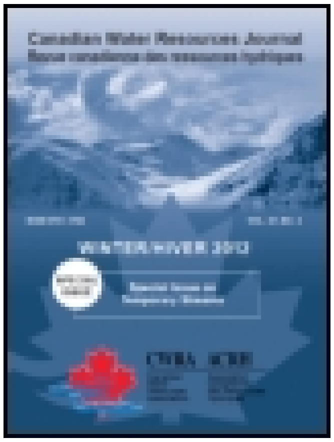

Canadian Water Resources Journal / Revue canadienne des ressources hydriques
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tcwr20

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Published online: 19 Jun 2014.

Canadian Water Resources Journal / Revue canadienne des ressources hydriques, 2014
http://dx.doi.org/10.1080/07011784.2014.914791

Toward water sustainability for Waterloo Region

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(*Received 22 February 2014; accepted 17 March 2014*)

The groundwater of the Waterloo Moraine has served the Region of Waterloo as a water source for over a century. Can it be a sustainable source for a future marked by rapid growth? By integrating socio-political aspects of water governance with a sound science-based understanding of the complex Moraine groundwater system, the Region is showing that this source will be sustainable in meeting the water needs of the community and the ecosystem for at least the next few decades. This paper discusses the various aspects of this successful strategy.

L'eau souterraine de la moraine de Waterloo approvisionnent la région de Waterloo depuis plus d'un siècle. Constituera-elle une source d'approvisionnement durable dans un avenir qui sera marqué par une croissance rapide? En intégrant les aspects socio-politiques de la régie de l'eau à une solide compréhension scientifique du système aquifère complexe de la moraine, les autorités régionales montrent que cette source continuera à répondre aux besoins en eau des communautés humaines et de l'écosystème durant au moins quelques décennies. Cet article traite des divers aspects de cette stratégie à succès.

Introduction

The Regional Municipality of Waterloo (the Region), located at the centre of the Grand River watershed in southern Ontario, is one of the fastest growing communities in Canada. The Region is a centre of higher education, with two universities, a community polytechnic college and several independent research institutes. While predominantly associated with high-tech industry, the Region is economically diverse; major industrial sectors include information and communications technology, automotive and advanced manufacturing, financial services, life sciences and food processing (Malone Given Parsons Ltd. 2013). In 2003, the Province of Ontario enacted its *Places-to-Grow Act*, designating the Region as one of the province's primary growth centres. As a result, the population is expected to increase by about 50% over the next 30 years, from the 2012 population of approximately 550,000 (Province of Ontario 2006; Region of Waterloo 2013d). These growth plans are economy-driven, and are based on the assumption that natural resources such as water will always be available to support this growth.

The main water sources for the Region, with its three cities and four townships, are the overburden aquifers of the Waterloo Moraine and associated sediments (for the Cities of Kitchener and Waterloo) and the Silurian dolostone bedrock aquifers (for the City of Cambridge) (Figure 1). Of these sources, the Waterloo Moraine aquifers are the most important, providing an estimated 45% of the municipal drinking water supply to the entire Region, with the reminder coming from other groundwater sources (~35%) and surface water (~20%). The Grand River, although it flows through the centre of the Region, has not been a major municipal water source due to the abundance of groundwater and the historic unsuitability of the River – which in the nineteenth and early twentieth centuries was a polluted and seasonally unreliable source of water (Badgley 1991). Thus, the Region's water source, although historically abundant, is limited.

Rapid urban growth in the face of a limited water supply is now confronting the community with formidable challenges. Rising water demands due to the growing population must be met, water quality standards must be maintained and the needs of the ecosystem as well as the agricultural sector must be satisfied. Overall, the water needs of the population must be balanced with those of the ecosystem. In addition, future challenges arising out of climate change must be anticipated and included in the planning process.

This paper provides an overview of how water managers in the Region are meeting these challenges by integrating a science-based approach with certain principles of sustainable water governance. The Waterloo Moraine is a particularly interesting case: a landform contributing to sensitive ecological features that span municipal (city-township) boundaries, and containing aquifers extending under rural and urban land uses.

