How Floodplain Development Can Improve Flood Resilience: Best Practices and Recommendations for the Lake Champlain-Richelieu River Basin

International Lake Champlain - Richelieu River Study

A WHITE PAPER TO THE INTERNATIONAL JOINT COMMISSION

Submitted by

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EXECUTIVE SUMMARY

The Lake Champlain-Richelieu River (LCRR) basin is a geographically and culturally diverse region straddling the Canada-US border. The vast drainage area is susceptible to springtime flooding that affects both lakeside and riverside residents of New York, Vermont, and Quebec. The International Joint Commission's Lake Champlain-Richelieu River Basin Study Board has undertaken an extensive evaluation of both structural and non-structural approaches to reduce the impacts of flooding in the LCRR basin.

STUDY FOCUS

As part of this effort, the Study Board adopted a flood mitigation framework centered on four mitigation themes:

1. Reduce extreme water levels on the Richelieu River and by extension, on Lake Champlain
2. Reduce inflows into Lake Champlain or the Richelieu River
3. Improve flood response (emergency preparedness); and
4. Modify floodplain management (adaptation to flooding).

To address Theme 4 (floodplain management), the Study Board convened a group of experts to identify non-structural tools for flood risk management in the LCRR basin. A 2020 expert workshop identified four key areas that the Study Board should focus on in providing floodplain management recommendations to the International Joint Commission:

1. Better flood risk maps are needed.
2. Flood risk should be better communicated and understood.
3. Management of floodplain occupancy should adapt and evolve.
4. Developments in Canadian and US flood insurance should be recognized.

The Study Board subsequently commissioned four White Papers to address these recommendations. This white paper is the third in the series and focuses on management of floodplain occupancy.

FINDINGS

The LCRR basin is a diverse region with unique challenges and opportunities to develop context-specific land use strategies. This study examines ways to reduce vulnerability and exposure to flooding through land use planning. Through a review of the scientific and grey literature, the document presents different land use planning options, the challenges and issues that accompany their implementation, and some principles to support their success.

Moreover, it focuses more on the Quebec context, since the province was disproportionately affected by the 2011 floods in the LCRR basin. Quebec is currently revising its mapping and regulations regarding floodplains. This white paper also offers examples of inspiring local and international initiatives.

First, land-use planning actions must be based on a sound knowledge of risks and reflect analyses of hazards, vulnerabilities, and flood risks. The data collected and analyzed by the Study Board can help to prioritize implementation of adaptation solutions over the territory according to the most vulnerable sectors. They can help justify more complex, costly, and socially sensitive development decisions, such as demolition and relocation of residential buildings or construction of protective structures. According to the indices analyzed, these analyses can also support the development of a regulatory framework.

On the basis of risk assessment, then, adaptation solutions that are sustainable and aim to reduce our exposure and vulnerability to flooding should be considered. This will ideally be achieved by reducing the number of people, built-up elements and services located in floodplains. However, for a number of reasons, such as the desire to densify metropolitan areas or to preserve urban cores and built heritage in floodplains, it will remain impossible to relocate everything and completely eliminate the risk, especially as it continues to evolve. We will therefore have to think about land use and a built environment that can coexist well with water.

In the LCRR basin and elsewhere in Quebec, there is a need for innovative architectural and landscape projects, supported by comprehensive studies, to enable safe coexistence with water. This is an opportunity to use the numerous hydrological, hydraulic and vulnerability studies that have been conducted in the basin as well as the Integrated Social, Economic and Environmental analysis tool.

In all cases, resilient development will not be based on a single strategy, but rather on a set of measures whose complementarity will depend on the specific context of a sector. In the LCRR basin, each municipality has its own context, development opportunities, priority areas for consolidation, and others for transformation.

If planning solutions are to be adapted to the specific context of a sector, where possible, our choices should be supported by detailed analyses of their costs and benefits, taking into account not only economic parameters, but also societal and ecological value. In addition, due in part to climate change, the context in which flood risk management is conducted is not static, but dynamic. This has important implications for the development of a strategy. Therefore, to avoid maladaptation, it will be necessary to focus on measures with positive results under uncertain conditions.

Finally, to ensure that solutions promoted at the watershed level or by municipal professionals reach out to community circles and individuals, it will be important to review water management mechanisms through greater involvement of local actors and improved citizen participation.

THE INTERNATIONAL JOINT COMMISSION

Under the Boundary Waters Treaty of 1909 (the Treaty), the governments of the United States and Canada established the basic principles for managing many water-related issues along their shared international boundary. The Treaty established the IJC as a permanent international organization to advise and assist the governments on a range of water management issues. The IJC has two main responsibilities: regulating shared water uses; and investigating transboundary issues and recommending solutions.

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1 BACKGROUND

The Lake Champlain-Richelieu River (LCRR) basin is a geographically and culturally diverse region straddling the Canada-US border. The vast drainage area is susceptible to springtime flooding that affects both lakeside and riverside residents of New York, Quebec, and Vermont. The International Joint Commission's Lake Champlain-Richelieu River Basin Study Board has undertaken an extensive evaluation of both structural and non-structural approaches to reduce the impacts of flooding in the LCRR basin.

As part of this effort, the Study Board adopted a flood mitigation framework centered on four mitigation themes:

1 Reduce extreme water levels on the Richelieu River and by extension, on Lake Champlain

2 Reduce inflows into Lake Champlain or the Richelieu River

3 Improve flood response (emergency preparedness)

4 Modify floodplain management (adaptation to flooding)

A *Floodplain Management Solutions in the Lake Champlain-Richelieu River (LCRR) Basin* workshop was held February 6-7, 2020 in Montreal, Quebec. The findings from this workshop were synthesized in a report (Henstra and Shabman 2020), which was submitted to the International Lake Champlain- Richelieu River Study Board.

The workshop report identified four key areas that the Study Board should focus on in providing floodplain management recommendations to the International Joint Commission:

1 Better flood risk maps are needed.

2 Flood risk should be better communicated and understood.

3 Management of floodplain occupancy should adapt and evolve.

4 Developments in Canadian and US flood insurance should be recognized.

The Study Board agreed with the proposed framework to examine these four areas in more detail. Experts in floodplain management were subsequently contracted to explore best management practices and provide recommendations for each of these specific areas. The result was four White Papers, each of which focused on one of these topics. Better communication of flood risk helps assure that decisions about floodplain use are based on facts. The first and second white papers are closely connected because flood maps help communicate an accurate assessment of risks. Throughout the study area, floodplain management has already reduced the vulnerability to flooding since 1976. Quebec is in the process of revisiting its floodplain management techniques in its Normative Framework, and the United States will be instituting a new approach called *Risk Rating 2.0*. The third white paper explores these developments, including new ideas that may or may not be part of any new policies. The fourth paper explores the potential of universal flood insurance to both reduce personal financial hazard and drive improvements in floodplain management. The fourth paper is closely connected to the third, in that it discusses a specific and novel floodplain management measure.

The unifying focus in developing these four White Papers is improving floodplain management. The goal is to ensure the wise use of floodplains. The principal characteristic of *wise use* is that it is sustainable; i.e., property owners understand flood risks but feel that benefits justify or outweigh these risks without the need for an external subsidy. Each of the white papers in this series focused on compiling best management practices based on interviews with experts and a literature review. The goal was to identify those practices that may apply to the basin, while also considering existing jurisdictional efforts. This report is White Paper # 3: How can Floodplain Planning Improve Flood Resilience.

1.1 POLICY CONTEXT

The Lake Champlain-Richelieu River Basin is a socially, politically, and geographically diverse region. This diversity presents unique challenges for flood risk communication. Governance of the basin involves two national governments (Canada and the United States), three regional governments (Quebec, New York, and Vermont) and dozens of local governments. Variations in topography, flood experience, and exposure to flood hazards make understanding flooding especially difficult for basin residents.

The severity of the flood threat also varies considerably across the region. The floods in the spring of 2011, the worst in recorded history, affected residents in Quebec more severely than Basin residents in New York and Vermont. Quebec sustained almost 80 percent of total damages from the flood, and twice as many primary residences were flooded in the province as on the US side of the border.

Quebec

In Canada, the federal, provincial, and municipal governments are involved to some extent in managing flood risks. The government of Canada plays a role by providing forecasts of weather conditions that could lead to flooding, monitoring flood hazards through the Government Operations Centre, funding small flood mitigation projects, and contributing post-flood disaster assistance.

The Quebec government has a more direct role in flood risk management. The ministère de la Sécurité publique (Ministry of Public Security) sets regulatory standards for development, funds structural mitigation projects, and administers disaster relief. The province recently created a network of experts to improve flood protection and has made changes to land use policies in floodplains. Provincial flood maps, which were notoriously outdated, inaccessible, and esoteric, are being updated (Valois, Tessier et al. 2020). The major floods of 2017 prompted adoption of a Civil Protection Flood Action Plan, consisting of 24 measures to strengthen flood risk management, such as intermunicipal aid, financial support to improve municipal flood preparedness, and better flood risk communication. The Quebec government has also bought properties that were severely damaged by floods.

Municipal governments serve several key flood risk management functions, including enforcing zoning by-laws to control or prevent development in flood-prone areas, issuing flood warnings when an event seems imminent, and subsidizing property-level flood protection measures (MELCC, 2021c).

New York and Vermont

In the United States, flood risk management is executed primarily through local government regulatory and spending decisions, which are influenced by incentives and deterrents embedded in the federal system. The Federal Emergency Management Agency (FEMA) provides grants that aim to encourage pre-flood planning to reduce hazard exposure and vulnerability, and that support post-flood recovery and resilience-building. Annual appropriations are limited and there is intense competition among states and localities to access these funds. FEMA recovery grants are initiated after a flood emergency is formalized through a presidential disaster declaration.

