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Climate Change, Floods, and Municipal Risk Sharing in Canada

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UNIVERSITY OF TORONTO

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About IMFG

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Abstract

Canadian municipalities are vulnerable to climate change risks, particularly in the form of extreme weather. Risk management demands public policies that share both the responsibility for risk reduction and the burden of costs with other levels of government and with non-governmental actors. What tools are available to municipalities seeking to share the growing risks associated with a changing climate? To what extent and how have these tools been employed in Canadian cities? With a focus on urban flooding, this paper systematically identifies and explains ways in which governments can share climate-related risks. It then evaluates whether and how these tools have been used in two major Canadian cities – Calgary, Alberta, and Toronto, Ontario – which have recently faced severe flooding, and are likely to experience more in the coming years. From this analysis, conclusions are drawn about the state of local climate risk management and how it might be improved.

Keywords: climate change, flood, risk management, cities

JEL codes: H84, Q54, Q58

Climate Change,
Floods, and Municipal Risk Sharing in Canada

1. Introduction

Climate change poses significant risks for Canadian municipalities, particularly in the form of extreme weather, such as severe thunderstorms, ice storms, hailstorms, windstorms, blizzards, and tornadoes. Canada's major cities are especially vulnerable to extreme weather, due to their large, dense populations, valuable and geographically concentrated property, and complex, interdependent infrastructure networks, all of which are susceptible to threats from localized climate hazards.

Municipalities have traditionally relied on a hazard-based approach to managing extreme weather, whereby the likelihood of an extreme event is used to inform policy that emphasizes separating people and assets from the hazard (e.g., limiting development in the 1-in-100-year flood plain). In recent years, governments have started to explore alternative policy approaches to manage their exposure to the effects of climate change based on the principles of risk management. This approach emphasizes the consequences of hazards and draws on a range of instruments with a broader objective than just protection; they include mitigation, response, and recovery. The shift towards risk management involves an expansion of the government and non-government stakeholders involved in designing and implementing policy.

The United Nations Hyogo Framework for Action, the European Union, and the Canadian federal government have all adopted risk management as a policy principle (Hartmann and Spit 2016b; Public Safety Canada 2015a). The application of risk management to climate change at the municipal level, however, remains overlooked, as most experts focus on national-level implementation. This is unfortunate, because risk management requires that municipalities share both the responsibility for risk reduction and the burden of costs with other levels of government and with non-governmental actors.

What tools are available to municipalities seeking to share the growing risks associated with a changing climate? To what extent and how have these tools been employed in Canadian cities? This paper addresses these questions through a policy instrument analysis, a systematic effort to identify and explain the ways in which public resources can be employed to share climate-related risks. By addressing these two questions, an instrument analysis on risk sharing also reveals how climate change risk is concentrated or diversified by municipal policy. The failure to embrace risk sharing, for example, can concentrate climate change risk, exposing a municipality and its citizens to an unnecessary and unplanned outflow of resources. To ground the analysis, the paper focuses on flooding, a major hazard that threatens people and property in virtually every Canadian community, and is expected to become more frequent and severe due to climate change.

We begin by explaining the climate change challenge and contextualizing floods as a significant climate risk. We then outline the traditional approach to flood management in Canada and highlight its limitations. Next, we examine flood risk management, an evolving paradigm that engages the principles and practices of risk management to reduce the likelihood and consequences of flooding. In the following three sections, we present our instrument analysis, identifying concrete mechanisms by which municipalities can spread the burden of flood-related losses, share the responsibility for risk reduction among a broader set of actors (such as developers, builders, and property-owners), and distribute the costs associated with publicly funded flood risk-reduction measures. We also evaluate how and the extent to which these tools have been employed in two major Canadian cities – Calgary, Alberta, and Toronto, Ontario – which have recently faced severe flooding, and are likely to experience more in the coming years. The final section draws analytical generalizations about the state of local climate risk management and how it might be improved.

1.1 Climate change, extreme weather, and urban climate risks

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), issued in 2014, assesses published research by the world's leading climate scientists. Working Group II reviewed the scientific, technical, environmental, economic, and social aspects of climate change. The report projects that over the next two decades there will be an increase in average annual temperatures over North America (particularly in northern and eastern Canada), an increase in average annual precipitation (particularly in winter), a greater number of days with hot temperature extremes, and drier summer seasons (Romero-Lankao et al. 2014, 1454–1456).

Canada's national climate change assessment indicates that average surface air temperatures increased over the period 1950–2010, as did the volume of rainfall, particularly in the spring and fall (Bush et al. 2014). Moreover, it projects that in coming decades there will be more frequent and intense extreme weather events in most parts of Canada. These events are infrequent, but significant, departures from a location's normal weather conditions, which are potentially destructive because they exceed the range of weather intensity a location normally experiences (CCME 2003, 137; Francis and Hengeveld 1998, 2). They can be labelled *climate hazards*, meaning specific manifestations of climate change that are potentially harmful for people and property (Brooks 2003, 3). Models simulating future climate conditions based on projected levels of greenhouse gas emissions consistently indicate that the return period of extreme weather events – the interval of time between occurrences – will be shorter in future (Kharin and Zwiers 2005). These changing weather patterns present a number of *climate risks* for Canadian cities, defined here as *potential negative consequences of climate hazards on human life, health, property, and the environment* (Aven et al. 2015; Mehrotra et al. 2011).

1.2 Flooding: A significant climate risk

Analyzing urban climate risk in Canada is difficult, given the many and varied hazards that cities face, the inherent uncertainties in projecting their frequency and severity, and variable exposure from one geographic area to another (Hultman, Hassenzahl, and Rayner 2010). Researchers can quickly become overwhelmed by the scope and complexity of climate risks, which complicate attempts to systematically identify and evaluate potential courses of action to manage them (Fünfgeld 2010; Travis and Bates 2014). Therefore, this paper focuses on one hazard – flooding – which in its various forms poses a risk to people and property in virtually every community in Canada (Brooks, Evans, and Clague 2001). Although this approach artificially isolates one hazard from the rest, it helps to bring the governance implications of climate risk management into sharper relief. Many risk-sharing tools analyzed here are also applicable to other climate hazards.

Flooding is currently the most costly hazard in terms of urban property damage, and water-related losses have surpassed fire and theft as the principal source of property insurance claims (KPMG 2014; Oulahen 2014; Public Safety Canada 2015d). Flooding has many negative consequences for communities, including:

- population displacement (Levine, Esnard, and Sapat 2007);
- disruption of critical infrastructure (Kidd 2011);
- business interruption (Ingirige and Wedawatta 2011);
- output loss due to capital damage and displacement of workers (Davies 2016);
- threats to physical health (Burton et al. 2016; Carroll et al. 2010);
- mental health maladies, including post-traumatic stress disorder, depression, and anxiety (Lamond, Joseph, and Proverbs 2015; Stanke et al. 2012).

There is mounting evidence to suggest that flood risk in Canadian communities is no longer socially acceptable – that is, it no longer lies within the limits that society is prepared to tolerate (Bell, Danscheid, and Glade 2006; NRTEE 2011, 79). First, there has been a dramatic increase in urban flood damages over the past two decades. For example, more than $20 billion in losses was attributable to sewer backup and extreme rainfall in urban areas from 2003 to 2012 (Kovacs and Sandink 2013a, 3). In recent years, several major Canadian cities have experienced unprecedented flood damages resulting from a combination of extreme rainfall, overwhelmed drainage infrastructure, and development in flood-prone areas (CTV News 2011; Kauri and Rogers 2013; Mills 2013). In Calgary and the surrounding areas, for instance, six days of torrential rain in June 2013 triggered what became Canada's most expensive natural disaster up to that time,[1] with estimated economic

1. The 2016 Fort McMurray wildfire is expected to surpass this record, with insured losses estimated in the $5-9 billion range.

losses of more than $6 billion (Canadian Underwriter 2013b). That same year, record rainfall caused severe flooding in Toronto. The flooding inundated city streets, severed power to approximately 300,000 residents, caused more than $940 million in insured property losses, and cost the municipal government more than $65 million for response and recovery (City of Toronto 2013b; Nelson 2014).