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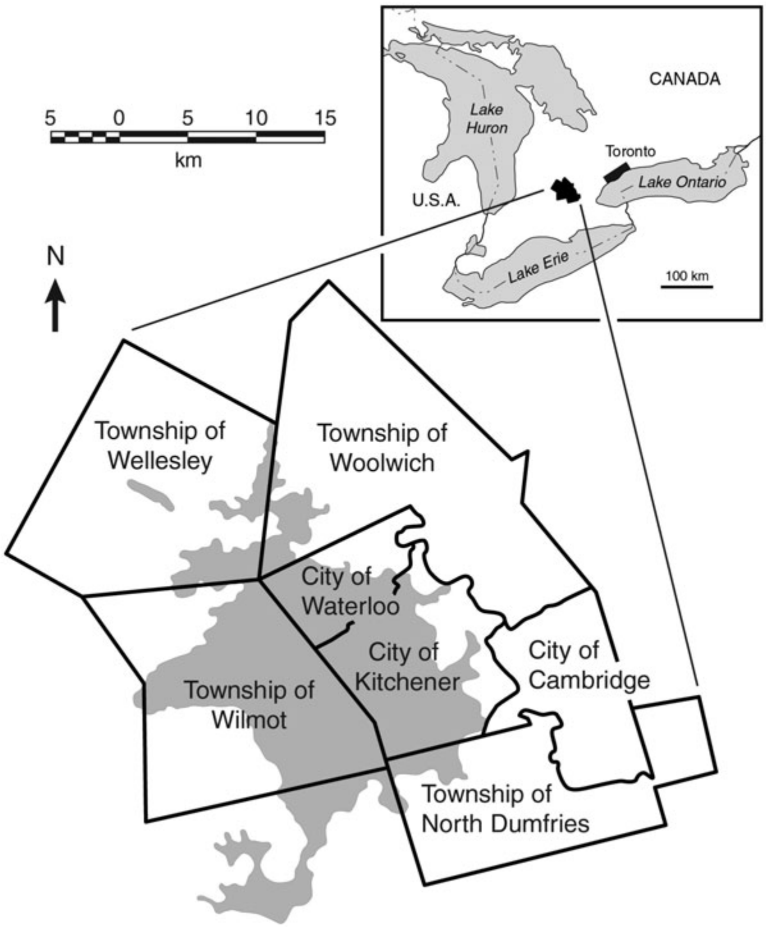

Figure 1. Waterloo Region with its three cities and four rural townships, also showing the Waterloo Moraine (shaded grey).

Development of the Moraine as a public water supply source

The residents of the twin Cities of Kitchener (formerly Berlin) and Waterloo realized in the late nineteenth century that they needed a reliable water supply for their community to prosper, and that this need would be best served through public ownership of the water facility. Thus Kitchener and Waterloo were among the first Ontario municipalities to create publicly owned water systems (Badgley 1991).

The earliest exploitation of the Waterloo Moraine for groundwater did not require any deep understanding of the hydrogeology. Indeed, the first municipal well fields for the Cities of Kitchener and Waterloo (circa 1900) were simply located next to existing city facilities, without the benefit of groundwater exploration (Berlin Water Commission 1899). These wells were flowing wells drilled into the Salina bedrock, a source of mineralized groundwater of inferior quality. At that time, a well was deemed unacceptable if not flowing strongly. Over the next two decades, as groundwater use increased, technology shifted from flowing wells and air lift pumping to conventional pump equipment, and there was concern about the lack of "easily" available groundwater. There were growing consumer complaints about the sulphurous water, likely worsened by the shift away from air lift pumping. By the mid-1920s, the overburden aquifers under the cities (on the eastern flank of the Waterloo Moraine) were finally recognized as sustainable sources of groundwater of superior quality (Kitchener Water Commission 1926).

Rapid municipal growth in the 1940s after World War II led to the Cities of Kitchener and Waterloo conducting groundwater exploration programs farther west into the rural areas on the Waterloo Moraine. This led to some local conflict with rural residents who were concerned about the possibility of lowered groundwater levels in the rural areas, for the benefit of the urban areas. By 1954, a feasibility study was sponsored by a number of Ontario municipalities to formally evaluate the benefits versus the cost of a water pipeline to one of the Great Lakes; this issue was often revisited over the next

60 years and became a matter of great public debate in the Region (for example, The Kitchener-Waterloo Record 1958).