Most post-flood funding is (a) intended for immediate emergency relief, (b) directed to rebuilding public infrastructure (not supporting individuals), and (c) designed to reduce flood hazard exposure and vulnerability in anticipation of future events (Kousky and Shabman, 2015). In sum, post-flood aid to individuals is limited, its distribution is delayed by congressional appropriation and grant approval processes, and it is tied to the random nature of storms large enough to warrant a presidential disaster declaration. Federal assistance often requires monetary or in-kind cost sharing from the recipient and/or undertaking some flood risk management actions as a condition of its receipt.

Flood insurance is much more developed in the United States. than in Canada (see White Paper #4). The main source of coverage is the National Flood Insurance Program (NFIP), which targets properties in Special Flood Hazard Areas that are bounded by the elevation of the 1 percent (or 100-year) flood. To enroll, a community must first adopt an NFIP-specified land-use plan designed to limit flood risk.

Within the LCRR basin, there are notable differences in the administration flood risk management between New York and Vermont. In New York, state emergency management is organized at the regional level, so hazard mitigation plans are developed at this scale. These plans do not differentiate between lake and tributary flooding. New York also has a strong county administrative system. When floods occur, communities and municipalities work together on mitigation. Vermont, by contrast, has strong state support for hazard mitigation planning, but weak county administration. There is a great deal of diversity in how counties across the state integrate flooding into their hazard mitigation planning. In both New York and Vermont, there was a strong push for hazard mitigation and defence planning following the 2011 floods, but the priority may have waned since there has not been any significant flooding since that event.

1.2 THE NEED FOR BETTER LAND-USE PLANNING FOR FLOODPLAINS IN THE LCRR BASIN AND ELSEWHERE

In Canada and the United States, flooding is the most common and costly natural hazard. Every year, it causes billions of dollars in direct damage to property and infrastructure and affects the lives of thousands of citizens. The decade of the 2010s was also marked by a succession of flood disasters in several Quebec communities (Le Journal de Montréal, 2019; Ministère de la sécurité publique, 2017; Organisation de la sécurité civile du Québec, 2013) and resulted in material, social, health, psychological and economic consequences (Burton et al., 2016; Bustinza & Gosselin 2014; Larrivée et al., 2015; Maltais et al., 2000; Ministère de la Sécurité publique, 2017; Ouranos 2015a).

The Lake Champlain-Richelieu River (LCRR) watershed straddles the Canada-United States border and includes the states of New York and Vermont and the province of Quebec. With a large surface area of about 24,000 km^2, this basin has a diverse topography ranging from the Green Mountains and Adirondacks to the St. Lawrence Lowlands, and large quantities of water flow through Lake Champlain. However, its size has a buffer effect on outflows and flooding in the Richelieu River.

Despite significant anthropisation of the territory over the years, including the creation and expansion of the Chambly Canal, which changed water levels and natural runoff, the hydrological regime in the LCRR basin is not controlled by man-made structures and remains essentially natural (Boudreau et al., 2019).

Nevertheless, in the spring of 2011, unprecedented flooding in the LCRR basin affected more than 3,800 properties in Quebec, New York and Vermont and caused total estimated damage of approximately US$82 million (FMMM/HHM, 2019; Saad et al., 2016). Quebec suffered nearly 80 percent of the total flood damage, and twice as many main residences were flooded in the province than on the US side of the border (Henstra & Shabman, 2020).

This flood revealed the fragility of a territory that had previously been spared from large-scale flooding. While this flood was exceptional in terms of its duration and intensity, only six years later, in 2017 and again in 2019, spring flooding nevertheless affected thousands of homes in other Quebec watersheds, resulting in numerous damages and affecting the lives of tens of thousands of people (Ministère de la sécurité publique, 2017).

These disasters resulted in a significant governmental response, as well as media and scientific attention (Milot et al., 2013), as is often the case in the aftermath of severe disasters (Crozier et al., 2017). Development in floodplains, flood-proofing structures, construction and maintenance of dikes and dams, and conservation of wetlands are all topics that are now at the heart of social and political debates in Quebec.

Although explored for decades, it was during this period that land use planning was brought back into the collective consciousness, both as a source of the problem and as a vehicle for solutions (Milot et al., 2013; Poitras, 2019). This dimension of flood risk management plays an integrative role by being affected by both risk perception and insurance plans, and by giving practical and regulatory meaning to mapping tools. The ultimate goal of floodplain development planning is to reduce vulnerability and exposure to the hazard of flooding.

In the same way as for adapting to the various climatic hazards, the floodplain development planning is based on an iterative process, where risk analysis and a good understanding of the context are essential decision-making prerequisites. This is the first of the four priorities of the Sendai Framework for Disaster Risk Reduction (DRR) 2015-2030: (1) Understanding disaster risk; (2) Strengthening governance; (3) Investing in disaster risk reduction for greater resilience; (4) Improving disaster preparedness for better reconstruction. These priorities are discussed in a paper describing the framework adopted by the Third United Nations World Conference on Disaster Risk Reduction (UNISDR, 2015).

Furthermore, in the context of climate change, land-use planning choices and implementation should be monitored to the extent possible and based on principles of adaptive management and continuous learning (Ouranos, 2015b).

The efforts of the International Lake Champlain-Richelieu River Study Board to develop flood adaptation solutions are based on four themes: reducing high water levels during extreme flooding; reducing water supplies; improving flood response (flood forecasting and emergency preparedness) and improving floodplain management.

This white paper examines the latter theme and provides an overview of the scientific and grey literature on land use planning focused on reducing vulnerability. In addition, it focuses more on the specific context of Quebec, which was disproportionately affected by the 2011 floods in the LCRR basin, and which is currently revising its regulations on floodplains. It also offers inspiring local and international examples.

2 UNDERSTAND THE CONTEXT

The development of a planning strategy involves asking a number of questions as a society, including the level of risk we are willing to tolerate, which areas need to be redeveloped or protected first, and what criteria should be used to select them (Thomas et al., 2021).

Accordingly, the management of floodplain occupation should first be based on a good understanding of the flood risk. Informed prevention decisions can be made by understanding the impacts of flooding. This involves assessing the ability of communities and infrastructure to bear the consequences of these hydrological events, as well as understanding the dynamics and expected trends in the context of climate change.

There are many definitions of risk in the literature, but they have one thing in common: risk is generally a function of the hazard (flooding) and the vulnerabilities of the environment (people, goods, services, economic activities, critical infrastructure, etc.) that are randomly affected (European Environment Agency 2016; IPCC, 2014; Morin 2008).

These elements are often assessed through hydrological studies and vulnerability diagnostics and are typically mapped. These analyses and maps are tools that, on the one hand, can inform land use decision-making, while on the other hand, being associated with a regulatory framework that controls certain activities within risk zones. Flood risk factors and the Study Board projects are explored and discussed in the first white paper in this series on the theme of mapping as a key step in flood risk management (Alberti-Dufort, 2021).

In its 2017-2021 Study Plan, the LCRR International Basin Study Board looked at ways to mitigate flood impacts. The plan is divided into four themes, the last of which is floodplain management. The Study Board's work on this topic focused on knowledge of the hydrological context and vulnerability.

Since the hazards and vulnerabilities affecting a territory and a society are not stable over time, consideration of flood risk in land use planning guidance should be accompanied by adaptive management mechanisms through use of conventional development tools (planning, zoning by-laws, etc.) to allow for the adjustment of adaptation measures according to new knowledge (climate and socio-economic).

Finally, it is important to emphasize that risk analysis always involves a degree of uncertainty that must be addressed when making decisions. The objective for professionals and decision makers is to limit irreversible choices and to implement planning solutions that adapt well to uncertainties.

2.1 HAZARDS

Knowledge of hazards is a fundamental step in risk assessment. According to the ministère de l'Environnement et de la lutte aux changements climatiques (Ministry of the Environment and the Fight Against Climate Change), a flood is an "overflow of water that submerges land that is normally dry most of the year" (MELCC, 2021a). These overflows, however, can have different origins and occur in different shapes and speeds (e.g., presence of ice, presence of waves, increased speed of water flow, very slow ebb, etc.); it is important to consider this when making planning decisions.

Five types of flooding are typically identified, including ice jam flooding, coastal submersion flooding, backflow flooding, rising groundwater, and open water flooding (MELCC, 2021b; Moudrak & Feltmate, 2019a). The latter occurs when there is

a significant increase in the amount of water in a river or lake that leads to its overflow. In the spring, it is usually characterized by slow recession if the snow cover is large enough to last several months. This type of flooding occurred in 2011 in the LCRR basin (ILCRRSB, 2019).

In addition, Lake Champlain is large, and the wind and waves can exacerbate flooding as they do in the Great Lakes region. The combination of a flood with a southerly wind causes water levels at the lake outlet to rise significantly and also affects the duration of flooding—six weeks in the case of the 2011 event in the LCRR basin. A long submersion period may cause additional damage to homes and infrastructure, as well as severely testing flood-proofing tools such as sandbags and pumps. In addition, a great deal of debris is carried by waves, which increases the hazard level.

When assessing the hazard of open water flooding, one of the questions is where the flood will go and where it will be most dangerous. Several characteristics are considered, such as the extent of the floodplain under different flood intensities and their probability of occurrence, or the water depth and current velocity (RNCan, 2018). Using hydrological, hydraulic and hydrogeomorphological models, these elements can be represented through flood mapping. Some of these maps are used for regulatory planning purposes.

