there are two types of resilience: engineered and ecological. Engineered resilience focuses on maintaining functional ability and resisting change. Ecological resilience, focuses on the ability to tolerate change and to reorganize or renew after an event, in essence finding a 'normal' state – either returning to the former normal or creating a new one.

Good Practices

In writing the recommendations for this report the use of the phrase 'best practice' versus 'good practice' was considered.

'Best practice' is defined in the Cambridge Dictionary as 'a working method or set of working methods that is officially accepted as being the best to use in a particular business or industry, usually described formally and in detail' (Cambridge Dictionary, n.d.). Beyond formal definitions, another way to define best practices is that it is a way of improving public organizations by identifying, communicating, and facilitating the transfer of practices that seem to work successfully elsewhere (Vesely, 2011).

In terms of inclusive language, 'best practice' does have some criticism. When the phrase is applied to a set of practices that were selected without a clear and consistent theoretical framework, use of the term can lead to confusion, bias, and unintended meaning (Vesely, 2011; Osburn et al., 2011). Boven & Morohashi (2002) observe that by referring to practices as 'best' it could suggest an element of competition. The term has potential to be problematic when referring to knowledge that is derived from different epistemological backgrounds, such as Indigenous knowledge and scientific knowledge.

Traditional knowledge from Indigenous communities is increasingly being recognized by academics, policymakers, and managers, both in Canada and globally, as an essential component of planning processes. Traditional knowledge is contextualized as a body of cumulative knowledge, passed on through generations, and associated with a specific place for a long period of time. In the context of flood adaptation, traditional knowledge contributes to understanding weather patterns, biophysical vulnerability, social-ecological resilience, and adaptation. This is well documented in many fields, including natural resource management, environmental impact assessment, climate change adaptation, and natural hazards and disaster risk reduction. (Muhammad-Arshad et al., 2019)

To foster inclusive discussion and recommendations, TRI uses the term 'good practice,' which underscores the value of considering multiple viewpoints. Likewise, the United Nations Framework Convention on Climate Change uses the term 'good practices' when referring to the use and collaboration of local and Indigenous knowledge.

Climate Change & Flood Risk in Southern Alberta

Climate change is progressively influencing several environmental factors that exacerbate the risk of flooding in Canada, and particularly Southern Alberta.

Climate change can alter precipitation patterns (Kundzewicz and Schellnhuber, 2004), causing more or less rain than normal to fall over a region or outside its expected season. Warmer temperatures can amplify the hydrological cycle, cause more precipitation to fall as rain rather than snow, and cause rain-on-snow events, causing snowpacks to melt earlier and faster. This is significant for the Prairie provinces of Canada, as the warming trend in the Prairies between 1948 and 2014 was 1.5˚C, which is twice the global average over the same period (Phillips et al., 2017). Canada is feeling the impacts of climate change more acutely and much faster than many regions of the world.

Other changes due to human influences that can aggravate floods include increased urbanization and population growth, deforestation, occupation of at-risk areas, and decreasing soil permeability. As urban centers induce these types of changes, they are more susceptible to hydrological extremes and, by extension, to more extreme flooding. (Few, 2003; Jensen et al., 2017; Liao 2012 & 2014; Moudrak et al., 2018; Zimmerman et al., 2016)

In Canada, floods are the most pervasive and costliest natural disaster (Asrat, 2015; Moudrak et al., 2018). Decades of monitoring and documentation show that the number of catastrophic flood events in Canada has increased overtime. The top five worst floods on record, in terms of extent of flooding and cost of restoration, have all occurred after 2010. Seven out of the ten most expensive floods in Canada have occurred within Alberta, accounting for $7.5 billion in insured losses, which is 70% of the country's total (Kaufmann, 2018). Among them is the 2013 Southern Alberta flood, which ranks as #1 in Canada in terms cost of recovery, and is estimated at $6 billion (ECCC, 2017; Canadian Freshwater Alliance, 2019). Approximately one quarter of the province of Alberta experienced severe flooding.