In the 1960s and 1970s, the public water systems struggled to supply enough water to the growing communities and there was growing awareness of the need for water management within the Grand River watershed, with more than 30 studies carried out by provincial and municipal agencies (Badgley 1991). The first comprehensive hydrogeological study of the Moraine area, including a numerical model, was completed in 1973, with the goal of providing an important scientific tool for groundwater management (International Water Supply Ltd. 1973).

In 1973, the Regional Municipality of Waterloo was formed as a second-tier municipality, encompassing the three Cities of Waterloo, Kitchener and Cambridge, and the four rural townships of Woolwich, Wellesley, Wilmot and North Dumfries. The Region assumed responsibility for the municipal water supply of the three cities and the 15 individual rural water supply systems (Region of Waterloo 2013c). In addition, the Region implemented comprehensive programs for groundwater level monitoring and water conservation. Using groundwater from the rural areas to satisfy urban needs became an issue, keeping alive the seemingly endless debate over the merits of local groundwater resources versus a pipeline to one of the Great Lakes. Several Regional water supply master plans were completed that involved comprehensive groundwater investigations (Region of Waterloo 1987, 2000) and the recommended plan continued to be based on short-term reliance on groundwater supplies, with a long-term plan to eventually replace most groundwater sources with a Great Lakes pipeline. In addition, benefitting from the hydrogeologic expertise at the University of Waterloo, the Region's water management plans made use of various innovative and successful schemes to optimize the groundwater source and avoid over-exploitation of groundwater supplies. These measures, implemented from the 1970s through the 1990s, included a Regional agreement to limit the taking of water in the rural areas of the Moraine for urban use, exploration for new groundwater supplies throughout the Region, construction of river infiltration wells adjacent to the Grand River, using the Grand River as a seasonal source of municipal water, and then Canada's first artificial recharge-aquifer storage and recovery system on the Moraine.

Up until 1989, the Region's water management activities focused on water quantity issues. But in the 1990s, the Region's science-based approach to groundwater protection for water quality issues began in earnest in response to a severe local groundwater contamination problem. In 1989, groundwater contamination was discovered in the municipal wells of the town of Elmira, situated to the north of the City of Waterloo on the northeastern flank of the Waterloo Moraine. The chemical n-nitrosodimethylamine (NDMA) was discovered in the water, and the town of 8000 people suddenly lost its only potable water supply. The plume of contaminated groundwater was later mapped to be some four square kilometres in extent. The water supply problem was quickly mitigated by building a pipeline from Waterloo to Elmira, linking the town to the Region's Moraine water source.

Up to this time, like all Canadian municipalities depending on groundwater, the Region had no hydrogeologists on staff and instead relied on provincial government staff and private consultants to provide professional support on groundwater matters on a case-by-case basis. The events in Elmira made it apparent that this was not adequate. In 1990, the Council of the Region of Waterloo passed a motion asking the Waterloo Centre for Groundwater Research (WCGR) at the University of Waterloo to provide recommendations for a comprehensive assessment of the Region's groundwater resources. The resulting WCGR recommendations outlined detailed steps for a comprehensive assessment of the resource to meet long-term strategic planning needs, focusing on water quality and quantity, as well as on potential threats and ways to prevent future contamination (Waterloo Centre for Groundwater Research 1990). WCGR also recommended that the Region hire professional hydrogeologists to take charge of source water management.

By 1993, Waterloo Region had created a pioneering Water Resources Protection Strategy, and the first task was a comprehensive study of local groundwater resources. This groundwater protection strategy was the first of its kind in Canada and incorporated components including groundwater resource mapping, threats mapping, land-use policies, incentive programs and public education. This pioneering work later served as a model for the *Clean Water Act* (Province of Ontario 2006), which now provides a groundwater protection framework for the Province of Ontario.