Open water flooding is usually defined by a recurrence interval or annual exceedance probability (AEP) defined as a percentage. For example, a flood with an AEP of 0.01 (1 percent) and a flood with a 100-year recurrence interval are equivalent. The flow rate reached during this flood was statistically exceeded once every 100 years and has a 1 percent chance of occurring every year.

These AEPs are generally used to define flood risk areas in local regulations throughout Quebec, Vermont and New York. They give an idea of where flooding is more likely or less likely to occur. High-probability areas are more likely to be flooded and planning decisions in those areas must take this recurrence into account.

However, the probability of occurrence alone is not sufficient to represent the risk associated with the flood hazard. The depth of submersion and the speed of the current are also unavoidable variables, since they can greatly vary the consequences of a flood, making it possible to establish consistent planning standards (CMM, 2020).

Finally, flooding cannot be limited to the strict definition of overflow, as it is accompanied by geomorphological processes that are an integral part of river dynamics and it is important to identify them. The inherent stability of the channel, its sensitivity to the risks of erosion and avulsion, the presence of natural or anthropogenic containment elements and several other characteristics will affect the mobility of a watercourse and may have significant consequences for people, goods and riparian activities (Desjarlais et al., 2013; Kline & Cahoon, 2010; Lelièvre et al. 2008).

Quebec's current normative framework as well as risk and vulnerability studies are based mainly on an "open water" type of flood with a 0-20- and 20-100-year delineation. They do not consider other types of flooding or specific risk factors such as susceptibility to erosion and the influence of wind and waves and climate change on the magnitude and duration of the hazard.

2.2 VULNERABILITY

While knowledge of hazards is crucial, it is also important to focus on elements exposed to floods, such as citizens, housing stock, economic activities, agriculture, critical infrastructure, natural heritage, etc., to predict the potential impacts.

Some of these elements have heritage value or strategic importance, such as a hospital, for example. Considering that their vulnerability varies according to their susceptibility to hazards and ability to adapt (IPCC, 2014), the elements presented may also cover intangible aspects such as public health or the social cohesion of a community (Morin, 2008), thereby impacting the adaptive capacity of exposed areas.

The elements of vulnerability may vary in nature and precision. Social vulnerability is often distinguished from territorial vulnerability. The former refers to the composition of the population facing disaster, the socio-economic factors and characteristics of individuals, households, and families. The latter refers to the physical reality of a community: the infrastructure, i.e., the buildings, structures, equipment, or networks necessary for the normal operation of a community. In some cases, the height of the first floor of each building will even be assessed, which has been done for some areas of the LCRR basin and included into the *Integrated Social Economical Environmental* (ISEE) analysis tool, which is currently being developed by the working group on social, political, and economic analysis (SPE) of the LCRR study.

The consideration of vulnerability in planning decisions regarding floodplains is relatively recent. It makes it possible to prioritize the implementation of adaptation solutions in the territory according to the most vulnerable sectors. It can help justify more complex and costly planning decisions that involve many social issues, such as demolition and relocation of residential buildings or construction of protective structures. Finally, based on the vulnerability indices analyzed, it can also support local regulation and overall planning at the municipal level, for example, through RCM development plans.

Some vulnerabilities and specificities of the territory are generally known by stakeholders at the local and regional levels (Thomas & Gagnon, 2019). It is therefore important to use this knowledge and share it with that of other experts and citizens to consolidate our understanding of vulnerability in a comprehensive diagnosis (Cloutier & Demers, 2017; Massé et al., 2018; Thomas, 2017). These analyses not only help to make better planning decisions possible, but also to know the audience when communicating the risk of flooding. More information on methods and vulnerability maps in the LCRR basin is available in the white paper on mapping (Alberti-Dufort, 2021).

2.3 RISK AND ITS EVOLUTION

Neither randomness nor vulnerability alone can define risk. For example, a potential flood in an uninhabited area where there is no economic activity does not pose a significant risk, as few vulnerable elements are exposed. However, this same flood could pose a significant risk if it is likely to occur in an urban setting with a high population density and flood-sensitive buildings and infrastructure.

Risk assessment involves cross-referencing the hazard and its probability of occurrence with vulnerability indices to extract risk levels in the area. It makes it possible to synthesize and popularize relatively complex information, but above all, it predicts the consequences of floods much better than a strict reliance on the hazard.

During the 2011 flood, many properties outside the 0–100-year regulatory area were flooded or rendered inaccessible for many weeks. Some of these lands had been backfilled, which put them at risk during a major flood, because they were completely cut off from the world by an "island effect." Because they were not located in the official flood zone, they were not required to implement flood-proofing measures; this caused them harm. Hence it is important to update knowledge with an overall view of risk (Thomas & Gagnon, 2020).

The United Kingdom and France use risk management approaches, including classification of risk zones and compatible uses by zone (Therrien et al., 2021; UK Department for Communities and Local Government, 2012). In Quebec, in collaboration with provincial government departments, the Communauté Métropolitaine de Montréal (Montreal Metropolitan Community) is currently undertaking an approach inspired by this and other approaches (Thomas & Gagnon, 2020).

On the other hand, over time, science will evolve, as will climate, demographics, and land use planning. It may be that in 30 years, our vulnerability will be different and the estimated flood zones will have changed. More detailed information on climate change is presented in the first white paper of this series, on the topic of flood mapping (Alberti-Dufort, 2021). The LCRR study is using a process called "decision scaling" to integrate joint considerations on how to manage flood risks and assess the range and uncertainty of future flood magnitudes.

A number of land-use planning decisions have implications for dozens or hundreds of years. With a view to sustainable development, it will therefore be appropriate to consider this evolution of floodplains by providing for mechanisms to review mapping and vulnerability diagnostics and to avoid maladaptation by adopting the precautionary principle, as discussed in Part 5 of this paper

3 LAND-USE PLANNING FOR FLOODPLAINS

Based on the risk assessment, we then need to think about adaptation solutions that are sustainable and aim to reduce our exposure and vulnerability to flooding. Ideally, this will be achieved by reducing the number of people, built-up elements and services located in floodplains. However, for a number of reasons, such as the desire to densify metropolitan areas or to preserve urban cores and built heritage in floodplains, it will remain impossible to relocate everything and completely eliminate the risk, especially as it continues to evolve. It will also be necessary to think about land use planning and a built environment that can co-exist well with water (Corriveau et al., 2019).

The response, from a local perspective, may involve different adaptation solutions and land use planning strategies. Based on the management of coastal issues, several researchers and practitioners in Canada and elsewhere have organized these strategies into four broad categories that include natural, structural and regulatory solutions: (1) avoidance; (2) relocation; (3) accommodation; and (4) protection (Doberstein et al., 2018; Gouvernement du Québec, 2020; Harford, 2016; K 2015; ministère des Affaires municipales et Habitation, n.d.; Neale et al., 2013).

This classification is not new, it was already suggested in the early 1990s by the Coastal Zone Management subgroup of the IPCC's first climate change assessment report (Natural Resources Canada, 1990). Although typically used in the context of coastal and sea-level rise, it can also be used when choosing planning options to reduce the risk of open water riparian flooding (Doberstein et al., 2018; Henstra & Thistlethwaite, 2017). Approaches are generally applied in conjunction with one another.

3.1 PLANNING STRATEGIES

Avoidance

The avoidance approach refers to the proactive prevention of construction in floodplains. It primarily targets areas in floodplains that are not yet occupied. This may involve identification of future "no build" areas (Doberstein et al., 2018; Henstra & Thistlethwaite, 2017; Neale et al., 2013).

In Quebec, certain planning tools enable municipalities to take into account the physical characteristics and natural uses of the territories and can be used in the avoidance approach. For example, a zoning by-law may prohibit uses, structures or works for reasons of public safety or environmental protection specific to the features of the area (e.g., proximity to wetlands or water, risk of flooding or landslides) (ministère des Affaires municipales et Habitation, n.d.). This tool can be supported by land use and development plans (LUDP) of Regional County Municipalities (RCMs) or agglomerations.

Quebec's current Protection Policy for Lakeshores, Riverbanks, Littoral Zones and Floodplains prevents construction in floodplains where the probability of annual exceedance is 5 percent or more and in special intervention zones (SIZs) that were flooded in 2017 and 2019.

To prevent development of potential sites, it may be useful to emphasize zones where the probability of flood occurrence is very low or zero.Avoidance can also take the form of land acquisition through a land trust (Doberstein et al., 2018; Neale et al., 2013). This is an opportunity to increase its area of conserved land and to create green spaces where more people have access to the shore, for example. For instance, in the Venise-en-Québec section of the LCRR basin, the green space on the eastern tip of the city is expected to remain undeveloped, as this is a natural water expansion field (Thomas & Gagnon, 2020).

Avoidance is a measure that should be considered early in the planning process. Further development in flood zones should be avoided immediately to prevent new risks, as the next steps are more onerous and costly (Middle, 2018; Neale et al., 2013). However, this measure will generally be applied in conjunction with others in an already-built context, particularly following relocation or a change in land use.

GREAT WESTERN PARK

In 2019, the City of Montreal announced creation of a nature park with an area of over 30 km^2. Connecting existing parks in the west end, the city acquired 175 hectares of land, including rare wetlands and water bodies in the heart of the Grand parc de l'Ouest (Great Western Park), for use as a protected area. The main objective of this project is protection of terrestrial and aquatic natural environments, but it is generally consistent with the city's climate change adaptation objectives (Ville de Montréal, 2020). Many sections of this park are part of the area that was flooded in 2017 and 2019 and mapped as part of the Quebec government's special intervention zone. Although the implementation strategy has not yet been launched, we already know that a portion of the territory, including the area acquired by the city, will not be subject to new development and will be protected.