Second, the risk of urban flood damage is increasing. Changes in snowmelt run-off caused by rising temperatures and intense rainfall associated with severe storms are expected to heighten the risk of flooding in many Canadian communities (White and Etkin 1997; Loukas and Quick 1999; Cunderlik and Simonovic 2005). Moreover, growth in high-value development in flood-prone areas has put more people and property at risk (Tucker 2000). A new model commissioned by the Insurance Bureau of Canada (IBC),[2] which combines river gauge, rainfall, snowmelt, and terrain data with flood defence information and historical flood records, indicates that 1.8 million Canadian households (about 10 percent) are at “very high risk” of flood damage (Meckbach 2016).

At the same time, our capacity to anticipate and mitigate flood damages has diminished, due to outdated flood maps (Noël 2013); deferred investment in maintenance, repair, and replacement of flood control structures like dams, dikes, and channels (Conservation Ontario 2013a); and infrastructure designed to standards based on historical meteorological data, which may be inadequate to cope with future climatic conditions (Auld 2008; Gibbs 2012). In addition, whereas traditional flood-prevention programs focused primarily on riverine flood hazards, a growing proportion of flood-related damages in urban areas stems from sanitary sewer backup and stormwater and groundwater infiltration, which require different solutions (Sandink et al. 2015).

Third, public expenditures on disaster financial assistance programs have expanded dramatically. For instance, due largely to major floods, payments under the Disaster Financial Assistance Arrangements (DFAA) – a federal program that reimburses provinces and territories for a portion of disaster response and recovery costs – increased from an average of $118 million per year in the period 1996–2011 to $280 million per year in the period 2012–2015, far surpassing the program’s nominal $100-million annual budget (Public Safety Canada 2015c). Moreover, based on the insurance industry’s estimates of flood losses, DFAA costs due to floods are projected to increase to more than $650 million annually over the next five years (Canada 2016). In 2015, recognizing its escalating liability associated with the DFAA program, the Government of Canada changed the expense thresholds at which federal funding is triggered from $2 per capita to $6 per capita, effectively reducing its future contributions to disaster-related recovery (Public Safety Canada 2015b).

2. The Insurance Bureau of Canada is the national industry association representing private property and casualty insurers.

Municipal governments have also been compelled to devote financial resources to disaster relief, fuelled in part by the surge in flood-related property damage. For instance, since it was first enacted in 2005, Hamilton's Residential Municipal Disaster Relief Assistance Program has paid out more than $5.1 million in grants to compensate residents who have experienced basement flooding caused by heavy rains (City of Hamilton 2013a). Similarly, the City of Ottawa has distributed $1,000 grants to 49 property-owners since it approved its Residential Compassionate Grant Policy in 2009 (K. Graham, personal communication, May 9, 2016).

A final indicator that flood risk is no longer socially acceptable is the attempts by affected local residents to seek restitution through the courts. Within the past 10 years, for instance, plaintiffs in class-action lawsuits in Mississauga, Stratford, and Thunder Bay, Ontario, have argued that municipal authorities failed to uphold their duty of care in protecting residential properties from flooding; these legal actions may illustrate evolving public expectations of local governments (CBC News 2013; Clay 2016; O'Connor 2010). The emerging discourse around municipal liability in a changing climate (particularly as it concerns stormwater management) suggests that the standard of care municipalities might reasonably be expected to uphold is becoming more stringent (Crawhall and Martin 2014; Saxe and James 2014; Zizzo, Allan, and Kocherga 2014).

2. Flood management in Canada

The management of flooding in Canada is predicated on a hazard-based model, whereby a static standard (such as the 100-year flood) is used as the basis for decisions about public infrastructure and flood protection (Jakob and Church 2011). Structural flood control works such as dikes and dams are intended to reduce flood risk to the standard flood level, and disaster-assistance programs are in place to compensate communities and individuals when this level is exceeded. With a virtually exclusive emphasis on the *likelihood* of a particular flood hazard (that is, one in 100 years), comparatively little attention has been paid to the possible *consequences* to people and property.

This hazard-based approach to flood management has a number of well-documented weaknesses, including:

- the enormous cost of building and maintaining structural flood control works;
- a lack of basin-scale coordination, which leads to conflicts between upstream and downstream communities over issues such as water diversion and agricultural drainage;
- a false sense of security due to structural protection, which encourages increased settlement in flood-prone areas;

- disaster relief programs that compensate flood victims for losses, effectively encouraging risk-taking behaviour;
- an emphasis in the post-disaster period on restoring communities to the pre-flood state without any additional measures to mitigate future flood risk, setting the stage for repeat losses (Jakob and Church 2011; Shrubsole 2000; Shughart 2011).

As Tucker (2000, 85) argued nearly two decades ago:

> Canadian society puts particular emphasis on sharing the loss, such as public compensation, insurance, and restoration…based upon the debatable assumption that current loss rates are sustainable, and that the social and other costs resulting from extreme events beyond design safety factors are not prohibitive.

Evidence has mounted that the traditional hazard-based approach is unsustainable in light of increasing risks posed by a changing climate (Canadian Press 2013; Paris 2010; Struzik 2015). For this reason, government officials have started to explore the adoption of "risk-based" approaches to flood management. The demand for such policy was heightened in the aftermath of the 2013 Alberta floods, in which the hazard-based approach had contributed to higher losses because residential and commercial development had been permitted in the floodplain, despite the higher risk (Gollom 2013; Groeneveld 2006).

3. Flood risk management

Risk management is the organized, institutional process of dealing with risk (Ale 2009, 5). As a systematic framework for addressing risk problems, risk management is typically divided into a series of steps (Black, Bruce, and Egener 2014). These include:

1. *risk identification*, which involves itemizing the potential hazards that could have a negative impact on the system of interest;
2. *risk analysis*, by which detailed estimates of the likelihood and consequences of identified hazards are prepared, in consultation with stakeholders;
3. *risk evaluation*, whereby the social acceptability of the risks posed by identified hazards is considered;
4. *risk treatment*, which involves selecting one or more *risk controls* to reduce unacceptable risks to a tolerable level.

Risk controls are specific measures – processes, policies, devices, or practices – implemented to modify risk (ISO 2009), of which there are five basic variants, including avoidance, prevention, mitigation, sharing, and retention (see Table 1).

Table 1. Risk Controls	
Risk avoidance	Purposely declining to engage in an activity that carries risk (which also means forgoing potential benefits)
Risk prevention	Eliminating or containing hazards that pose risk
Risk mitigation	Reducing the severity of loss, by mitigating the consequences associated with hazards
Risk sharing	Sharing with another party the burden of loss from risk and/or responsibility for measures to reduce the risk
Risk retention	Making an informed decision to accept loss from a risk when it occurs

As applied to floods, risk management involves identifying and analyzing potential sources of flooding, evaluating the level of flood risk that is socially acceptable, and selecting appropriate risk controls to avoid, reduce, share, or accept flood risks, including modifying the probability of flooding or reducing the exposure and vulnerability of people, property, systems, and other assets subject to potential losses (Sayers et al. 2013, 23).

Flood risk management represents a shift away from the traditional, hazard-based model of flood management, whereby public funds are used to build flood defences based on a pre-defined level of flood protection, disaster financial assistance is made available to compensate those affected by residual risk, and there are few incentives to proactively reduce flood risk (Johnson and Priest 2008; van Stokkom, Smits, and Leuven 2005). Instead, this approach involves sharing responsibility with those who contribute to flood risk, increasing the participation of stakeholders in decision-making, and allocating resources across a broader portfolio of technological, social, economic, and institutional measures to reduce and manage flood risk (Begum, Stive, and Hall 2007; Klijn, Samuels, and Os 2008; Simonovic 2013) (see Table 2). States such as the United Kingdom, Germany, and the Netherlands are leaders in adopting this approach, driven in part by the European Union's 2007 Flood Directive, which mandated member countries to design and implement flood risk management plans (Hartmann and Spit 2016a).