The 2013 flood was a result of a series of hydrometeorological events that occurred in the headwaters of the Bow Valley watershed. The preceding winter season was longer than average, with significant snowpack accumulating from October 2012 through to April 2013. Following the heavy snowfall, the Bow River watershed saw significant precipitation in June 2013 accompanied by warm temperatures. An extreme rainfall event occurred, releasing up to 300 mm of precipitation over three days in the front ranges of Kananaskis Country. This precipitation fell on frozen ground and snow in alpine areas, causing high runoff and rapid snow melt. Regional groundwater tables were higher than average at the time. The land had little capacity to take up excess rainfall and extensive flooding occurred across Southern Alberta. (ECCC, 2017; Liu et al., 2016; Kochtubajda et al., 2016)

The impacts of the flood were widespread and substantial. Banff and Canmore, which were at the epicenter of the flood, became isolated as the Trans-Canada Highway was inundated with water. The flood washed away thousands of kilometres of roads and hundreds of bridges and culverts, while impacting over 4000 businesses in Calgary. Over 100,000 Albertans were forced to leave their homes, the largest evacuation across Canada in more than 60 years. Four people lost their lives after being swept away in fast-moving water. The event disproportionately impacted First Nations communities, with many residents not being able to return to their homes until six months after the event. (ECCC, 2017; Public Safety Canada, 2021)

Return period is the probability of an event reoccurring each year. For example, the return period of a flood might be 100 years; otherwise expressed as its probability of occurring being 1:100, or 1% in any one year. The likelihood of a flood occurring is inversely related to its size. Relatively small annual floods are the most common, while larger floods are decreasingly likely to occur in any given year. The 2013 flood in Southern Alberta, the worst natural flood disaster in Canadian history, was less than a 1:100-year event. The actual return period is estimated to be between 1:22 and 1:50 years. Forecasters presume from the data that it has only been luck that a similar flood has not occurred since 1932 (Teufel, 2017).

The scale of flooding seen in 2013 occurred with protective flood infrastructure in place. This points to the need for a comprehensive set of flood mitigation strategies, in order to create safe, resilient communities in the context of climate change.

Seven out of the ten most expensive floods in Canada have occurred within Alberta.

Overview of Flood Mitigation Strategies

Flood mitigation refers to methods used to reduce or prevent the detrimental effects of flood waters. Common techniques used for flood mitigation are grouped into two categories: structural methods and non-structural methods.

Figure 1. Categories of Flood Mitigation

Structural methods of flood mitigation protect a specified area from floodwater damage by using hard infrastructure such as dams, levees, retention walls, river channels, and sediment management structures. Non-structural methods focus on adopting systems and practices that promote flood adaptation and community resilience. This includes green infrastructure and social methods. Green infrastructure refers to protecting and/or restoring wetlands, increasing vegetation cover, and increasing green spaces, natural drainage, and permeable surfaces. Social methods refer to strategic planning, zoning, building bylaws, insurance, and public education.

This report will look at the range of structural and non-structural flood mitigation measures, providing a discussion of the strengths and weakness of each in the context of climate change.

Structural Methods

Structural methods of flood mitigation are implemented widely to prevent flood waters from reaching at-risk areas. The term encompasses all 'hard' or 'grey' infrastructure developed to contain floodwaters, including berms, levees and dykes, dams, reservoirs, detention basins, channels, and floodways.

Hard infrastructure for flood mitigation has a long history of use in Southern Alberta and worldwide, providing ample data on its effectiveness at water storage, flood prevention, protection of assets, and longevity (Daigneault, et al., 2016). Table 1 describes the advantages of hard infrastructure in flood mitigation.