Relocation

While it seems obvious to avoid development in unoccupied high-risk floodplains, the issue is less straightforward when those areas are inhabited. Relocation is sometimes necessary. It involves moving homes, communities, facilities and infrastructure permanently to safer areas (IPCC, 2014).

This planning choice is particularly sensitive in terms of social acceptability and may raise issues such as vested rights, municipal taxation, development, equity, and urban sprawl; this sensitivity is why the targeted areas have generally suffered severe damage and present a high risk. To overcome these challenges, it is important to have a solid plan that actively involves the concerned citizens and demonstrates the benefits in various ways (public good, avoided costs, etc.).

Given these many challenges, relocation after a flood is usually the exception, not the rule. A recent article in the NewYork Times suggests there is strong resistance to relocation in the United States. The author explains that this solution is perceived as "simply too extreme to be considered—an attack on Americans' love of private property," and that the Federal Emergency Management Agency (FEMA) is now trying to invest in relocation to change attitudes and reduce vulnerability of floodplain residents.

Where possible, it is good practice to plan relocation well in advance with a long-term view by moving buildings gradually, sector by sector, and to provide a suitable relocation site that meets the needs of the displaced as much as possible (Neale et al., 2013). In addition, aid and transfer resources can be provided to displaced citizens or businesses/organizations to anticipate the challenges of such an operation.

Depending on the environment, the relocation strategy can lead to a loss of vitality in a community, particularly when complete de-urbanization is not occurring, and some buildings will remain in the floodplain (Morisseau, 2012). This is why it is important to fight against a potential sense of abandonment, reinvent a way of living in an area and avoid the erosion of social cohesion and neighbourhood life (Thomas et al., 2021).

With a view to reducing damage and in response to floods that took place over the past decade, the Quebec government had to intervene and offer financial assistance to move homes that had suffered serious damage and were in high-risk areas. In addition, the new Flood Protection Plan provides funding to support relocation of structures built in areas deemed to be at high risk.

However, it is important that relocation be considered on a house-by-house basis, as well as with an overview of an area (Thomas et al., 2021). It should be remembered that even when a small number of residents choose to remain in the floodplain, municipalities must continue to provide essential services such as drinking water, electricity, roads, etc.

It goes without saying that the idea is not to rebuild a relocated area, but rather to think about less sensitive uses that could contribute to its vitality, such as a recreational tourism area, ephemeral facilities, an urban agricultural park, etc. However, these new vocations should be considered over the long term and chosen according to their relevance to the sector or region and according to flood-resilient uses (Morisseau, 2012). As well, regulatory tools are useful to prevent inappropriate new developments.

It should be noted that relocating agricultural land is much more complex than relocating buildings. With high arable land requirements, there are generally few relocation sites that meet the specific needs of farmers and their relocation. Moreover, many impediments, such as zoning, soil quality, and land-clearing regulations can complicate agricultural relocation (Ursule Boyer-Villemaire, personal communication, May 4, 2021).

In the LCRR watershed, mass relocation is not a popular strategy among local actors; however, some citizens suffer repeated damages or are isolated for long periods of time, resulting in major stress, particularly among vulnerable people such as the elderly, those who live alone or have a special physical condition. For that reason, this option should be offered as an adaptation strategy, in conjunction with a regional vision and existing planning. Municipalities will need to focus their urban development to consider relocation and avoid risk areas. Relocating to promote tributary freedom spaces could be an interesting avenue to explore (Thomas & Gagnon, 2020).

RELOCATION OF RESIDENCES TO STE-FLAVIE IN EASTERN QUEBEC

In the eastern Quebec municipality of Sainte-Flavie, removal of some 50 residences that were too close to a heavily deteriorated shoreline was chosen as the best option for adapting to the problems of coastal erosion and flooding. To anticipate the challenges of such an operation, a coastal resilience project manager was hired to help residents with the process. According to the Mayor of Sainte-Flavie, "When you lose citizens and families, you lose vitality in its pure state" (Gendron, 2018). That is why a new street in the heart of the village has been dedicated to them, where homes can be moved if their owners so desire (Bourdillon, 2018; Paquette-Comeau, 2018). Furthermore, the Mitis RCM, where Ste-Flavie is located, adopted new regulations in 2018 to limit new construction in the risk area (Ville de Métis-sur-Mer, 2018).

Accommodation

While some areas present too great a risk for buildings and residences to remain, many already highly developed urban areas are in medium- and low-risk areas and represent important social, economic and heritage values for communities (Thomas et al., 2021). Accommodation therefore refers to adaptation strategies designed to continue using floodplains, but reduce the vulnerability or exposure of users either by flood-proofing structures or selecting uses that are less sensitive to floods (Neale et al., 2013).

This planning approach is part of the recognition of the interdependence of humans and nature (including water) over a given territory. This is where innovation at both the architectural and landscape levels must be allowed to take place, so that the development of projects that promote cohabitation with the river is prioritized and any attempt to control or contain the waterway is avoided (Biron & Thomas, 2019; CCM, 2018; Crozier, 2018; Grenoble-Alpes Métropole, 2017).

The purpose of flood-proofing the built environment is to provide the necessary protection to avoid damage that could be caused by water. Over the past decade, many experts in urban planning, geography and water management have combined their strengths to improve knowledge around flood risk management (Lewis, 2019). However, "the voice of architects has so far had few forums, and has been limited to discussions about houses on stilts at the expense of a more serious exploration of residential typologies, construction practises and adaptations of building codes" (Lizarralde, 2021).

Moreover, these solutions present specific challenges. For example, pile construction raises the issue of accessibility and the relationship to the ground; it does not always take into account the degradation of empty spaces over time. Elevating crawl spaces, while reducing household property damage, raises health issues (waste accumulation, mould formation) that need to be considered.

To compensate for this lack of knowledge, it would be possible to draw inspiration from France, which has chosen to organize a planning competition adapted to buildable flood-prone land. The objective of this architectural competition is to promote innovative projects and solutions for better building in floodplains and to encourage development by reducing the vulnerability of people and property during floods. The competitions dealt with land where the hazard was neither strong nor serious for human life. Their primary focus was on existing neighbourhoods and those undergoing urban renewal (CEREMA, 2017; MTES & MCT, 2016).

The Protection Policy for Lakeshores, Riverbanks, Littoral Zones and Floodplains offers several flood-proofing measures for the built environment, such as placing openings (windows, light wells, access doors, garages, etc.) and ground floors above the 100-year flood level. Structures below the 100-year flood level should be designed to withstand the flood through waterproofing, stability, reinforcement, pumping capacity to discharge seepage and the resistance of concrete to compression and tension. Backfill and grading measures are also proposed (MELCC, 2015).

Despite these recommendations, this aspect of accommodation remains a "blind spot" in the Quebec flood response (Feltmate & Moudrak, 2021; Lizarralde, 2021). That is why Architecture Without Borders Quebec, in collaboration with the University of Montreal's planning department, has begun a research project on flood-resilient architecture. This project, the first of its kind in Quebec, will generate new knowledge about adapting the built environment to flooding and disseminate it to building owners, designers, builders, decision makers and managers (Architecture Without Borders Quebec, 2021). It has produced an initial state of knowledge on adaptation of buildings to flooding to support considerations for an update of adaptation measures for the flood-prone built environment in Quebec (Levasseur, 2021).

An innovative idea that will be of interest is amphibious construction. This architectural solution allows a basic structure to float on the surface of rising water, rather than succumb to flooding. Erected on floating pedestals, buildings rest on the ground during normal times. "In case of flooding, they rise or fall as the water level changes along guiding columns, preventing the building from drifting" (Crozier, 2018). Adapting this option to the Canadian climate is currently being studied at the University of Waterloo (Levasseur, 2021).

Amphibious construction also refers to hybrid situations; for example, there are buildings where the weight of the structure rests partly on the ground and in water simultaneously. This term also covers a mechanical system or hydraulic pumps that raise the structure temporarily, in line with the water level (English et al., 2016; ICAADE, 2019).

Furthermore, as is often the case even outside Quebec, measures proposed by the Protection Policy for Lakeshores, Riverbanks, Littoral Zones and Floodplains are very focused on the reference hazard and on the building or its immediate environment. However, beyond flood-proofing the structure, it is important to think about the networks on which it is built (road, water, sewer, etc.) so that it is resilient overall. Comprehensive planning and landscaping at the level of a neighbourhood or road network should be applied in conjunction with flood-proofing solutions. Internationally, examples of neighbourhoods and innovative built forms demonstrate the possibility of living safely with water. In Quebec, blanket regulations have failed to establish many precedents and deal with flooding situations specific to certain municipalities (Thomas & Gagnon, 2020). To further expand on the accommodation approach, a genuine "water architecture" (Crozier, 2018) is currently emerging.

In the LCRR basin, there is a need for innovative projects, supported by comprehensive studies, to enable safe coexistence with water (Thomas & Gagnon, 2020). This is an opportunity to use the numerous hydrological, hydraulic and vulnerability studies that have been done in the basin as well as the ISEE analysis tool. For example, in Sainte-Anne-de-Sabrevois, due to accessibility issues during a flood, it will be important to plan for flood-proofing the local road network to create safe, 24/7 access to residential areas (Thomas & Gagnon, 2020).