Risk sharing refers to the distribution to other parties of some of the burden of loss associated with flood risk and/or the responsibility and costs for measures to avoid, prevent, and mitigate flood risk (World Meteorological Organization 2013, 12). To qualify as a risk-sharing measure, the policy must not only share responsibility with another stakeholder, but also be designed to share the risk, which includes consideration for the consequences of the hazard in addition to the likelihood. For example, some policy mechanisms, such as disaster assistance, share responsibility for managing floods with other levels of government, but

Table 2. Two Approaches to Flood Management				
Approach	**Foundation**		**Policy Objective**	**Example of Practice**
Hazard-based (traditional approach)	Probability	Historical event	Prevent flooding during a repeat of a specified historical event.	Design flood defences to withstand an event the magnitude of Hurricane Hazel in 1954 (Ontario).*
		Design event	Prevent flooding during a storm event of a specified return period.	Design flood defences to withstand a 1:100 year flood
Risk management (evolving approach)	Risk		Reduce flood risk to socially acceptable level; share responsibility.	Analyze and evaluate flood risk; implement portfolio of instruments to reduce and share responsibility for risk.

*The Hurricane Hazel Flood Event Standard means a storm that produces over a 48-hour period, in a drainage area of 25 square kilometres or less, rainfall that has the distribution set out in a table (such as 73 millimetres of rain in the first 36 hours).

Adapted from Sayers et al. (2013)

may be designed based only on the hazard likelihood without consideration for exposure and vulnerability. Disaster assistance offers compensation when an event exceeds a design threshold based on hazard likelihood; there is no effort to address a property's exposure or vulnerability to future events by requiring changes in the design or location.

Among the various risk controls, risk sharing is particularly important for Canadian municipalities, given their increasing exposure to extreme weather, growing flood-related costs, and limited means and authority to raise revenue. Unlike the provincial and federal governments, which derive revenue from a large population through sales and income tax, municipalities must rely on property taxes within their jurisdiction (Kitchen and Slack 2016). Whereas other levels of government can spread the costs of flooding across a much wider and deeper tax base, municipalities have less capacity to absorb the financial shock of floods, the costs of which displace other important priorities.

The next three sections divide flood risk-sharing into three dimensions and identify specific instruments available to municipal governments in each category. We assess whether and how the flood risk-sharing instruments are used in practice by Canadian urban municipalities, using evidence from Calgary and Toronto, two cities significantly affected by flooding in recent years. The assessment is important, as municipalities can share policy responsibility with another stakeholder, but may not actually share the risk if the policy is not designed based on a risk assessment that includes considerations of the consequences of hazards.

4. Sharing the burden of loss

One dimension of risk sharing involves spreading the burden of flood-related losses across multiple parties. Two key instruments are notable here, and Canada's model of flood management relies heavily on both.

4.1 Disaster financial assistance

Disaster financial assistance refers to financial transfers from governments to individuals, organizations, and other governments to help them cope with disaster-related losses that are not recoverable through private insurance. Since it involves appropriating funds from the general public treasury, disaster financial assistance spreads individual losses across the broader tax base. Both the federal and the provincial governments offer financial assistance to communities and individuals affected by disasters, as do some municipal governments, though these local programs are less common and more targeted (such as those that cover basement flooding).

Although generally effective in supporting community economic recovery, disaster financial assistance has significant weaknesses as an instrument of flood risk management (Sandink et al. 2015). First, contrary to a common misperception among emergency victims, disaster financial assistance programs are designed to provide minimum relief only, and are not intended to restore households and property to their pre-disaster condition but rather to a level that is "safe" and "livable." Second, the comprehensiveness and specificity of coverage under provincial disaster financial assistance programs vary across the country, and complex (and often opaque) conditions determine which type of disaster relief is authorized (Burgess 2012, 37). Third, there are often long delays – sometimes several years – between the time a community submits a claim for disaster financial assistance and when it receives payment. Finally, disaster financial assistance has long been criticized for weakening individuals' incentive to implement risk-reduction measures (Burby et al. 1991; Harrington 2006; Shughart 2011). As Wamsley and Schroeder (1996, 238) pointed out two decades ago, "political leaders...at all levels of government, find it impossible to deny disaster assistance to those who failed to invest in protection."

Provincial and federal disaster assistance plays a role in sharing the burden of flood-related losses when municipalities face significant or "extraordinary" emergency management and recovery costs. In Ontario, the Municipal Disaster Recovery Assistance Program uses a cost threshold: a municipality can apply for assistance when its costs "equal at least three per cent of the municipality's Own Purpose Taxation levy" (MMAH 2016). Although the July 2013 flood in Toronto was one of the costliest natural disasters in Canada's history, the City did not qualify for assistance because most damage occurred on private property and was insured, which limited the municipality's exposure. The Province notified Toronto officials that the City was ineligible for assistance because a "key eligibility criterion is that the disaster must be beyond the financial capacity of the municipality to manage" (City of Toronto 2013a).

By contrast, the City of Calgary was eligible for provincial disaster financial assistance for costs related to the 2013 flood. As in Ontario, Alberta's Disaster Recovery Program (DRP) provides funds for losses attributable to "extraordinary" and "widespread" events, which do not qualify for insurance (AEMA 2016). For the 2013 floods, these non-insured losses amounted to more than $1.9 billion, which was transferred to property owners (MNP 2015). In addition, the federal government contributed about $1.3 billion towards eligible expenses identified by the province to support recovery from the flood, but it is unclear whether any of this allocation was directed specifically towards the City of Calgary (PBO 2016). To help recover from damage to its infrastructure, and to pay for the costs of emergency response and staff, Calgary applied for $55 million in provincial DRP funds (Expert Management Panel on River Flood Mitigation 2014).

Some municipalities, such as Hamilton, Mississauga, and Ottawa, have offered compassionate grants to support recovery in the aftermath of flooding, but neither Toronto nor Calgary appears to have employed this means of sharing the burden of loss with property owners. Calgary did offer to pay for the permits for property owners seeking to reconstruct their homes following the 2013 flood, but did not pay the costs of reconstruction.

Despite the benefits of disaster assistance in supporting recovery from floods, provincial and federal governments are increasing the requirements necessary to qualify for funding, because the costs of the programs are becoming prohibitive (PBO 2016; Public Safety Canada 2015a). Indeed, climate change represents a considerable source of uncertainty for disaster assistance programs as events once considered "extraordinary" become more frequent and fail to qualify for funding. In addition, stormwater and urban flooding risk, which represents a more costly source of damage for Canadian municipalities, fails to qualify for the burden-sharing benefit of disaster assistance, since it occurs on private property and is insurable (Kovacs and Sandink 2013b).

4.2 Private insurance

The second burden-sharing instrument is *insurance*, by which policy-holders enter a contractual relationship with an insurer to submit a specified payment (premium) in exchange for the insurer's promise of compensation in the event the policy-holder suffers financial loss associated with specified perils. Insurance has long been a mechanism to share the burden of loss associated with particular types of flooding, such as sewer back-up, water main breaks, and seepage through foundation walls. Although overland flooding has historically been excluded, in 2015 Canadian insurers started to introduce expanded coverage that includes damage from overland flooding (Meckbach 2015).

Municipalities also purchase insurance to support burden-sharing from flood damage, specifically for legal liability and property damage caused by municipal infrastructure failures. Legal liability claims against municipalities have been growing in recent years as property owners argue that damage from sewer backups is a result of negligence on the part of the city to maintain its infrastructure (CBC News 2012; City of Hamilton 2013b). Only a handful of specialty insurers in Canada offer coverage to municipalities, and they are under pressure to raise premiums due to increasing exposure to liability claims (Canadian Underwriter 2013a).

Despite the exclusion of flood damage in 2013, many property owners in Calgary were compensated for sewer backups caused by floodwaters that entered the stormwater sewer system (Nelson 2013). The coverage of damage claims from overland flooding in addition to non-flood-related sewer backups led to a record $1.7 billion in insured losses (IBC 2013). Insurance also covered the majority of damage claims caused by the 2013 floods in Toronto, which amounted to $940 million in insured property damage.

Both Toronto and Calgary use municipal insurance in sharing the burden of natural disasters and have recognized the growing pressure on these systems as the costs of extreme weather increase. Toronto renewed its coverage in 2015 for an annual cost of about $5.1 million, which provides $100 million in liability coverage and $1.8 billion for property damage (City of Toronto 2015a). As a part of the contract, Toronto retains the first $5 million of the costs associated with liability or property damage. Calgary has a loss limit of $700 million for damage to property, with a deductible of $2 million, with similar retentions and coverages for liability (Official A, personal communication, July 11, 2016).