It took almost a decade for the Province to follow the Region's initiative by developing a province-wide groundwater protection framework. This was done in response to the well-known tragic event in 2000 at the town of Walkerton, Ontario, where a municipal well became contaminated by *E. coli*, resulting in seven deaths and many severe illnesses. A public inquiry, the Walkerton Commission, was formed to examine the causes of the contamination. It soon became apparent that the immediate cause, runoff from a cattle pasture near the well, led to this disaster because of a criminal failure to carry out the mandatory disinfection procedures (O'Connor 2002a). This was compounded by a lack of standards for wellhead protection. Among the many submissions received by the Commission was an invited report by the Department of Earth Sciences at the University of Waterloo making the case for groundwater protection in Ontario (Frind et al. 2001). To prevent further tragedies of this type, Part 2 of the Report of the Walkerton Commission (O'Connor 2002b) recommended that drinking water sources should be protected by developing watershed-based source protection plans. Key milestones that followed were the Technical Experts Report for Source Protection (Province of Ontario 2004), and the *Clean Water Act* (Province of Ontario 2006). As a result, science-based source-water protection is now mandatory for all communal water systems in Ontario.

Balancing demand and supply: Can groundwater provide long-term sustainability?

Groundwater presently provides about 80% of the Region's water needs, with surface water comprising the remainder. The Waterloo Moraine and other groundwater sources have served the Region well but, nevertheless, groundwater is a limited resource. This fundamental situation is the cause of much of the ongoing debate about the future of the Region's water supply, and the possible need for a Great Lakes (Lake Erie) pipeline at some point in the future. A Great Lakes source is perceived to be an essentially unlimited supply of water, thus removing a potential constraint to continuing growth. In 2000, a Long-Term Water Strategy study, based on the assumption of water demand increasing proportionately with population growth, concluded that the Region would need a pipeline by about 2035 (Region of Waterloo 2000).

A Lake Erie pipeline, however, raises concerns such as a price tag of approximately $1.2 billion (at last estimate) (Region of Waterloo 2009). Basically, water running through the Region down the Grand River to Lake Erie would have to be pumped back up again, resulting in an increased energy demand at a time of rising energy costs. Intangibles include the loss of control over source water quality (Lake Erie receives discharges from both Canada and the US), higher treatment costs, an increased load on the Grand River to carry treated effluent and the ability of the River to carry that increased load, greater vulnerability of the single source to disruptions versus the flexibility of the dispersed groundwater sources, and the loss of local control of the supply system. In addition, switching to a pipeline-based supply would likely require shutting down the high-quality Moraine water source, providing a disincentive for groundwater protection.

This brings back the fundamental question: Is continued growth in the Region possible with a limited water source? Over the last two decades, the Region has developed an approach to deliver an adequate supply of high-quality water to the growing community, based on both demand management and supply management. On the demand side, the Region has implemented water-savings measures such as rebates for water-efficient appliances, municipal leak detection and water conservation bylaws that include restrictions on lawn watering. These measures have helped to lower the per capita water consumption in the Region from the Canadian average of 510 litres per capita per day (2009 data) to about 285 litres per capita per day (2011 data) (Environment Canada 2011; Region of Waterloo 2013a). This makes Waterloo Region one of the most water-efficient communities in Canada. A consumption rate of 160 litres per capita per day, close to the European average, is targeted for the year 2025.

On the supply side, the Region's success in optimizing the groundwater source has been encouraging. Additional groundwater supplies have been developed. Demand peaks are being levelled out by using and expanding the Region's aquifer storage and recovery system (Region of Waterloo 2013b). Population growth will be accommodated by a combination of water efficiency programs and increased groundwater extraction, including new extraction in the northern part of the Moraine. Municipal planning policies include Regional Official Plan policies to maintain groundwater recharge areas and minimize contamination. The overall result is that, for the foreseeable future, the supply matches the demand. The updated Region of Waterloo Water Supply Master Plan concludes that a pipeline to Lake Erie will not be needed before at least 2051 (Region of Waterloo 2013b). This once again raises and reframes the question: Is long-term water sustainability feasible on the basis of the groundwater source?

Sustainable water governance

The fundamental question in water sustainability is how much water of acceptable quality can the groundwater system ultimately provide for domestic and industrial use, without compromising the ecological health of environmentally sensitive aquatic systems such as streams and wetlands, and in such a way that future generations will have the same benefit of the resource as present generations? Beyond this fundamental issue, a sustainable water supply also depends on how the resource is used and managed – the governance of the resource. Wiek and Larson (2012, p. 3162) define sustainable water governance as

> the process that involves all relevant stakeholder groups in coordinating the water-related supply, delivery, use, and outflow activities in a way that ensures a sufficient and equitable level of social and economic welfare without compromising the viability and integrity of the supporting hydro-ecosystems in the long term.