To be operational, municipal, and regional planning tools must reflect a change in practices (for example, housing policies, development plans, land-use plans, strategies) or lead to the definition of new regulatory frameworks. Oversight and rigorous evaluation of projects so they do not increase vulnerability locally or elsewhere in the territory are key components of the accommodation strategy (CMM, 2018).

THE PORTES DU VERCORS PROJECT: BUILDING BETTER IN A CONSTRUCTIBLE FLOOD ZONE

Les Portes du Vercors is a 100-ha urban renewal project in the heart of Grenoble, a French city with a population of 400,000. Located at the heart of a valley, the city has historically experienced major flooding due to significant increases in the water levels of the major rivers that flow through it. The Vercors gateway sector has significant potential for activity and housing and is considered strategic in Grenoble's territorial consistency plan.

This urban project was designed to deal with the presence of water in the territory, relying on the proximity of waterways to develop a strong project identity: "living close to the water/putting water back into the city/creating awareness of hazards related to the neighbourhood's changing landscape in response to rainfall events" (Grenoble-Alpes Métropole, 2017).

In terms of accommodation in the design of private spaces, Portes du Vercors stands out for its overall vision for the area and its redefinition of construction standards in floodplains based on mapping that takes into account the dynamic nature of the environment and its hydrological component.

Landscape architecture has been designed to improve the overall permeability of surface runoff. In addition, the overall framework of this urban project—the implementation of roads, buildable rights-of-way, routes—has been organized to reduce flooded rights-of-way when water levels rise and during overflows.

Source: (Grenoble-Alpes Métropole, 2017)

Protection

Protective approaches involve building structures and engineering systems (dikes, protection walls, diversion structures, weirs, dams, etc.) designed to keep flood waters away from homes, communities and critical infrastructure (Doberstein et al., 2018). They also involve softer or more nature-based solutions such as rip rap, plant stabilization measures, etc. Structural solutions in the LCRR basin are discussed in a recent Study Board report. The Study Board identified the diversion of water through the Chambly Canal as the most promising structural solution (FMMM/HHM, 2021).

It should be noted that some authors question the durability of certain structures such as dikes, as they would not be economically (cost of design and maintenance over time) or ecologically beneficial and create a false sense of security. In addition, this type of action may exacerbate downstream flooding (Biron et al., 2014; Kline & Cahoon, 2010; Roni & Beechie, 2013; Simard et al., 2019).

The idea is not to ignore this strategy, but rather to use it as a last resort. Moreover, it should be applied with great caution and supported by risk analysis and economic studies. For existing dikes, for example, it is important to assess the levels of protection and safety against the design flood, the potential consequences of failure, and possible improvement measures.

In Quebec, design standards for protection structures other than dams are not codified. There is a lack of information about the number of these structures, what they protect, their maintenance, their system implementation, etc. It is necessary to map the protection works in a systemic and global way, notably through the vision of the "diking system" and the "protected areas" (Alberti-Dufort 2021; Thomas & Gagnon 2020).

In the LCRR basin, several municipalities along the Richelieu River artificialized banks by using fill, low walls, farmland protection dikes and other extensions in the river. These measures cause erosion and affect water flow downstream. As well, there is a lack of regularization and monitoring of the effectiveness of these structures. For example, "the city of Venise-en-Québec, having raised the level of an emergency road, considers it 'new protection,' but it is difficult to say if there will be a concrete follow-up and whether the impact on the perception of risk is significant. The Haut-Richelieu RCM is also trying, through its Bylaw 557, to remove from flood zones lands located behind agricultural dikes (that are currently non-compliant)" (Thomas & Gagnon, 2020).

Cost-benefit analyses could help assess the relevance of this strategy in the basin. In all cases, education is needed on the roles and limitations of structural protection to avoid false feelings of safety, and a maintenance plan must accompany establishment of this type of infrastructure.

HAZARD STUDIES OF LOIRE RIVER DIKES AND TRIBUTARIES

France has developed regulations governing the supervision, maintenance, and authorized uses behind dikes. These regulations require hazard studies that enhance knowledge of containment systems.

In 2012, the French government carried out the first hazard studies of Loire River dikes, a river whose dikes are important in terms of height, length, and protected population. There are about 50 diking systems on the banks of the royal river, many of which have been built since the Middle Ages. Three containment systems (the levée d'Orléans, levées de Tours and the grande levée de l'Authion) were studied. They represent over 170 kilometres of dikes and protect some 230,000 inhabitants (Maurin et al., 2013).

Using a probabilistic approach, these studies assessed the hazard of dike failure based on geometric, geotechnical, and historical parameters, and the presence of vulnerable areas. They also described hazards associated with the breakage of dikes (water velocity in the valley, energy dissipation zone) and proposed improvement measures. As a result, they provide an objective view of the risks faced by the affected populations behind those dikes (DREAL, 2013; Maurin et al., 2013).

3.2 MAKING CHOICES THAT ENSURE RESILIENCE

Focus on Complementarity According to Specific Context

In practice, there are many overlaps and linkages between these four strategies. A resilient development will not be based on any one of these categories, but rather on a set of measures whose complementarity will depend on the specific context of a sector (Neale et al., 2013). Each approach will have strengths and weaknesses that will be more or less accentuated depending on the community. Planning choices should be based on several factors, such as risk level, risk tolerance or cost, sustainability, other development constraints (e.g., urban sprawl, historical heritage) and benefits associated with a particular solution.

Complementarity is also evident in the construction of development scenarios. On the one hand, the most ambitious control of the hazard is often costly to achieve, while the full withdrawal of assets from the risk area involves major disruptions. The risk-based approach identifies significant and highly exposed assets, those that generate the greatest amount of damage to avoid. The most beneficial scenarios collectively will act on these various sources of direct and indirect damage. They will reflect a certain tolerance for risk (removing the riskiest assets or activities but keeping the ones that are tolerable) and modestly control hazards where possible.

Within the LCRR basin, each municipality has its own context, development opportunities, priority areas for consolidation and other areas for transformation. For example, municipalities could seek to resiliently densify vacant land in Saint-Jean-sur-Richelieu that is not in a floodplain, adapt campsites in Venise-en-Québec, relocate residents of Noyan to a redeveloped area, etc. (Thomas & Gagnon, 2020). A normative framework that imposes a wall-to-wall solution does not leave much flexibility.

Use Decision Support Tools

While development solutions should be tailored to the specific context of a sector, where possible, choices should be supported by detailed analyses of their costs and benefits, taking into account not only economic parameters, but also societal and ecological value. One way of looking at these is to rely on feedback. Based on rigorous data collection methodologies, this allows lessons to be learned from emergency management and recovery, as well as from the predispositions of a territory that led to the consequences of a flood.

For example, a review of the 2017 spring flood in the City of Gatineau found that 75 percent of residences in the 0-20 year flood zone were flooded to the ground level, and that many citizens had no flood prevention measures before 2017 (Thomas, 2020). This type of information can help develop planning strategies and complementary awareness campaigns.

Furthermore, there are a number of prioritization/comparison tools (also known as decision tools) for choosing the development strategies to implement. Four of these are summarized in Table 1. The most widely used are based on economic valuation techniques, as well as on multi-criteria analyses that integrate several non-monetary indicators (Webster et al., 2008).

Table 1. Prioritization tools for choosing development strategies.

Evaluation method	Multi-criteria analysis	Scenario analysis	Cost-benefit analysis	Cost-effectiveness analysis
Key concepts	Multiple criteria Weighting Rating	Different plausible futures	Monetary costs and benefits.	Cost effectiveness. Economic efficiency.
Key assumptions	The decision is based on several criteria: socio-political, environmental, and economic, and cost is one of the criteria.	This method is based on the definition of "critical thresholds" whose exceedance triggers a series of graduated responses based on the criticality of the hazards involved.	The benefits (costs avoided) must exceed current costs for the response to be viable. Costs and benefits must be quantifiable in monetary terms.	Benefit per unit of cost is a key criterion. The lowest cost option for the objective is the chosen option.
Objectives	To select an option using multiple criteria.	To evolve responses to what is actually happening.	To assess whether an action is cost-effective.	To choose the most cost-effective option from among several for a given objective

Sources: (CCME 2015; Webster et al., 2008)

It is important to keep in mind that these tools are imperfect, complex, and sometimes time-consuming to use, since they usually require the work of several experts and specialists from various disciplines (climate science, hydrology, economics, engineering, etc.). As well, in the case of economic analyses, it is difficult to assess intergenerational equity and internalize long-term future costs and benefits.

Despite these challenges, these analyses allow for consideration of a range of contextual dimensions and provide informed criteria for prioritizing or selecting flood adaptation solutions. The French government has also chosen to promote evaluation methods in the various stages of flood prevention project development. Therefore, to receive public funding, any flood prevention project with structural measures in excess of 2 million euros must undergo a cost-benefit analysis, and where the amount is greater than 5 million euros, multi-criteria analysis is mandatory. State-developed methodologies must be used to conduct the analyses (Commissariat général au développement durable, 2019; Ministère de la transition écologique, 2021).

Cost-benefit analysis (CBA) is a method of comparing the sum of the net benefits of each adaptation option with the non-intervention and classifying them according to their economic performance (Circé, Da Silva, Boyer-Villemaire, et al., 2016). The non-intervention scenario quantifies the cost of impacts that a flood would cause, such as damage to buildings, loss of economic activities, loss of ecosystem services, etc. These all weigh on the economic viability of an adaptation solution (Da Silva et al., 2019). As such, CBAs are decision-support tools to support decision makers in their choice of adaptation actions (Circé, Da Silva, Boyer-Villemaire, et al, 2016).