Although each municipal insurance policy provides property and liability coverage, policies vary between different municipalities based on the scope of the infrastructure they protect (e.g., critical infrastructure), the size of the deductible, and whether catastrophic perils are covered by a separate policy. In addition, coverages are diversified among insurers who negotiate with the city to take on a portion of the total risk.

But as losses associated with climate change, aging infrastructure, and the concentration of residential properties in low-lying areas increase, insurance could become unavailable or prohibitive, particularly among lower-income property owners and vulnerable communities (Thistlethwaite 2012). Insurance claims associated with water damage have reached record levels in the past 10 years, paralleling the loss pattern experienced by disaster assistance programs (IBC 2014; PBO 2016). In response, insurers have started to cap coverage for sewer backups, charge higher deductibles, and exclude properties that are the subject of repeated claims.

Overland flood insurance is similarly limited in high-risk areas, because offering coverage is uneconomical for insurers, given the concentration of risk. The insurance industry is working to address this challenge by proposing a public-private arrangement whereby a risk pool administered by insurers and subsidized by the federal government sells coverage to ensure affordability in high-risk areas (Thistlethwaite 2016).

Disaster assistance and insurance represent two ways in which Toronto and Calgary are successfully sharing the cost burdens associated with recovery from extreme weather. Property insurance in particular represents a critical risk-sharing and management approach, as it creates price incentives for property owners, developers, and planners to adopt practices that reduce exposure and vulnerability to climate change.

The way in which disaster assistance is currently employed, however, fails to provide an incentive for pre-disaster risk mitigation. In addition, disaster assistance compromises the benefits of insurance, since its availability limits the incentives for the same stakeholders to manage risk and purchase insurance. Provinces and municipalities, for example, may ignore insurance market signals, knowing that policies allowing development in high-risk areas will go unpunished, since funds for recovery in the event of property damage will be available from the federal government.

5. Sharing responsibility for risk reduction

A second dimension of risk sharing involves spreading the responsibility for risk reduction among non-governmental parties that contribute to, or are affected by, flood risks. Although governments necessarily play a central role in flood risk management, Seher and Löschner (2015) argue that this responsibility must be broadened through collaboration between governments and stakeholders to generate and evaluate flood risk information, and collectively determine a tolerable and acceptable level of risk as the basis for planning decisions.

Similarly, Treby, Clark, and Priest (2006) assert that the responsibility for flood risk reduction must be shared with actors whose behaviour has an influence on exposure and vulnerability to flooding. Notably, these actors include (1) parties involved in land development, such as planners, developers, and builders, and (2) parties involved in real estate transactions, such as sellers, purchasers, agents, appraisers, lawyers, lenders, and insurers. Individual property owners also have an important role to play in flood risk reduction (Sandink 2011).

There are many ways to share the responsibility for flood risk management; the following sections identify specific instruments that municipal governments can use.

5.1 Stakeholder engagement

One of the key governing resources of municipal governments is their capacity to mobilize otherwise disparate actors and interests and direct them towards a common cause. Stakeholder engagement – a social process of collaboration to find a collective solution – is a critical, organization-based element of flood risk management that can be achieved in various ways (Green and Penning-Rowsell 2010).

One proposed model involves “risk dialogues,” whereby stakeholders are brought together for focused meetings in which experts present possible flood risk scenarios based on projected changes in climatic conditions and predicted development in flood-prone areas in order to facilitate decision-making (Seher and Löschner 2015). Another approach is to form an advisory group made up of representatives from stakeholder institutions who work closely with public authorities to make decisions, develop policies, and formulate implementation plans for flood risk reduction (World Meteorological Organization 2006).

Municipal governments in Canada have long used advisory groups to inform policy- and decision-making, and this instrument of stakeholder engagement has a record of success at the local level in planning, transportation, and energy projects. Finally, engagement can also be virtual, facilitated through online technologies. Experiments with web-based collaboration platforms in the United Kingdom and Germany have yielded promising results (Almoradie, Cortes, and Jonoski 2015).

The focus of stakeholder engagement in Calgary has historically been on water quality and quantity rather than flood risk management, but flood risk has received increased attention in the aftermath of the 2013 flood. The Alberta government's Water for Life Strategy allocates responsibility for watershed management to 11 Watershed Planning and Advisory Councils, such as the Bow River Basin Council, which is the main governance body for the Calgary watershed. The Bow River Basin Council is a non-government, non-profit governance organization that advises the municipality on watershed management. Its stakeholder engagement committee focuses on promoting awareness of water quality and quantity and of activities to protect the basin and supporting coordination between agencies responsible for water quality, but it has no mandate for engagement on flood risk (BRBC 2016). Research by Alberta WaterSmart, a group of experts convened to advise on flood risk reduction, identified this gap, recommending that the Watershed Planning and Advisory Councils "work with their memberships to assess flood risk, consequences and mitigation strategies, and to provide advice to the Government of Alberta" (Alberta WaterSmart 2015).

At the provincial level, flood risk has been the subject of engagement with experts through the creation of a Flood Risk Mitigation Committee in response to significant flooding in 2005. The Committee's report included recommendations for municipalities such as the development of flood-risk maps, a disclosure system to identify homes located in flood-risk areas for homebuyers, the cessation of disaster-recovery payments for development in high-risk areas, and provincial support for municipalities to improve education through the deployment of technical expertise (Groeneveld 2006, 4). The failure to implement these recommendations was identified as a contributing factor in the devastating 2013 floods (Kovacs and Sandink 2013b).

After the 2013 flood, the City of Calgary created an Expert Management Panel on River Flood Mitigation. One of the panel's key recommendations was the creation of a permanent "team" within the City to monitor flood management and establish a link with provincial officials in charge of mitigation and loss reduction

(Expert Management Panel on River Flood Mitigation 2014). Calgary has also championed several public outreach and communication initiatives on flood risk (see section 5.3).

In Toronto, stakeholder engagement on overland flood risk is largely the responsibility of the Toronto and Region Conservation Authority (TRCA).[3] The City and the TRCA work with private property owners to develop a Coordinated Watercourse Management Plan for properties located within floodplains and along river banks (City of Toronto 2014). Toronto has also initiated stakeholder engagement to manage basement flooding risk through Environmental Assessments (EAs) in "priority study areas" identified as most vulnerable to basement flooding. These EAs were adopted as a part of the city's Basement Flooding Protection Program established as a part of the Wet Weather Flow Master Plan in 2003. City Council has expanded the program several times in response to basement flooding in 2005, 2012, and 2013.

According to City staff, the objective of the Basement Flooding Protection Program "is to reduce the incidence of basement flooding by enhancing both sewer capacity and overland flood design standards in key areas" (City of Toronto 2013a, 14). These studies examine the performance of the sewer system at times of extremely heavy rainfall and use this information to identify infrastructure improvements to manage flood risk. These improvements include constructing new stormwater tunnels, installing storage tanks, expanding the size of sewers, and increasing the number of catch basin and sanitary covers. The results of the EA are incorporated into a five-project list that goes before City Council for approval. To communicate City decision-making on the EA process, a "Field Ambassador" is made available to provide information to each community (City of Toronto 2016d).

5.2 Public participation

Beyond stakeholders, municipal governments can strengthen flood risk management by creating opportunities for *public participation*, which, if implemented in a systematic and meaningful way, offers a number of benefits (Oulahen and Doberstein 2012). First, it informs individuals and groups about flood risks and increases the likelihood that they will adopt property-level protective measures (Sandink 2011). Second, it helps public managers access site-specific data that would otherwise be difficult to compile, such as information on drainage problems that are frequently unreported. Third, it helps local authorities to develop risk-reduction strategies that fit appropriately with the local context and meet the social expectations of different population subgroups in the community (Affeltranger 2001).

3. Conservation authorities are local watershed management agencies in Ontario that are mandated through provincial legislation to protect and manage water and other natural resources in partnership with municipal governments and other organizations.