Seebe Dam on the Bow River

Table 1. Advantages of Hard Infrastructure in Flood Mitigation

Advantage	Comments
Design phase flexibility	In the initial design phase of the infrastructure, the design parameters can be chosen to suit many different locations and flood scenarios. Designs with proven records of efficacy can be adapted to various locations. Engineers can choose the scale of flood to protect for and balance this with available resources.
Proven effectiveness & familiarity	Hard infrastructure is highly effective in providing flood protection for downstream assets where the flooding occurs within the volume of water that the infrastructure is designed to manage. Flood mitigation infrastructure is widely implemented, and data is available that demonstrates the effectiveness of reducing physical and economic impacts on downstream communities. Governments and the public are often supportive of hard infrastructure for flood management as it has become familiar to many communities. The positive effects of reduced flooding are appreciated, as complex risk management efforts, such as community resettlement and post-flood compensation, may be avoided.
Timeliness	Depending on the scale of the development, hard infrastructure can be completed in a relatively short length of time. It has immediate, visible effects and can be positively received by the public,
Ancillary benefits	Dam and reservoir systems can provide an important source of community water during dry periods, for drinking, irrigation, and recreation. Hard infrastructure also has potential to mitigate flood damage in areas of high biodiversity value downstream, such as forests and parks.

Historically, flood control infrastructure was designed to withstand the highest flood experienced by a community, which is commonly a once-in-a-century event (1:100 flood level). The standards that the infrastructure is built to often depends on the available flood record. Some communities can have lower levels of protection if the worst flood they have experienced is, for example, a 1:30 or 1:50 year flood, although the possibility of a larger flood still exists.

The majority of existing hard infrastructure for flood mitigation is designed without accounting for climate change-induced shift in flood patterns (Asrat, 2015). As climate change is predicted to increase the frequency and magnitude of flooding, specifically from fluvial sources (rivers and lakes) and pluvial sources (rainfall events) (Moudrak et al., 2018), flood mitigation infrastructure is increasingly vulnerable to failure. Table 2 expands on the disadvantages of hard infrastructure.

Table 2. Disadvantages of Hard Infrastructure in Flood Mitigation

Disadvantage	Comments
Design limitations & dependence on unreliable factors	Hard infrastructure is designed to contain a specific scale of flooding. If a flood surpasses that capacity, the result can be loss of life, property damage, structural failure, and enhanced risk of devastating flood events (Schindler et al., 2016). Within the context of a rapidly changing climate and increasing severity of flood events, the design parameters to develop sufficient infrastructure to ensure community safety are steadily increasing over time.
High cost of construction, maintenance, and retrofit	Compounding the issue of climate change and shifting design parameters, flood mitigation infrastructure is typically difficult and costly to retrofit (Hatman et al., 2019). In addition, construction and maintenance costs frequently exceed initial estimates (Zimmermann et al., 2016).
Negative ecological impacts	Floodplain ecosystems are biodiversity hotspots and supply multiple ecosystem services. The negative ecological impacts to the floodplain from hard infrastructure are well documented (Schindler et al., 2016). Hydrologically disconnecting the floodplain from the river decreases habitat diversity (Klimo et al., 2008), limits wildlife movement on land and on water, and reduces biodiversity, particularly of specialist and sensitive species that depend on the availability of newly formed habitat and sediment accumulations created by the natural patterns of high and low discharge levels (Poff et al., 1997).
The Levee Effect and decreased flood risk knowledge	Hard infrastructure used for flood mitigation tends to increase the public sense of security, feeding the notion that flooding is the exception rather than the norm, and inviting further development on the floodplain. This phenomenon is common in communities and has been labelled as 'the levee effect' (Liao, 2014). The levee effect creates a positive feedback loop reinforcing the need for hard infrastructure. As the floodplain is increasingly urbanized, the population grows, the floodplain becomes increasingly less permeable thereby increasing drainage issues, and more flood protection infrastructure is then needed and requested by the community. Hard infrastructure for flood mitigation tends to reduce flood awareness and create a false sense of security in the public. Residents living within a floodplain often have no precautions in place to protect their own physical assets and personal well-being, thereby placing the onus of protection and recovery on governments (Liao, 2016; Rokaya et al., 2017). This lack of knowledge and action reduces residents' adaptability to flood scenarios and makes them susceptible to greater impacts from flooding.
Social injustice	Flood control infrastructure has potential to induce social injustice. For example, floodwaters may be diverted away from one population, but increase flood risk to another.