The results of five case studies conducted in the coastal regions of the Bas-Saint-Laurent, Gaspé and Îles-de-la-Madeleine regions show that it is often more cost-effective to take action than to do nothing in almost all areas studied (Circé, Da Silva, Boyer-Villemaire, et al., 2016; Circé, Da Silva, Duff, Boyer-Villemaire, Corbeil et al., 2016; Circé, Da Silva, Duff, Boyer-Villemaire, Desjarlais et al., 2016; Circé, et al., 2015; Circé, Da Silva, Mercier, Boyer-Villemaire, et al., 2016; Circé, Da Silva, Mercier, Duff, et al., 2016).

EXAMPLE OF A PLANNING DECISION BASED ON ECONOMIC ANALYSIS IN THE GASPÉ

The coastal town of Percé in the Gaspé is facing flooding and coastal erosion problems. The hazard is not the same as that of open water flooding, but the stakes are similar. Storms on December 30, 2016 and January 11, 2017 completely destroyed over 200 metres of the aging Anse du Sud boardwalk (MELCC, 2021c). The scale of the damage prompted the town of Percé to consider a more sustainable development solution to preserve the tourist infrastructure along the coast and the heart of the city.

To facilitate this decision, a cost-benefit analysis was conducted to assess the economic cost effectiveness of many development measures, compared to a no-response scenario. The analysis revealed that in the absence of a response, expected damages could lead to total discounted losses of more than $700M over 50 years. Among several development options (e.g., concrete wall construction, rip rap, relocation, etc.) infilling the beach with rip rap proved to be the most cost-effective (Da Silva et al., 2019).

In the summer of 2017, more than one kilometre of the beach was rebuilt in Percé (Ville de Percé, 2017). Without this analysis, the municipality might have chosen to replace the concrete wall, which would have been more expensive and less sustainable.

Consider the Extent of the Watershed

The above strategies focus on land use planning for areas exposed to the hazard of flooding. However, planning decisions cannot be systematically confined to the territory delineated by the flood zone to generate improved resilience in the face of this hazard.

Indeed, certain actions throughout a watershed, such as surface waterproofing, river channelization and dredging, removal of wetlands and vegetation, among others, can accelerate water drainage to major rivers and exacerbate flooding. In many cases, these developments have been present for decades and it is not always easy to restore an area to a more natural state, hence the importance of preserving natural environments and existing green spaces (Regroupement des organismes de bassins versants du Québec, 2018; Sauvons l'eau, 2015).

Furthermore, biophysical processes related to flooding extend beyond administrative boundaries and correspond instead to the unity of the watershed. To avoid worsening floods and upstream-downstream conflicts, watershed management is now recognized within the scientific community as a *sine qua non*[1] condition for any attempt to respond to flood risk (European Environment Agency, 2016; Feltmate & Moudrak, 2021; Milot et al., 2013; Sayers et al., 2014).

In the LCRR basin, existing wetlands play a key role in flood mitigation, as well as in the regulation of low-flow events. They affect daily water levels in Lake Champlain and flows in the Richelieu River. They helped to reduce water levels during the 2011 flood, which is why it is important to protect them throughout the basin (Rousseau et al., 2021).

Isolated actions taken by stakeholders impact the entire watershed, affecting water infiltration and runoff (e.g., dikes and low walls, agricultural stream linearization, etc.). Upstream-downstream solidarity is therefore important for the implementation of mitigation and adaptation measures. This can be facilitated by intermediaries.

In the Quebec part of the basin, **watershed organizations** are important intermediaries between various players on the territory. Despite the absence of legislative or enforcement powers, these non-profit organizations play a key collaborative role by providing advice to the RCM and municipalities on their land use planning and coordinating actions regarding watersheds that may impact land use planning and development (Arnaud et al., 2020; Therrien et al., 2021).

Internationally, the **Lake Champlain Basin Program** coordinates and funds projects that support water quality, fisheries, wetlands, wildlife, recreation, and cultural resources in the Lake Champlain basin, in partnership with government agencies in New York, Vermont and Quebec, private organizations and local communities.

[1] essential

4 PRINCIPLES TO FOSTER SUCCESS

Regardless of future planning choices, these will generally be accompanied by a number of issues (problems of social acceptability, loss of revenue, costs, risk of failure, risk of impacting more downstream municipalities, etc.). Some adaptation principles will help overcome those obstacles.

4.1 AVOID MALADAPTATION AND CONSIDER CO-BENEFITS

As mentioned above, flooding is a hazard that is affected by climate change. Although climate knowledge is improving year after year, it will be necessary to learn to work on the basis of uncertain trajectories that will require constant adjustment. The challenge, therefore, is to adapt by taking uncertainties into account and limiting irreversible choices (maladaptation).

Maladaptation refers to inadequate adaptation measures that can lead to an increase in the risk of adverse climate-related consequences, an increase in vulnerability, exposure or degradation of living conditions in the present or future (IPCC 2014). Maladaptation can be as much about planning choices as it is about types of regulations.

For example, to protect part of a territory from flooding, a shoreline dweller builds a stone wall in front of his property, but the strength of the waves is then transferred to neighbouring lands, increasing their vulnerability (transfer of vulnerability). Current decisions should limit future options as little as possible (COBALI, 2019).

The context in which flood risk management is done is dynamic, not static. This has important implications for the development of a strategy. Accordingly, to avoid maladaptation, emphasis should be placed on measures with positive results under uncertain conditions. Several approaches ensure maintenance of this flexibility.

"No Regret" and "Low Loss" Measures

No-regret measures are relatively low-cost solutions whose benefits can be potentially significant and assured, given the uncertainty of future climate change. Sometimes they are "low-hanging fruit," actions that are within reach and offer tangible benefits in the short or medium term. Examples include restrictions on construction in certain high hazard areas, protection of wetlands and green spaces in floodplains, creation and dissemination of knowledge and strengthening of technical and institutional capacities of key stakeholders involved (Sanscartier et al., 2018).

Win-Win Measures

Win-win measures are actions that have significant environmental, social or economic co-benefits and that can mitigate multiple risks simultaneously (Sanscartier et al., 2018). Many planning solutions offer other benefits and justify choices that are consistent with an integrated view of the issues. For example, wetlands play a vital role in flood control, since they can capture some of the flood water, but choosing to conserve them will also have positive impacts on water quality, resupply of groundwater, biodiversity, ecotourism activities such as hunting, fishing or hiking, and even Quebec's carbon footprint (Ducks Unlimited Canada, n.d.; He et al., 2017; Poulin et al., 2016). Green spaces or green infrastructure are generally accompanied by significant co-benefits, including improved quality of life for citizens (Simard et al., 2019). These measures are sometimes consistent with a municipality's political agenda and can be combined with other sustainable development and planning goals. This presents an opportunity to leverage different sources of funding.

Flexible Measures

Flexible options are based on adaptive management; they can be implemented gradually and adjusted without major impact on their final cost. For example, flood protection infrastructure whose design could be modified in the future, accompanied by adaptation plans developed to take into account different climate scenarios. Through evidence-based adaptive management, the chances of success for these measures' longevity are significantly increased (Sanscartier et al., 2018). Adaptive management is an iterative approach based on consistent and targeted monitoring of the effectiveness of adaptation measures. It aims to improve scientific knowledge and develop management regimes that consider a range of potential impacts and even take advantage of unforeseen events (Webster et al., 2008).

4.2 COORDINATE TO ENSURE CONSISTENCY OF ACTIONS

Climate change adaptation and land management are complex and involve a multitude of actions not necessarily within one organization, but rather based on a large network of "stakeholders" that include citizens, non-governmental organizations, the private sector (insurance specifically), scientific institutions and government agencies (Buchecker et al., 2013; Council of Canadian Academies, 2019). Territorial planning tools are often implemented at the municipal level, but their adoption and effectiveness are also influenced by the rest of the network (Henstra & Shabman, 2020).

The Collaboration of Organizations

Collaboration between stakeholders involved in floodplain planning is a key principle in the success and sustainability of planning choices and aims to avoid making decisions in isolation. Indeed, it has been shown that stakeholders' capacities increase when they are linked through direct relationships or intermediaries: "While centralization is beneficial for coordination, a structure involving more distinct sub-networks linked to central actors by bordering organizations (intermediaries) would improve prospects for innovation and efficiency" (Therrien et al., 2019). Governance should correspond not only to hierarchical relationships between levels of government, but also to the coordination of multiple actors whose actions and powers are necessary and complementary (Baril et al., 2020).

To understand policy implementation prospects in complex areas such as climate change resilience and adaptation, a good knowledge of the network of stakeholders involved in flood risk management (i.e., organizations that have the potential to influence the political feasibility of mitigation measures) is critical (Therrien et al., 2019).

An analysis of the system in the LCRR basin found that it includes 172 organizations with activities related to water management and flooding in the Quebec portion of the basin, 35 of which identified flooding as a priority (Figure 1). This network has an impact on political feasibility, as organizations can influence problem definition, options and implementation of measures, and can advocate for or against a measure (Arnaud et al., 2020).

Indeed, the analysis identified 24 organizations with a high number of relationships and a strong capacity for collaboration and coordination. These organizations are likely to have a major influence and play a central role in disseminating information. Their importance in the network does not automatically mean that they hold a great deal of political power. Some have only a coordinating role for actions within the watershed, such as the Comité de concertation et de valorisation du bassin de la rivière Richelieu (identified as the network's most influential organization)., the Montérégie regional environmental council, the Union des producteurs agricoles, etc. (Arnaud et al., 2020).