One promising mechanism to involve the public in flood risk management policy-making is a *public participation geographic information system*, a web-based interface that allows users to work with geospatial data (such as digital maps and satellite imagery) to make informed judgments about place-based flood risk management proposals, scenarios, and debates (White, Kingston, and Barker 2010). Online engagement using a public participation geographic information system has a number of advantages over traditional public meetings, including:

- *flexibility*: since online engagement is not fixed to a particular time and location, the potential for participation is expanded;
- *accessibility*: participation is easier for people with disabilities, particularly those who are mobility-impaired;
- *data processing*: user-inputted electronic data can be analyzed more efficiently and displayed instantaneously to facilitate group consensus;
- *interactivity*: real-time feedback can be collected in response to changing scenarios and visual impacts.

A related instrument to involve the public and generate valuable intelligence to support decision-making is a *citizen observatory* – a network of citizens who use information and communication technologies to help collect flood risk data and exchange knowledge (Wehn et al. 2015). Citizen observatories are a form of "citizen science" – research that enlists public volunteers in collecting and processing data to support scientific inquiry and decision-making – an approach that is increasingly common in environmental management and weather services (Gura 2013; Silvertown 2009). This participation can take many forms, including collecting photo evidence of flood damage, monitoring water levels using sensors, and providing real-time observations of river and stream activity via mobile applications or social media.

There is no formal system of citizen observation for flood management in either Calgary or Toronto. Twitter, however, is being used as an approach to share information during flood events. In Alberta, the hashtags "#ABflood" and "#YYCflood" were used by citizens and municipal officials to provide updates on the flood status including information about evacuations. Similarly, "#TOflood" was used in Toronto to communicate information about service disruptions and road closures. Although researchers are exploring the use of Twitter to help spatially identify flood risk through geocoding tweets, the practice has not been widely adopted by municipalities.

Other practices, such as risk dialogues, coordinated public participation, and GIS public interfaces, remain underutilized. But this is not entirely surprising: despite the importance of stakeholder and public engagement in flood risk management, identifying and working with diverse individuals and organizations is a daunting challenge for municipal governments (Albright and Crow 2015; Tseng and Penning-Rowsell 2012).

5.3 Risk communication

Information is a powerful resource that municipal authorities can harness to share the responsibility for flood risk reduction. Risk communication refers to the transmission of information about risks to interested parties. In the context of flood risk management, risk communication serves both short-term objectives, such as alerting at-risk populations about an immediate flood threat, and long-term objectives, such as raising awareness of flood hazards and promoting self-protective behaviour.

An effective *flood-warning system* gives property owners and emergency responders more time to prepare for a flood in order to mitigate damages and reduce threats to life and safety. Components of a flood-warning system include:

- detection of flood threats (usually by monitoring meteorological conditions);
- flood forecasting (modelling to simulate potential floods);
- monitoring critical thresholds (the point at which a warning should be issued);
- warning dissemination (issuing a warning via one or more communication channels).

The quality and execution of these technical components is important, but the effectiveness of a flood warning system also depends heavily on the public's behavioural response to warning information (Parker, Priest, and Tapsell 2009). For instance, it is common for residents to underestimate the implications of warnings for themselves and their property, to seek confirmation of warning information by consulting other sources before taking protective action, and to resist evacuation unless flooding is expected to be severe (Handmer 2000; Mileti 1995). Therefore, a warning system must be complemented by preparedness planning, including public education to ensure that people at risk know in advance what to do during a flood emergency (Carsell, Pingel, and Ford 2004).

In Calgary, responsibility for flood forecasting and warnings is shared by the City and Alberta's River Forecast Centre. Information on river conditions is collected by City staff and distributed to TransAlta (the utility that manages dams on the Bow River), and provincial emergency management officials (Expert Management Panel on River Flood Mitigation 2014). While Calgary is responsible for issuing warnings, data collection and monitoring of river flows are conducted by a provincial ministry, Alberta Environment and Parks.[4]

In the aftermath of the 2013 floods, Calgary has taken steps to improve the communication of flood risk to citizens. These include the creation of a corporate flood communication plan that provides "citizens with year-round information on flood readiness and how to prepare for all types of flooding" (City of Calgary

4. Formerly Alberta Environment and Sustainable Resource Development.

2016d). The plan includes a public awareness campaign, newsletters, open houses and workshops, and a community advisory group. Demonstration Low Impact Development projects[5] have also been used as a way to encourage public awareness of flood risk management (City of Calgary 2016a).

Toronto shares responsibility for flood warnings with the Toronto and Region Conservation Authority and the Credit Valley Conservation Authority. The Conservation Authorities (CAs) collect information from a network of flood gauges and also manage important flood-control mechanisms such as dams and dikes. The CAs use information from gauges to influence river flows and provide notice to municipalities and the public in the event of potential flooding (Conservation Ontario 2013b).

Risk communication efforts in the City of Toronto are evident in the Wet Weather Flow Master Plan, which allocated a budget of $6 million to a print and an advertising campaign and a Community Program for Stormwater Management. The latter supported demonstrations of best practices in urban water management, including workshops, education brochures, tree planting, and the planting of riparian vegetation (City of Toronto 2009a, 63).

It is important to note that the outreach discussed above has, for the most part, focused on stormwater pollution rather than urban or basement flooding. Although cities have drawn attention to this risk, they have not done so in a formalized process similar to overland flooding.

Flood hazard disclosure – a legal requirement that sellers and their agents inform potential buyers that a property has experienced, or is at risk of experiencing, flood damage – is a relatively simple information-based instrument to share the responsibility for flood risk management with property owners. The logic is that informed buyers will factor flood risk into their purchasing decision by, for example, adjusting their offer price or planning ahead to implement risk-reduction measures.

Hazard disclosure has been successful in other jurisdictions: for instance, the U.S. state of California's *Natural Hazards Disclosure Act* was passed in 1998, requiring sellers to complete a standard form that discloses whether their property is vulnerable to six specified hazards, including flooding. At the local level, municipal governments in several flood-prone U.S. states, including Florida, Louisiana, and North Carolina, have adopted ordinances in recent years requiring flood hazard disclosure for real estate transactions. While there are significant benefits to building greater flood-risk awareness among property buyers, research indicates that the impacts of flood hazard disclosure on real estate values is marginal (Yeo 2003).

5. Low Impact Development is an approach to stormwater management in which on-site natural features such as vegetated rooftops and permeable pavement are used to manage rainfall at the source.

Neither Calgary nor Toronto has adopted a by-law compelling property sellers to disclose previous flood damage or future flood risk. Based on documentary analysis and testimony from municipal informants, it appears that this policy tool has never been seriously considered in either city. Moreover, there is no obvious means by which property owners in either city might know whether their property has been flooded before or is in an area at risk of flooding in the future. Not only are records of both insurance claims and municipal compensation not publicly available, but also flood hazard maps are not easily accessible to the public and do not accurately depict urban flood risk.

5.4 Economic tools to share the responsibility of risk reduction

Municipal governments have access to a variety of economic instruments that can be used to induce residents to change their behaviour and share the responsibility for flood risk reduction.

Subsidies are conditional contributions toward the cost of an activity that serves the municipality's interests. For example, to cope with increasingly frequent and intense precipitation, many municipalities subsidize the installation of devices that prevent stormwater from backing up into underground spaces (Sandink 2013a). Winnipeg's Basement Flooding Protection Subsidy Program, for instance, offers homeowners a grant of up to 60 percent of the cost of installing a backflow prevention valve (a device that prevents sewer backup through floor drains) or a sump pump system (a collection basin with a pump to remove water) (City of Winnipeg 2015).

Credits use the reduction or elimination of a financial obligation in exchange for meeting specified performance criteria to stimulate behavioural change. In Waterloo, Ontario, for example, the Stormwater Credit Program offers residential property owners a credit of up to 45 percent of their assessed stormwater utility fee (see section 6), in exchange for managing stormwater on their property using approved techniques such as rain barrels, underground cisterns, or rain gardens (City of Waterloo 2016).

In both cases, municipal funds are used to create incentives for property owners to reduce flood risk, thereby sharing the responsibility for flood-risk reduction with individual homeowners, who are obligated to pay part of the cost.