Elbow River, Kananaskis

Non-Structural Methods

Methods that fall into the non-structural category include all systems that do not rely exclusively on hard infrastructure. Non-structural flood mitigation measures can be further categorized as green methods and social methods.

Green Methods

Green methods of flood mitigation are also known as nature-based solutions, natural flood management, and green infrastructure. The aim of green methods is to integrate natural processes into flood management strategies. A key aspect of green methods is adaptation. Natural flood management does not aim to stop floods or reroute them to another location as grey infrastructure does. Rather, flooding is approached as a naturally reoccurring phenomenon and communities and infrastructure are designed to accommodate them. Examples of green methods include naturalized detention basins and ponds, water features, rain gardens, submergible parks, wetland restoration, floodplain restoration, vegetation restoration, vegetated swales, land conservation, and green roofs. For green infrastructure to contribute in a substantial way to flood mitigation and adaptation, it should be strategically planned to form a managed network of natural features, including naturalized forests, wetlands, grasslands, and recreational spaces.

The concept of restoring floodplains in a manner that allows for flooding is called 'Room for Rivers.' This strategy was first implemented in the Netherlands and has been studied and replicated in other parts of the world, including in Calgary, Alberta (Asrat, 2015; Keesstra et al., 2018). Restoring and conserving the floodplain allows the river sufficient space to continue historic flood patterns.

The following provides an overview of the advantages of green methods of flood mitigation.

Table 3. Advantages of Green Methods of Flood Mitigation

Advantage	Comments
Effective in reducing floods and erosion	Green infrastructure absorbs and retains water that would otherwise become runoff and contribute to flooding. Implemented as part of a strategically planned network, green infrastructure can alleviate urban runoff and localized flooding, and significantly reduce the magnitude of flood events. Vegetation slows rates of erosion and protects soil surfaces, slows the speed and force at which floodwaters flow, limits the peak discharge and spread of floods, and alters the time profile of flooding (Anderson et al., 2006). By slowing the flood wave at a given point, the water depth and storage upstream increases, while downstream will see a lower wave peak but longer flood duration (Rutherfurd et al., 2006).
Provides ecological services	Green infrastructure and the water that is retained provide a wide range of ecological services, including wildlife habitat and movement corridors. Natural infrastructure sustains higher biodiversity, removes carbon from the air, and provides for water filtration and water storage (Burrell et al., 2007; Keesstra et al., 2018; Liao et al, 2016). Green infrastructure confers adaptive and resilient qualities to communities, which are essential to attenuate flood impacts brought on by climate change. The high visibility of green infrastructure means that it can be used for public education on flood hazard and risk. As natural systems of flood mitigation do not eliminate floodwaters, but instead allow for natural processes to take place, green methods of flood mitigation promote learning to live with flood hazard through preparation and enhanced ability to recover and benefit from flooding (Hatmann et al, 2019).
Contributes to community flood adaptation	Green infrastructure can be more cost effective compared to grey infrastructure. As natural processes are retained the cost of flood management is not transferred beyond the local area.
Cost effective	Lower energy is required for maintenance, and it is more easily updated and retrofitted compared to grey infrastructure.