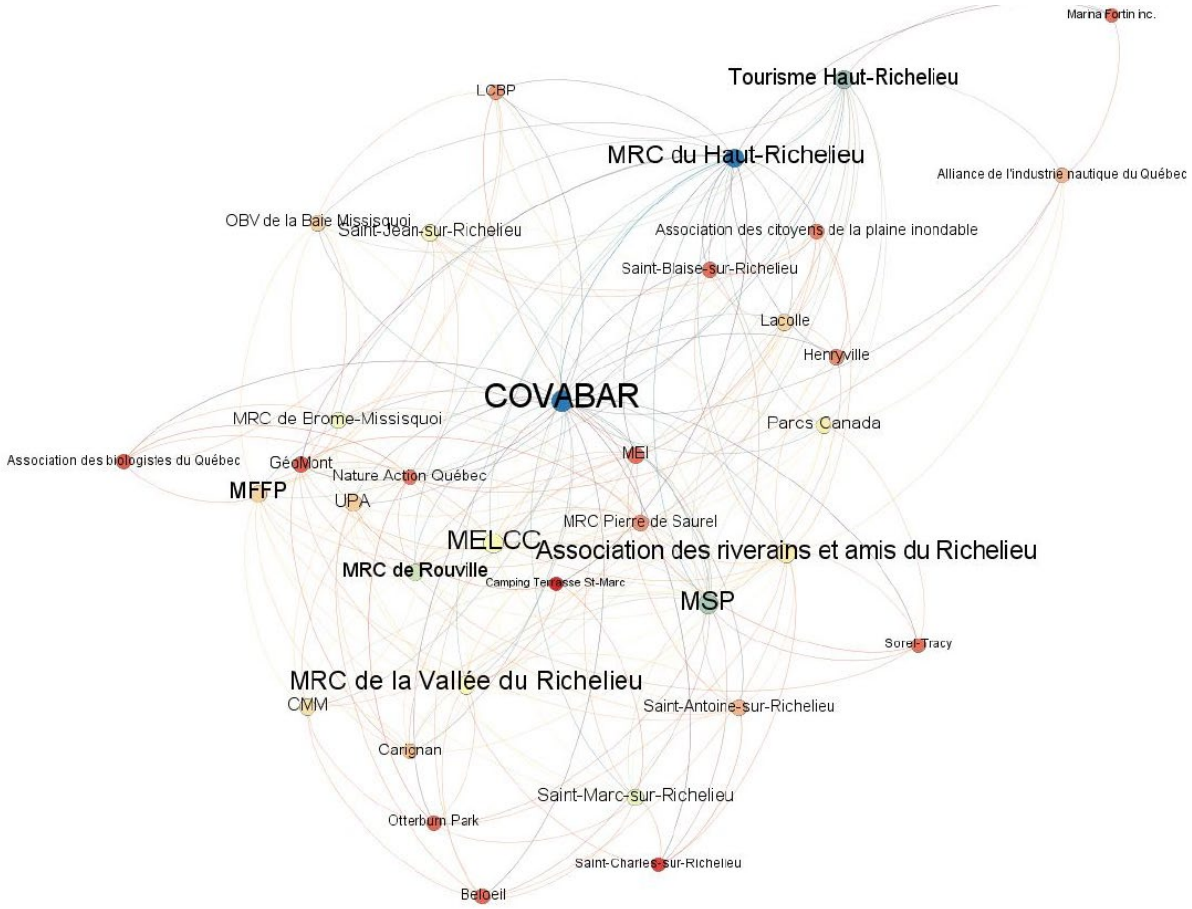

Figure 1. Organizations that see flooding as a priority in the Quebec portion of the LCRR. Source: Arnaud et al., 2020.

Collaboration also helps to tap into local knowledge, which is absolutely essential for planning strategies (Cornell et al., 2013). As part of the vulnerability and resilience analysis of riparian communities in the Quebec portion of the LCRR, a social acceptability study of potential structural mitigation measures in the Richelieu River was conducted.

In interviews with local stakeholders at the municipal level, they wanted to emphasize the fact that their local knowledge was not being used enough, particularly by senior levels of government. One participant commented on the situation, "We're faced with a rather fundamental contradiction: local actors who know their environment better than anyone else are not being consulted" (Thomas & Gagnon, 2020).

Moreover, in the particular case of flooding, the biophysical processes associated with this phenomenon go beyond administrative boundaries and correspond instead to the unity of the watershed. Therefore, although the Quebec legislative framework assigns specific jurisdictions to local municipalities, the RCM and the provincial government, it delegates certain responsibilities to non-profit organizations, i.e., watershed organizations (WOs). Although they are very limited in terms of resources and do not have legislative or regulatory authority, WOs collaborate extensively with other stakeholders and are excellent intermediaries among organizations (Baril et al., 2020).

Beyond the WOs, when planning projects, it will be important to consult not only the levels of government, but also tourism, regional and supra-regional organizations, as they can influence the feasibility of options and play a significant role in their implementation. They could ideally be integrated into the process of defining mitigation measures (Arnaud et al., 2020).

As part of the implementation of the new Flood Protection Plan, the Quebec government set up project offices to plan the development of flood-risk areas in certain watersheds. The mandate of each office will be to provide an overview of flooding problems in its area, develop a response plan based on scientific expertise, consult with stakeholders and support municipalities in implementing the plan.

Public Awareness and Engagement

While the strength of the network of all stakeholders is important, one group has a special status: citizens. Often ignored in decision-making processes, citizen outreach and involvement in flood-risk management and land-use planning decisions can benefit the success and sustainability of these decisions.

On the one hand, awareness of flood risks facilitates adherence to the measures put in place. On the other, raising awareness is important to promote behavioural change and to help communities cope: informing people about the risks and their evolution, how they can be affected, and what they can do to prepare and protect themselves (Moudrak & Feltmate, 2019a). A significant number of Canadians are unaware that they live in a floodplain and that they are exposed to that risk; they cannot logically feel the need to put measures in place to be more resilient in the face of this hazard (Thistlethwaite et al., 2017).

However, many adaptation measures at the level of lots and buildings, of the no-regret type, can be implemented by citizens (Moudrak & Feltmate, 2019b). For example, not storing valuables in the basement, installing pumps, moving electrical installations to the ground floor, etc., are inexpensive and can be very effective in preventing damage (Exchange with Ursule Boyer-Villemaire, 2021-05-04). Outreach issues are addressed in the first white paper of this series on the theme of risk communication (Henstra & McIlroy-Young, 2021).

Furthermore, citizen involvement in decision-making processes could increase individual accountability and buy-in to selected risk management measures (Cloutier & Demers, 2017; Massé et al., 2018), thereby ensuring greater success for development projects (Feltmate & Fluder, 2018). For example, to ensure that solutions promoted at the watershed or municipal levels are shared in community circles and among individuals, it will be essential that governance mechanisms be reviewed to provide better citizen participation (Cloutier & Demers, 2017).

Watershed organizations are important players in this niche, as they have specific expertise in integrated water management. Their input can therefore be used to conduct awareness and information campaigns aimed at the general public or to develop tools for more specific consultation functions (Regroupement des organismes de bassins versants du Québec, 2018).

In concrete terms, a wide range of activities can be organized to encourage participation: “advisory committees, working groups, participatory mapping, knowledge transfer workshops, interactive forums, deliberative workshops on management alternatives, collection of knowledge and testimonies from local residents and water stakeholders at the watershed level, interactive analysis of disaster scenarios, community analyses of vulnerability profiles, outreach activities on the ground” (Massé et al., 2018).

Despite its popularity, there are also limits to citizen participation that need to be acknowledged to take full advantage of them. The inadequacy of participatory mechanisms can be particularly evident when emergencies arise that require rapid decision-making. There is also a challenge in maintaining participants' long-term motivation. Finally, the division of powers is not easy to operationalize due to organizational cultures that are resistant to change (Massé et al., 2018). It is therefore important that those who promote implementation of citizen participation heed lessons learned in other contexts to keep in mind the challenges they present.

Furthermore, there is no formula for participation and power sharing that is appropriate in all cases. Notwithstanding this, "partnership, delegation of power and citizen control" are the three most active forms of participation that promote effective stakeholder power (Massé et al., 2018). This is all the more evident when authorities do not exercise full control over the purposes of the process and when achieving the objectives is part of a consensual process.

EXPERIMENTATION WITH COLLABORATIVE GOVERNANCE IN FLOOD ADAPTATION IN THE MUNICIPALITY OF SAINT-RAYMOND

The downtown area of the Quebec municipality of Saint-Raymond has experienced numerous overflows of the Sainte-Anne River since the late 19th century (Cloutier, 2018; Ville de Saint-Raymond, 2018). In 2014, a flood caused by an ice jam raised the river to historic levels, resulting in numerous damages (Thomas 2017; Ville de Saint-Raymond, 2018). This event triggered the creation of a river committee that brought together elected officials, municipal service managers, residents and representatives of the local WO (Cloutier & Demers, 2017).

The river committee is a forum for collaboration in line with the principles of integrated water management by watershed. According to the Cloutier and Demers analysis (2017), establishment of the committee, its facilitation by the watershed organization and its relationship with experts in hydrology and planning (Morse & Turcotte, 2015, 2018; Thomas, 2017) are factors that support a transformation in how to problematize risk, organize resources to address it, and develop solutions that differ from traditional, reactive, and short-term approaches (Cloutier & Demers, 2017).