Toronto's Basement Flooding Protection Subsidy Program offers up to $3,400 per property towards the cost of installing a backflow prevention valve or sump pump or disconnecting the foundation drain from the sewer system (City of Toronto 2016a). However, the cost of such a retrofit to an existing home usually exceeds this amount because of the high costs of re-routing underground plumbing (Sandink 2013b). Moreover, these programs have historically suffered from weak uptake among targeted property owners. Calgary does not use subsidies to avoid flood risks or prevent basement flooding. And neither Toronto nor Calgary has adopted a credit-based stormwater management program.

5.5 Regulatory instruments

A municipality's legal authority is an important governing resource, which can be employed in various ways to share the responsibility for flood-risk reduction.

5.5.1 Land use planning, flood mapping, and development control

Perhaps the most important authority-based instrument available to municipal governments is *land use planning*, which determines the location, type, scale, and density of development and the infrastructure that supports community life (Holway and Burby 1993). Land use planning can reduce flood risk by, for example, reserving land along waterways to make space for flood waters, regulating the type of development that is permitted in areas at risk of flooding, and restricting building density to minimize people and property at risk (Finlinson 2011).

Using land use planning in this way requires detailed spatial information on flood exposure in *flood hazard maps* (Kron 2007). Mapping areas and assets at risk of flood inundation graphically depicts legal and economic priorities for flood control and planning and facilitates estimates of potential losses associated with a particular flood. However, the value of flood maps in flood risk management depends on their accuracy, currency, and specificity. A recent national assessment revealed that flood maps in Canada have a median age of 18 years; most maps were produced before 1996. Only about 35 percent of the maps include urban areas, and most mapping is concentrated in Ontario (59%), Quebec (21%), and British Columbia (10%) (MMM Group Limited 2014). Moreover, while existing flood maps plot the likelihood that an area will experience a flood of a particular return period, they give no indication of the risk associated with these floods, because they do not consider the exposure of people and property (Reid 2014). Although publicly available demographic, hydrologic, and spatial data can be combined to assess and map flood risks at the city scale (Armenakis and Nirupama 2014), many municipalities lack the technical capacity or resources to undertake this analysis without assistance from higher-level governments.

Responsibility for floodplain maps that inform land use is shared in both Toronto and Calgary, but Toronto cedes responsibility for regulating development in the floodplain to conservation authorities, whereas Calgary delegates mapping authority to the province and retains responsibility for development based on these maps. Neither Toronto nor Calgary, however, carries out land use planning to minimize the risk of groundwater or urban flooding, which in recent years has caused much more damage than riverine flooding.

A second way in which municipal governments can use their authority to share responsibility for flood-risk reduction is by imposing conditions on development, such as minimum building elevations, the inclusion of protective walls and embankments, and the use of flood-resistant materials, defined as "any building product capable of withstanding direct and prolonged contact with floodwaters without sustaining significant damage" (FEMA 2008). In Kelowna, British Columbia, for example, the *Mill Creek Floodplain By-law* imposes conditions on the location, design, and construction of buildings in a floodplain area, including a minimum setback distance of 30 metres, a minimum elevation of 600 millimetres above the high groundwater table for the lowest habitable floor, and a maximum size increase of less than 25 percent of the structure's site coverage (City of Kelowna 2016). These rules affect approximately 6,000 property owners.

Toronto and Calgary rely on land use planning to manage riverine flood risk, whereas design standards and by-laws represent the main means of enforcing stormwater management outside of floodplains. Although these regulatory instruments represent powerful tools for flood-risk sharing, they are informed by historical frequency and inundation levels associated with flood hazards, rather than by flood risk. As a consequence, land use, design standards, and by-laws are standardized, rather than being more rigorous in areas with concentrations of physical and economic assets (such as downtown areas).

5.5.2 How Calgary uses planning and development controls to reduce risk

Alberta Environment and Parks (AEP) develops and maintains floodplain maps for the City of Calgary. These are based on the one-in-100-year flood design standard (Expert Management Panel on River Flood Mitigation 2014). Unlike Ontario, however, authority for development in the floodplain remains with the municipality rather than with Alberta's Watershed Planning and Advisory Councils. The Government of Alberta has sought to adjust this approach by proposing legislation that would restrict new development on the floodplains identified by mapping conducted by AEP, but until these changes are adopted, municipalities have authority over development in floodplains (PBO 2016). In addition, the floodplain maps used by the City of Calgary for development purposes were updated based on new modelling completed in 2014. Municipalities can invoke authority to restrict development only if the provincial map identifies an area as a floodplain. If city governments develop their own maps that suggest different risk exposures, they cannot restrict development and can only offer advice on strategies for protection against flooding.

In addition to regulating land use, by-laws and design standards can be used to influence the type and density of development and support infrastructure in ways that manage flood risk. Calgary's by-laws regulate development based on the location in the floodway, flood fringe, and overland flow area. No new buildings can be developed in the floodway, but the replacement of existing structures is allowed as long as they retain the same footprint. Other categories of development are permitted that do not place property at risk, such as agriculture, parks, or utilities (City of Calgary 2007b, 69). New development in the flood fringe or overland flow areas is allowed, but must be set back from the edge of the river by 6, 30, or 60 metres, depending on the location. Buildings in the flood fringe must be designed to limit structural damage from floodwaters; the first floor must be above the "designated flood level"; electrical and mechanism equipment must be above the flood level; and a sewer-back up valve is required (City of Calgary 2007b, 70). Buildings in the overland flood area require similar design elements, but must be constructed at a less restrictive 0.3 metres “above the highest grade existing on the street abutting the parcel that contains the building” (City of Calgary 2007b, 71).

All development in Calgary must also adhere to the City’s Stormwater Management & Design Manual, which enforces the dual-concept drainage approach by outlining design standards for “minor” and “major” stormwater systems. Developers are free to employ a range of these “minor” and “major” practices as long as these design standards are met and reported on through a Storm Water Management Report. The minor system is the first level of stormwater control (e.g., foundation drains, catch basins) while the major system (e.g., swales, culverts, stormwater ponds) should be designed to handle overflow that exceeds the minor system. The minor system is designed using a one-in-five-year storm calculated on a per-hectare basis for each tributary to the storm trunk. The major system is designed for a one-in-100-year storm (City of Calgary 2011, 72).

Calgary has also taken the important step of requiring the installation of backflow prevention devices in any new residential development (City of Calgary 2011, 122). According to Calgary’s Drainage Bylaw, downspouts in Calgary are required to be positioned two metres away from any roadway to help divert stormwater from the sewer system, and residents must keep any surface drainage instruments (such as swales) clear of debris (City of Calgary 2005). As in Toronto, downspout connections to the sanitary sewer system are banned (City of Calgary 2011).

5.5.3 How Toronto uses planning and development controls to reduce risk

In Toronto, land use regulation within the floodplain is the responsibility of the Toronto and Region Conservation Authority (TRCA), which is authorized under the provincial *Conservation Authorities Act* to establish regulated areas where development could be exposed to flooding or erosion, or lead to changes in watercourses that have negative effects on the local environment (TRCA 2016). Development can be permitted in these regulated areas through a rigorous permit process that requires a demonstration that the development meets technical standards identified in Section 8.4 of TRCA’s Living City Policies. For example, the developer must prove that “the control of flooding, *erosion*, dynamic beaches, *pollution* or the *conservation of land* will not be affected” (TRCA 2014, 122, emphasis in original).

Ontario’s conservation authorities are empowered to develop flood hazard maps in municipalities and restrict development in these areas. Ontario’s floodplain maps also adopt a relatively rigorous standard based on the one-in-100-year flood, or the worst flood on record. For this reason, the TRCA uses a design standard based on the levels and extent of inundation caused by the 1954 storm Hurricane Hazel, which is considered greater than a one-in-200-year event. This novel arrangement, whereby conservation authorities have authority over land use in floodplains, has been identified as an effective approach for managing flooding in Ontario (Shrubsole et al. 2003). For development outside flood-risk areas, Toronto employs a similar approach to Calgary. Developers must complete a Stormwater Management Report that identifies the practices they are adopting to meet the City's Wet Weather Flow Management Guidelines (City of Toronto 2006, 3). These include source controls (e.g., lot-level measures), conveyance controls (e.g., roadside ditches, swales, infiltration systems), and end-of-pipe controls (e.g., wastewater treatment, stormwater tanks).