Table 4. Disadvantages of Green Methods of Flood Mitigation

Disadvantage	Comments
Larger land area requirements	For green methods to effectively mitigate flooding, they must be applied as part of an interconnected network of green infrastructure. This often requires large areas of land. Purchasing land can contribute to high initial costs, although not necessarily as high as grey infrastructure.
Flooding still occurs	The aim of natural infrastructure is not to prevent all flooding, but to preserve natural processes, minimize impacts, and maximize benefits. As such, flooding still occurs, the scale of which depends on the extent of the green infrastructure network.
Longer timeline for results to be achieved	Green infrastructure often relies on vegetation to achieve flood mitigation effects. Vegetation can take many seasons to fully mature and provide the full services intended.
Higher level of cooperation required	Natural infrastructure networks often rely heavily on public support for successful implementation. Implementation at the watershed level is more effective than small-scale local projects functioning in isolation. At the watershed scale, private land is often required to function as part of the network, requiring the cooperation of multiple landowners.
Less data available on effectiveness	The shorter history of planning natural infrastructure as flood mitigation means that there is less available data and case studies to support funding requests.

Social Methods

Social methods of flood mitigation and adaptation include policies, programs, behaviours, and actions carried out by government, the business community, not-for-profit and educational institutions, and the public. These activities are independent of the physical structures of green and grey infrastructure. Social methods typically include the following:

Methods carried out by government and institutions:

- Flood adapted community planning such as zoning bylaws, building codes, development permit areas, floodplain management bylaws, and municipal development plans,
- Public education programs,
- Floodplain and flood hazard mapping,
- Water level monitoring,
- Weather and flood forecasting,
- Emergency evacuation planning and exercises,
- Risk communications and consultation,
- Emergency warning systems,
- Flood recovery strategies,
- Emergency services and health supports.

Social methods carried out by individuals, strata corporations, and businesses include:

- Local flood hazard research,
- Floodproofing existing buildings and becoming familiar with the building's plumbing, electrical, and utilities,
- Flood insurance,
- Flood preparedness kits,
- Evacuation plans and exercises, and,
- Volunteering in flood mitigation or recovery efforts.

There are three types of flooding that can affect homes: infiltration and seepage, stormwater overland flooding, and sewer backup. In Canada, only sewer backup is insurable for single family homes, although provincial disaster relief may be employed for stormwater flooding (Sandink, 2016). Strata corporations may be able to purchase flood insurance for overland flooding of multifamily structures.

Social methods of flood mitigation focus on adaption to flood hazard and prevention of negative impacts from flooding. The outcome of implementing a broad range of social methods can be drastically reduced impacts from flooding, with a much lower cost relative to building green or grey infrastructure. Creating a sense of individual responsibility is critical to timely and effective response to flood hazard. Social methods also have their own positive feedback loop: higher public education and awareness of flood hazard tends to lead to better reception of mitigation measures.

Conversely, the level of cooperation required to implement social methods can be a challenge. Large-scale spatial planning at the watershed level is ideal but may be difficult to achieve due to conflicting goals and opinions across multiple jurisdictions.

Good Practices for Southern Alberta

Flood adaptation in Southern Alberta means adopting new behaviours and infrastructure that will limit damage from flood events while accommodating changes in the environment and weather patterns. The overarching goal is to create resilient communities – communities that tolerate change, reorganize, and renew following natural disasters in a timely and efficient manner. In this report, the advantages and disadvantages of a wide range of flood mitigation measures have been explored, leading to strong indications of which measures best promote adaptation and resilience.

Increasingly, the sole use of grey infrastructure for flood mitigation is seen as ineffective over the long term, as it is 'designed and operated under the obsolete assumption that pattern of flow variability remains unchanged over time, [it] is not a reliable mitigation approach in the face of climate change uncertainties' (Liao, 2012).

To achieve resilient, flood adapted communities, The Resilience Institute suggests the following three good practices for flood adaptation in Southern Alberta:

1. watershed-level collaborative planning,
2. green infrastructure, and,
3. public education.