These authors formally lay out the principles for sustainable water governance as:

- *Social-ecological system integrity:* This balances the needs of residents and industry with maintaining the viability of ecosystems.
- *Resource efficiency:* Reduce water use, enhance efficiency, recycle waste water and eliminate water losses.
- *Livelihood sufficiency and economic opportunity:* Everyone is provided with equal access to water of acceptable quality and quantity, including for recreation and enjoyment as well as for economic activities.
- *Socio-ecological civility and democratic governance:* All users collaborate in decision-making, and all assume personal and institutional responsibility for sustainable practices.
- *Inter-generational and intra-generational equity:* The water source will continue to provide future generations with the same opportunities arising out of access to water of acceptable quantity and quality, with benefits and costs continuing to be distributed fairly.
- *Interconnectivity from local to global scale:* Local-scale actions and processes can impact the larger-scale system, and vice versa.
- *Precaution (mitigation) and adaptability:* The community is expected to anticipate potential shortages and challenges, such as due to climate change, and find ways to mitigate problems.

These principles of water governance, originally written for the American Southwest (Larson et al. 2013), apply for the most part also to Waterloo Region. Key aspects are covered in the four papers of this Special Issue concerned with the societal components of the Region's approach to water management. The principle of socio-ecological system integrity, which calls for a balance in governance between human and ecosystems needs, is reflected in the Region's pioneering approach to the establishment of groundwater protection as official policy by integrating environmental protection and source water protection (Blackport and Dorfman 2014, this issue). The principle of interconnectivity across scales and processes is demonstrated by showing that Waterloo Moraine aquifers are part of the larger Grand River watershed and that groundwater and surface water act as one system (Veale et al. 2014, this issue). These same authors also stress the importance of adaptive management and coordinated multi-scale planning.

Principles of socio-ecological civility and democratic governance are reflected in the collaborative decision-making process integrating expert science, local knowledge, and community beliefs and values that has been implemented successfully in rural areas of the Region (Simpson and de Loë 2014, this issue). Precaution, adaptability and mitigation are also important guiding principles for protecting the quality and quantity of the water from various threats; these principles are set down in a proposed threat assessment framework for different types and scales of threats (Sousa et al. 2014, this issue).

Finally, the principle of resource efficiency (see discussion above) now forms one of the pillars of the Region's water management strategy for water sustainability. At present, consumption is actually deceasing in spite of growth; future projections see increases in supply keeping up with the growth in demand. Intergenerational equity is addressed to the extent possible by means of the Region's Long-Term Water Supply Plan (Region of Waterloo 2013b).

Science-based understanding of the water resource

Water governance as defined above by Wiek and Larson (2012) provides a socio-political framework for managing a water resource – what to do with the resource, and how to do it. It does not address the question of how much water there is – the limits of the resource. This question can only be answered on the basis of a science-based understanding of the water resource itself.

In the case of the Waterloo Moraine, the resource is a highly complex system of interwoven sedimentary units of sands, gravels, tills and clays that in some locations form continuous layers and in other locations form lenses of limited extent. To effectively manage this resource, water managers must understand the natural system. This requires understanding the dynamics of the groundwater flow system (precipitation, recharge, storage and flow, discharge), the structure of the aquifers and aquitards that control the flow, the linkages to environmentally sensitive features and the potential impacts due to land-use changes. Environmental needs (sustained base flow, wetland maintenance) can place a constraint on the groundwater volumes that are available for withdrawal. The quantity of water available for recharge can be potentially impacted as groundwater recharge areas are altered to accommodate development. Perhaps more importantly, the quality of the recharge can also be affected by typical urban contaminants such as road salt. For rural areas, threats and impacts differ in both type and scale (e.g. point vs. non-point threats, herbicides and pesticides, nitrogen loading, etc.). These threats, and how they are handled in a rapidly growing community depending on a finite water resource, can lead to societal conflict involving opposing economic and environmental goals and values.