Toronto's approach requires that developments retain stormwater on site "to the extent practical" as the same location before development. The minimum requirement is a "small design rainfall event" quantified as 5 millimetres over 24 hours (City of Toronto 2006, 7). For overland flows, properties must be protected from the one-in-100-year level of precipitation. Toronto also has more rigorous requirements for areas identified as at risk of chronic basement flooding or where an overland stormwater system has not been installed. The TRCA has developed flood-flow criteria for areas for new developments that contribute run-off to specific watercourses (City of Toronto 2006, 21).

Toronto has implemented several by-laws that share responsibility for flood risk management. For existing and new residential development, Toronto has mandated downspout disconnection to be phased in between 2011 and 2016, and instituted a ban on reverse-slope driveways and below-grade garages and connections to the sanitary sewer (City of Toronto 2016c). Toronto has also implemented a green roof by-law for new development, which reduces run-off from precipitation that infiltrates into the stormwater system. The by-law requires that new commercial developments that exceed a certain square footage include a green roof (City of Toronto 2009b).

5.5.4 Integrated stormwater management and low-impact development (LID)

Integrated stormwater management is a comprehensive approach to decreasing the volume of stormwater run-off into watercourses, primarily by retaining stormwater on sites and allowing it to infiltrate the soil (Chocat et al. 2001). It involves employing source water controls such as bioswales (vegetated areas near roads and parking lots), infiltration trenches (sub-surface, stone-filled furrows), retention ponds, pervious pavement (porous concrete or interlocking bricks that allow water to pass through), and green roofs (which use lightweight, absorbent media to retain rainfall). Municipalities can provide guidance on these practices as a way for developers to meet the design standards for stormwater management.

Effective integrated stormwater management spreads the responsibility for flood-risk management by requiring the participation of municipal authorities, developers, and residents. Responsibilities are typically codified in a master plan (Nie 2015). For instance, as part of Metro Vancouver's Stormwater Management Program, most municipalities in the region have completed integrated stormwater management plans through a collaborative process involving consultation with stakeholder groups, engagement with an advisory group of experts representing sectors such as development and agriculture, and public participation to review and evaluate the draft plan (Richardson 2012, 14–15).

Toronto and Calgary both encourage the use of low-impact development (LID) or source-control stormwater management practices to meet their design requirements. Calgary has guidelines for LID in its 2011 Stormwater Management and Design Manual. Research and demonstration projects for LID projects are also identified as priorities in Calgary's Stormwater Management Report. These efforts are designed to help inform future guidelines on integrating LID into mainstream stormwater management practices (City of Calgary 2009). Calgary also collaborates with the Alberta Low-Impact Development Partnership, a non-profit organization that generates knowledge on LID use in stormwater management through training, education, and demonstration projects.

Toronto employs a similar approach by establishing minimum storm management design standards, but also encourages the use of LID. Toronto has worked with area conservation authorities to develop the *Low Impact Development Stormwater Management Guide*, which outlines the information engineers and planners can use to ensure LID in addition to advising on the costs of different approaches (TMIG 2011).

Both cities support better site planning, the use of swales, permeable landscaping, green roofs, and bio-retention strategies (City of Toronto 2006; City of Calgary 2007a). Although these practices are not required (other than green roofs in Toronto for commercial developments), Toronto and Calgary are quantifying their contribution to stormwater source control at the lot level.

5.6 Limitations of risk reduction

This analysis of shared responsibility for risk reduction reveals a wide range of policies that a municipality can use to support flood risk management. The uptake of these instruments, however, appears to be limited, as we see in this assessment of their adoption and how they are used in Toronto and Calgary. There is little evidence of stakeholder engagement that focuses on flood risk and only partial adoption of some economic instruments.

Flood plain mapping, land-use planning, development conditions, and integrated stormwater management are employed as forms of risk sharing with other stakeholders, such as developers and conservation authorities (in Ontario). But the way these policies are employed is more consistent with the hazard-based approach than with risk management. In particular, policies sharing the responsibility for risk reduction are designed using information on the hazard rather than on exposure and consequences. Design conditions, for example, are not more rigorous in geographical areas with a higher exposure and vulnerability to damage where there are concentrations of population or economic assets; rather they represent a standard historical benchmark for the frequency and intensity of the hazard. Risk reduction instruments also reveal a disproportionate focus on riverine flooding rather than urban flooding, which represents a costlier source of damage.

6. Sharing the costs of risk reduction

The third dimension of flood risk sharing is the distribution of costs associated with publicly funded flood risk-reduction measures. The authority of municipal governments to levy taxes and fees provides a flexible set of instruments to raise revenue to fund collective risk-reduction initiatives. More specifically, a municipality can use policy to share the costs of investing in flood-risk-reducing measures with those properties that contribute disproportionately to the costs of flooding.

6.1 Corrective taxes

Corrective taxes aim to raise revenue to offset the costs of undesirable behaviour (such as development in a floodplain) (Cordes 2002). As a tool of flood risk management, differential property tax rates could be used to allocate the costs of flood defences to inhabitants of risky areas such as floodplains and coastal zones that disproportionately contribute to higher overall risk for the municipality (Mori and Perrings 2012).

Although there are few examples of such corrective taxation in practice, a simulation by Deyle and Smith (2000) in Florida found that, while the financial impact on property owners would be modest, "tax benefit equity" – the distribution of the costs of government services in proportion to their consumption – would be improved dramatically.

6.2 Risk-based charges

Municipal governments can effectively share flood risk reduction costs by levying a *risk-based charge* from property owners that is roughly proportionate to their property's contribution to urban flood risk. Akin to the "polluter-pays principle" (the economic tenet that firms or consumers should pay for the cost of correcting negative externalities they create) a targeted fee ensures that the costs of risk reduction are distributed equitably.

In Edmonton, for example, property owners are assessed a monthly Stormwater Utility Charge calculated based on the area of their property, its development intensity (proportion of lot used for its intended development), and a "run-off coefficient" relating to the permeability of the lot's surface (City of Edmonton 2016). Similar charges have been implemented in many other Canadian cities and in some cases they are coupled with incentives for property owners to reduce their contribution to flood risk (see section 5.4).

Aquije (2016) found that among the various financial tools available to fund stormwater infrastructure, user charges provide the best combination of stable revenue and fairness, in that beneficiaries of the stormwater management service are directly charged for their consumption of that service.

6.3 Special surcharges

A third economic instrument to share risk reduction costs, one that is more familiar to municipal governments, is a *special surcharge*. Unlike corrective taxes, which impose higher costs on properties that contribute to higher flood risk, these surcharges are applied municipality-wide in order to share the cost of flood mitigation measures.

For example, in 2015, Halton Regional Council approved a special surcharge to be added to residential utility bills (approximately $40 per house), intended to raise revenue to pay for a basement flooding mitigation strategy (Halton Region 2016). The strategy includes a comprehensive study of factors that contribute to basement flooding, financial assistance of up to $1,000 to help affected homeowners with flood-related clean-up costs, a subsidy of up to $2,725 to encourage disconnection of weeping tiles and foundation drains from the sanitary sewer system, redirection of downspouts away from homes, and the installation of sump pump systems or backflow prevention valves.

6.4 Examples of cost sharing in Toronto and Calgary

Toronto has recognized the need for cost-sharing tools. In December 2015, Toronto City Council approved the development of a separate "risk-based" stormwater charge to fund its Wet Weather Flow stormwater management plan. This charge will replace the existing funding model, which used the water rate to fund stormwater management. Flat rates will be assessed for residential properties, condominiums, multi-family residences, and commercial and industrial properties, whereas properties that exceed one hectare will be assessed based on their contribution to run-off (City of Toronto 2015b). Since many commercial and industrial properties exceed one hectare, the charge will be higher and act as an incentive to increase permeable surfaces or source control measures to divert run-off from the stormwater system (Smith Cross 2015).

Toronto also has an extreme weather reserve designed to absorb unanticipated financial impacts on the capital and operating budgets. There is both a corporate reserve to offset costs for the Parks, Forestry, and Recreation budget, and a transportation reserve to absorb deficits in the Transportation Services budget (City of Toronto 2016b).