1. Watershed-Level Collaborative Planning

Watershed-level collaborative planning for flood adaptation can be described as the holistic and continuous societal analysis, assessment, and reduction of flood risk, involving all levels of government and a broad range of stakeholders and rightsholders. This type and scale of planning, as well as emergency preparedness, is critical for reducing the impacts of flooding in Southern Alberta (Sauchyn et al., 2020). Flood management plans should address flood prevention, probability reduction, and attenuation of damaging effects for those floods that cannot be avoided (Burrell, 2007; Schanze, 2006). Flood planning documents must evolve over time as concepts informing watershed-level collaborative planning change, and as future floods change in frequency and magnitude.

Canada has adopted the United Nations' Sendai Framework for Disaster Risk Reduction, a voluntary agreement recognizing that the responsibility for reducing disaster risk lies with all levels of government and their emergency management partners. Watershed level collaborative planning for flood adaptation should encourage participation from all stakeholders and rightsholders that have potential to be impacted by flooding. When responsibility is shared among all groups of interest, the strongest response can be developed, and community cohesion enhanced. (Asrat, 2015; Henstra et al., 2019; Keesstra et al., 2018; Moudrak et al., 2018; Rivera-Letelier, 2018; Sandink, 2016; Schanze, 2006)

Crowsnest River

The human-nature connection is a core aspect of collaborative planning for natural disaster mitigation, as perceptions vary between regions, communities, and over time. Cultural perception of floods (for example, considering a flood an unfortunate anomaly negatively impacting their way of life, versus a natural part of life), a community's flood memory, perceptions on the importance of ecological sustainability, how the thoughts of those who have experienced flooding differs from those who have not, and which assets are seen as more valuable, all influence how decisions are made.

As part of watershed-level collaborative planning for flood adaptation, members of at-risk communities must be invited to the decision-making process. Consultation with Indigenous communities is a critical part of any watershed-level planning process, noting that Indigenous communities experience a greater rate of displacement from flooding than non-Indigenous people, which can contribute to greater socioeconomic impacts (Thompson, 2015). A critical component of watershed-level collaborative planning is post-flood recovery planning. Montesanti et al. (2019) emphasize the need for Indigenous-led recovery efforts. Indigenous management of emergency operations and recovery supports opportunities to build on community strengths and provide an opportunity to increase the community's capacity to build a flood adapted future.

2. Green Infrastructure

The Sendai Framework recognizes that maintaining and restoring natural infrastructure is a key priority for disaster risk reduction. Under the Sendai Framework, governments are advised to strengthen the sustainable use and management of ecosystems. The best system of flood mitigation in the context of an uncertain climatic future, will incorporate an interconnected system of green infrastructure and natural areas at the watershed-level scale. Effectiveness of structural barriers to flooding is increased when implemented together with green infrastructure and social methods of flood mitigation and adaptation.

3. Public Education

Delivering public education on the role of individuals in flood adaptation is vital (CCR Network, 2014; Asrat, 2015; UK Environment Agency, 2017). When the public is well informed of the risks and impacts of flooding emergency response is optimized, and residents of at-risk communities can reduce flood impacts on their property and recover from a disaster more easily.

The City of Calgary offers a strong public education program to raise flood awareness and improve outcomes. Themes covered in the City of Calgary flood adaptation program include understanding flood risk, preparing for floods, and staying informed. Elements of the campaign include a Flood Readiness Guide aimed at educating the public on how to prepare for a flood and what to do during a flood, and a Flood Readiness e-newsletter.

Residents are advised to:

- Make an evacuation plan, for all family members and pets. Determine where you will go, what you will take, and how you will communicate with family and friends.
- Create a 72-hour kit that includes medication, important documents, and items that may be needed during and after evacuation.
- Move valuables and documents out of low-lying areas of the home.
- Finish basements with easy-clean materials in the event they are flooded with river water, groundwater, or sewage.
- Direct downspouts away from building foundations.
- Install and maintain a sump pump and sewer backflow valves.
- Have a back-up battery power source for sump pumps in case power is shut-off.
- Stay informed about weather and river conditions, and,
- Download an app that provides alerts to emergency conditions.

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