The critical role of the Waterloo Moraine water source requires a science-based management approach to assure sustainability. Science, in the context of Moraine studies, involves geologic, geophysical, hydrogeologic, geochemical and modelling tools, all working together to create a conceptual model that can be used to give insight into the complexities of the Moraine system. Tools such as advanced exploratory methods including geophysics, isotopic techniques and advanced numerical modelling have evolved over time. Also, the emerging use of more advanced stratigraphic visualization tools and geologic databases (such as applied to the Oak Ridges Moraine; Sharpe et al. 2002) has significantly enhanced the understanding of the hydrogeology of moraine systems in general, assisting in the sustainable management of the resource.

The cumulative efforts of data collection and the adoption of evolving methodologies over the past 40 years have established a solid science base for the continual advancement of understanding of the Waterloo Moraine water resource. A regional geological investigation led by the Ontario Geological Survey has integrated existing data, assessed data gaps and collected new data in a modern basin analysis context (Bajc et al. 2014, this issue). The outcome of this work, a three-dimensional numeric geological model, has been integrated by Blackport et al. (2014, this issue) with the existing hydrogeological database to develop a detailed conceptual model of the Moraine architecture that reflects the hydrogeological characteristics of this complex system. The conceptual model frames the extent of the aquifers that provide the water source, the aquitards that protect the aquifers and the key recharge areas that replenish the system, as well as the linkages between municipal aquifers and sensitive environmental features such as cold-water streams and wetlands that depend on groundwater discharge. Waterloo Region is fortunate in the wealth of data available and the ability to use complementary data and analysis to support continual iterative improvement of the conceptual model. A good example is the value of geochemical and environmental tracer data, which clearly reveal the anthropogenic origin of certain contaminants in the groundwater, not only at surface locations but also in deeper parts of the aquifer that had been thought of as protected and isolated from surface contaminants (Stotler et al. 2014, this issue).

The empirical and deterministic framework of the Moraine requires dynamic modelling of the groundwater flow system to resolve issues of water supply and sustainability. Modelling of the Moraine has been evolving from its early beginnings in 1973, building on better data and improving computational resources, and resulting in better understanding and sophistication (Frind et al. 2014, this issue). The history of modelling over 40 years highlights the effects of unavoidable uncertainties in the data and the conceptualization. The latest iteration of the dynamic groundwater modelling for the Moraine by Meyer et al. (2014, this issue) has reached a level of sophistication where it can serve as a practical tool for the management and protection of the resource within the current legislative requirements of the Provincial source water framework (Province of Ontario 2006). The model has been calibrated against the large database and is judged to be valid for predictive purposes. In a detailed water budget and risk analysis study, this model indicates that the projected municipal water demand to 2031 can be met with the existing system of wells without causing a significant reduction in groundwater discharge to ecologically sensitive streams and wetlands, thus giving credence to the claim of long-term sustainability of the Region's water supply.

As scarce as data may seem for regional groundwater studies, there are now large amounts of commonly disparate data available for integration and analysis. An ongoing challenge will be to find ways to efficiently manage this accumulated knowledge – to store, access and integrate with new information as the knowledge base expands. Data collection costs continue to rise and the need for more sophisticated data continues to increase in response to the increasing impact of land use pressures. Holysh and Gerber (2014, this issue) discuss the challenge in the management of the groundwater knowledge base and offer a blueprint for knowledge management based on transparency and accessibility.

Conclusion

A successful water management strategy to meet the needs of a growing community in the face of a limited resource requires both the consideration of socio-political aspects of water governance and a sound science-based understanding of the resource itself. For Waterloo Region, the basic principles of water governance are reflected in the societal components of the Region's approach to water management. Scientific tools have evolved to provide a conceptual understanding of the complex Moraine water source and to translate this understanding into effective policy. Using these tools, the Region is successfully meeting the challenges of providing a sustainable water supply to the growing community, and at the same time maintaining the health of the ecosystem dependent on groundwater. Aspects of this science-based water management strategy may be applicable beyond the boundaries of Waterloo Region.

Acknowledgements

We thank Chris Neville, Rob de Loë, Hazen Russell, David Sharpe and Ray Blackport for helpful suggestions that substantially improved this paper. We also thank Tracy Barry for help with the graphics, and Nicolas Benoit for verifying the French translation. This contribution to the Special Issue on the Waterloo Moraine was supported by the Groundwater Geoscience Program, Geological Survey of Canada, Natural Resources Canada, and the Water Institute, University of Waterloo.

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