Calgary uses a "Drainage Service Charge" to finance infrastructure supporting its stormwater system. Funds from the charge help to pay for "capital projects, retrofits, upgrades, operations, monitoring, regulatory reporting, and the maintenance of over 160 (wet and dry) ponds, almost 4,000 kilometres of pipe and over 800 outfalls" (City of Calgary 2016b). The charge is currently a flat rate rather than one based on lot size or run-off into the storm sewer system (City of Calgary 2016c). However, Calgary is considering the adoption of a run-off based model similar to that used in other Canadian municipalities (Grecu 2013).

Recent floods in Toronto and Calgary have prompted policies that share the cost of risk reduction, particularly the use of a separate stormwater charge. But until such measures are implemented, policies that share the costs of risk reduction remain underused.

7. Summary and conclusions

This paper used an instrument analysis to assess the way Toronto and Calgary are using public resources to share climate-related risks with a focus on flooding (see Tables 3 and 4). This analysis confirms that municipalities can use a range of risk-sharing policy instruments that engage multiple partners, including municipal departments, provincial governments, regional watershed management agencies, and the private sector.

Although Calgary and Toronto have adopted some risk-sharing instruments, they have not embraced the full range of tools available (see Table 4). For example, both cities encourage low-impact development and source-control practices by developers and property owners, but other than subsidies for backflow prevention valves, neither city uses economic instruments as incentives to promote the adoption of these practices.

In addition to exploring the extent to which risk sharing is (or is not) employed in Toronto and Calgary, the paper also looked at how these policies are used. Indicative of broader weaknesses in Canadian flood management, both Calgary and Toronto use flood hazard (e.g., one-in-100-year standards) rather than flood risk as a means of designing policy instruments. For example, design standards for buildings use historical flood experiences or stormwater discharge records to determine the drainage or land-use requirements for property development.

For some of these standards, such as Ontario's Hurricane Hazel Flood Event Standard, the requirements are quite rigorous (i.e., projection from a 1-in-150 year flood). However, flood risk exposure is not uniform across city boundaries: some areas contain more economically important and politically sensitive assets, such as downtowns or major transit routes and hubs. A risk-based approach would strengthen the design standard for development in these areas. In addition, most of the risk-sharing instruments adopted by Calgary and Toronto, such as flood maps, focus on overland flooding (e.g., riverine), rather than the more extensive problem of urban flooding (e.g., infiltration and sewer back-ups).

It is clear from this analysis that much more can be done to reduce municipal exposure to flood risk by expanding the use of risk-sharing instruments. Indeed, the limited use of these policies concentrates flood risk within urban areas, which can cause failures in insurance markets, increase the requirements for successfully obtaining disaster financial assistance, and risk legal liability through citizen-initiated or insurance-led lawsuits. This research represents a first step in expanding the conversation on the importance of risk sharing as a mechanism for sustaining urban resilience in the face of increasing flood risk and a changing climate.

Table 3. Instruments of Flood Risk Sharing	
Objective & Instruments	**Description**
Sharing burden of loss	Distribution to other parties of some of the burden of loss associated with flood risk and/or the responsibility and costs for measures to avoid, prevent, and mitigate flood risk
Disaster financial assistance	Financial transfers to help individuals, organizations, and other governments cope with disaster-related losses not recoverable through insurance
Insurance	Private risk management mechanism whereby policyholders buy protection against losses resulting from specified perils
Sharing responsibility for risk reduction	Spreading the responsibility for risk reduction among non-governmental parties that contribute to, or are affected by, flood risks
Stakeholder engagement	Interactive collaboration with individuals who could be affected by decisions, or who have resources to support implementation
Public participation	Engaging the public in flood risk reduction
Public participation GIS	Web-based interface with geospatial data for users to make informed judgments about flood risk management proposals, scenarios, and debates
Citizen observatory	Network of citizens using information and communication technologies to participate in flood risk data collection and knowledge exchange
Flood warning systems	Mechanism to inform residents about impending flood threats
Flood hazard disclosure	Legal requirement that sellers and/or their agents inform potential buyers that a property has experienced, or is at risk of experiencing, flood damage
Subsidies	Conditional contributions toward the cost of flood risk reduction activities (e.g., sump pump system; backflow prevention valve)
Credits	Reduction or elimination of a financial obligation in exchange for actions that reduce flood risk (e.g., stormwater credit)
Land use planning	Regulating the location, type, scale, and density of development and infrastructure to minimize exposure of people and property to flood hazards
Flood mapping	Graphic depictions of probable flood events used for planning purposes
By-laws	Rules that impose conditions on development with the objective of minimizing flood risk
Integrated stormwater management	Comprehensive approaches to decreasing the volume of run-off by retaining stormwater on site and allowing it to infiltrate into soil
Sharing costs of risk reduction	Distributing the costs associated with publicly funded flood-risk reduction measures
Corrective tax	Targeted tax to discourage risky behaviour and raise revenue to offset its costs (e.g., higher property tax rate in flood zones)
Risk-based charge	Fee levied from property owners roughly proportionate to their property's contribution to urban flood risk (e.g., stormwater charge)
Special surcharge	Fee added to property tax or utility bills to fund flood mitigation initiatives

Table 4. Risk-Sharing Instruments in Calgary and Toronto		
Instrument	**Calgary**	**Toronto**
Sharing burden of loss		
Disaster financial assistance	Province transferred nearly $2 billion in disaster assistance to property owners after 2013 flooding.	Did not receive provincial disaster assistance after 2013 flooding on the justification that the disaster was not beyond the City's fiscal capacity.
Insurance	Insurance covered much of the damage to private property in 2013 flooding, despite exclusion of overland flooding.	Insurance covered majority of damage claims in 2013 flooding.
Sharing responsibility for risk reduction		
Stakeholder engagement	No explicit engagement on flood risk. Some engagement through Watershed Planning and Advisory Councils and (temporary) Expert Management Panel on River Flood Mitigation.	No explicit engagement on flood risk. Achieved largely through Conservation Authority and environmental assessments.
Public participation	No formal system of participatory GIS or citizen observation. Limited public participation via Twitter feeds.	No formal system of participatory GIS or citizen observation. Limited public participation via Twitter feed.
Flood warning system	City issues warning based on data collected by provincial River Forecast Centre. Corporate flood communication plan under way.	Flood warnings issued to City and public by conservation authorities.
Flood hazard disclosure	No legal requirement to disclose flood risk during real estate sales.	No legal requirement to disclose flood risk during real estate sales.
Subsidies	No subsidies to support property-level flood mitigation measures.	Subsidies for backflow prevention valves, sump pumps and foundation drain disconnect, but weak uptake.
Credits	No credit-based stormwater management program.	No credit-based stormwater management program.
Flood mapping	Provincial government produces and maintains flood maps. Calgary produces local inundation maps.	Conservation authorities responsible for flood mapping.
Land use planning	City by-laws impose controls on development in floodway, flood fringe, and overland flow area.	Conservation authorities regulate development in flood risk areas.
Development conditions	Development must comply with standards set in City's Stormwater Management & Design Manual. Backflow prevention valve mandatory for new residential construction.	Development must comply with City's Wet Weather Flow Management Guidelines. Mandatory downspout disconnection. Ban on reverse-sloped driveways. Mandatory green roof for large commercial buildings.
Integrated stormwater management	Not required. LID guidelines specified in Stormwater Management & Design Manual. Collaboration with Alberta Low Impact Development Partnership for training, education, and demonstration projects.	Not required. LID Stormwater Management Guide informs site planning and encourages use of swales, permeable landscaping, green roofs, and bio-retention strategies.
Sharing responsibility for risk reduction		
Corrective tax	None. City lacks authority to set differential property tax rates based on flood risk. Provincial formula based on assessed value only.	None. Property tax rates set based on classes of property. Not used to target properties in risky areas.
Risk-based charge	None. Drainage Service Charge levies flat rate to properties based on lot size.	None. City designing a risk-based stormwater charge separate from water utility bill.
Special surcharge	Drainage Service Charge used to finance stormwater infrastructure.	Flat stormwater charge (bundled with water bill) used to finance stormwater infrastructure. Extreme weather reserve exists, but funds were not replenished after being used for the 2013 ice storm.

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