Indeed, the experience recounted testifies to an implementation of a mode of climate governance where some fifteen diverse actions were carried out, such as creation of an inventory of disaster victims, production of information capsules, training sessions, creation of a resilience plan, implementation of new prevention measures such as a floating boom on the river, etc. (Morse & Turcotte, 2015). Many residents even adapt their homes and behaviours individually by installing pumps in their basements or moving their belongings before winter (Les OBV du Québec, 2017).

The overall approach laid the groundwork—which has yet to be consolidated—for an alternative mode of operation where citizens and WOs occupy a central place (Cloutier & Demers, 2017).

4.3 LEVERAGE EXISTING INSTITUTIONAL OPPORTUNITIES

Flood protection is currently a societal issue that reaches all levels of government. To avoid reinventing the wheel or being paralyzed, decision-makers can approach this challenge from the point of view of certain normative and institutional achievements.

Regulations

In Quebec, the normative framework for land use planning is based on a number of laws and policies. In the specific case of land use and development in floodplain areas, there are two main legislative texts: the Land Use Planning and Development Act and the Protection Policy for Lakeshores, Riverbanks, Littoral Zones and Floodplains (PPRLPI), which is part of the Environment Quality Act (Therrien et al., 2021).

These were recently amended by Bill 67, which gave new regulatory powers to the provincial government in March 2021. The latter will eventually be able to develop a new normative framework applicable to shorelines, littoral zones, floodplains, and mobility zones. The Protection Policy for Lakeshores, Riverbanks, Littoral Zones and Floodplains will therefore include new regulatory provisions (MAMH, 2020; Therrien et al., 2021).

Furthermore, under the new legislation, RCMs and municipalities will play a more significant role by getting additional regulatory powers. The future framework will have to be applied by municipalities, as if it were part of their own regulations. These will include the issuance of certain permits, inspections and sanctions (MAMH 2020). As well, RCMs will have greater flexibility in areas of low flood risk. This reinforces the need to include these bodies, along with municipalities, in International LCRR Study Board discussions (Therrien et al., 2021).

It should be noted, however, that despite the recent adoption of Bill 67, existing regulations remain relatively complex and technical and there is a lack of training for municipal actors (public servants and elected officials), to whom many responsibilities are delegated and whose human and financial resources are limited (Thomas & Gagnon, 2020).

Some local stakeholders in the LCRR basin mentioned that getting information on regulations such as SIZs is difficult, and interpretation can vary depending on officials. In terms of regulatory framework enforcement, many local stakeholders have confirmed the problem of infilling the land, which diverts water to a neighbour's property. The limited number of staff available makes it very difficult to inspect the territory on a regular basis and identify illegal work when it is being done. In addition, it is very expensive to take a citizen to court over this issue and difficult to build a case (Thomas & Gagnon, 2020).

Nevertheless, local governments are at the centre of planning decisions and have access to a range of urban and territorial planning tools that allow them to take into account the natural vocations of territories or their physical characteristics (ministère des Affaires municipales et de l'Habitation, n.d.). For example, RCM Land Use and Development Plans (LDPs), WO master plans on water, or even regional wetland and water plans can facilitate development of an overall vision and collaboration among stakeholders. Staffing an expert at the municipal or RCM level is also an option to align decision-making processes with evidence-based practices to facilitate collaboration across the watershed (Cloutier & Demers, 2017).

Training of staff in positions of authority will therefore be necessary for the proper application of regulations, as well as to take full advantage of institutional opportunities. As noted above, as part of the implementation of the new Flood Protection Plan, the Quebec government will set up project offices for the planning of flood risk areas, which will have many responsibilities. The office for the Richelieu and Yamaska river basins will have a unique opportunity to quickly test development solutions based on the rigorous analyses conducted by the LCRR Study Board.

Funding Sources

The same stakeholders will benefit from existing initiatives (plans, strategies, teams) and funding sources at different government levels (Thomas & Gagnon, 2020). There are sources of technical support and funding at the provincial and Canadian levels to help local governments adapt to flood hazards, from vulnerability analysis to implementation of solutions.

Some examples of programs to which municipalities are eligible include: the program to support the integration of climate change adaptation into municipal planning and the financial assistance program for the restoration and creation of wetlands and water bodies. Financing and land control tools are also helpful in developing sustainable land use solutions.

The ministère de la Sécurité publique's 2013-2022 disaster prevention framework is also useful for funding pilot projects, as was done in the municipality of Saint-André-d'Argenteuil.

Some private sectors can benefit from financial assistance. For example, agricultural producers affected by flooding have access to a compensation program. Use of these resources is a regret-free flood adaptation measure that is relatively simple to implement and that could be described as "*low hanging fruit*" (Ursule Boyer-Villemaire, personal communication, 2021-04-05).

5 CONCLUSION

This white paper is the third in a series of four documents commissioned by the Study Board to assess best practices for flood risk management in the Lake Champlain-Richelieu River basin. This basin is a diverse region with unique challenges and opportunities to develop planning strategies tailored to specific contexts. These findings are not prioritized but reflect the order in which they were discussed in the report.

1 **Planning decisions and the regulatory framework should consider specific risk factors** such as physical (geomorphological or meteorological) changes. In the case of the LCRR basin, consideration of wind and waves around the lake shore is important because of their influence on water levels and flood duration. For example, the long duration of flooding—six weeks for the 2011 flood—has the potential to cause additional damage to homes and infrastructure and strain mitigation measures.

2 **Land-use planning actions should reflect hazard, vulnerability, and flood risk analyses**: the data collected and analyzed by the Study Board can help prioritize implementation of adaptation solutions in the territory according to the most vulnerable sectors. They can help justify more complex, costly, and socially sensitive development decisions, such as demolition and relocation of residential buildings or construction of protective structures. Finally, according to the indices examined, these analyses can also support development of a regulatory framework.

   The Study Board assessed structural mitigation measures such as bed excavation or diversion of the Richelieu River. If implemented, the impact of these measures on flood delineation must be taken into account in the definition of hazard, and therefore in land use planning.

3 **Land use planning should not encourage future development in areas of high flood risk**: future development in such areas should be avoided so that new risks do not have to be managed, since later measures are more complex and costly to implement. This is an opportunity to increase the amount of land conserved and to create green spaces where more people have access to shorelines, for example.

4 **We need to think of a built environment that can co-exist with water**: to reduce our exposure and vulnerability to flooding, we should ideally reduce the number of people, built-up elements and services located in the floodplain. However, for a number of reasons, such as the desire to densify metropolitan areas or preserve urban cores and built heritage in floodplains, it will still be impossible to relocate everything and eliminate the risk, especially since it continues to evolve. We will therefore also have to think about land use and a built environment that can coexist well with water.

5 **There is a need for innovative architectural and landscape projects in the LCRR basin and in Quebec**: while architectural solutions are being explored elsewhere in the world, in-depth studies will contribute to safe coexistence with water. This is an opportunity to take advantage of the numerous hydrological, hydraulic and vulnerability studies conducted in the basin, as well as the Integrated Social, Economic and Environmental analysis (ISEE) tool developed by the Study Board.

6 **Resilient development will not be based on a single strategy, but rather on a set of measures adapted to a specific context**: flood adaptation measures must be complementary according to the specific context of a territory, and experimentation and innovation are encouraged. In the LCRR basin, each municipality has its own context, development opportunities and priority areas. For example, municipalities could seek to resiliently densify vacant lands in Saint-Jean-sur-Richelieu that are not in floodplains, adapt campsites in Venise-en-Québec, relocate Noyan residents to a redeveloped area, etc.

7 **Decision support tools and feedback can guide land use planning strategies**: if adaptation solutions need to be tailored to a community's specific context, where possible, our choices must be supported by detailed analyses of their costs and benefits, taking into account not only economic parameters, but also their societal and environmental value. In addition, feedback from experience (FEX) allows us to learn about the predispositions of an area that led to a flood and its consequences. A collaborative decision support tool was developed by the Study Board to help synthesize and integrate data from the Integrated Social, Economic and Environmental Analysis (ISEE) tool, to assist in decision-making.

8 **We need to focus on measures that take into account uncertainty due to climate change and territorial and social evolution**: the context where flood risk management is conducted is not static but dynamic. Climate change and territorial evolution will modify the definition of hazard and vulnerability to flooding. This has important implications for the development of a land-use strategy. Therefore, to avoid decisions that will not be adapted to future conditions, it is necessary to focus on measures that will have positive results, regardless of the changing context.

9 **The success of land use planning will depend on effective coordination and stakeholder involvement** to improve the longevity, acceptability, and success of land-use planning options. It will be important to review governance mechanisms for greater coordination among stakeholders, better involvement of local actors and better citizen participation. Moreover, to avoid reinventing the wheel, decision makers can approach this challenge by drawing on certain normative and institutional achievements. To help inform these governance principles, the Study Board conducted analyses of the LCRR's network of stakeholders and of Quebec's normative framework.

10 **Apply the knowledge and data gathered by the Study Board to develop land use planning options for the LCRR basin**: the many research projects carried out by the Study Board should be used by local authorities in their planning and could inspire the Quebec government's current thinking on the new regulatory framework.

As part of the implementation of the new **Flood Protection Plan**, the Quebec government set up project offices to plan the development of floodplains in certain watersheds. The mandate of each office will be to provide an overview of local flooding problems, develop a response plan based on scientific expertise, consult stakeholders and support municipalities in implementing the plan. The Richelieu and Yamaska river basins office will have a unique opportunity to quickly test planning solutions based on the rigorous analyses conducted by the Study Board.

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