Approaches to address long-term, cumulative impacts of urban wastewater and stormwater on freshwater systems

-- Workshop Narrative --

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by:

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1. Introduction

A healthy water environment is important for human and ecological health. While the short-term effects of spills or urban discharges (e.g. stormwater and wastewater effluent) can be readily apparent, by the time many long-term effects of environmental degradation emerge, options for prevention or remediation may be hard to identify. Further, solutions can be costly to implement and the subject of higher uncertainty with respect to effectiveness, in part due to difficulties in attributing effects to specific causes or sources.

For example, phosphorus is a key nutrient contributing to eutrophication in freshwater systems [1]. Controls implemented to reduce current sources of phosphorus may not be sufficient to reduce the risk of eutrophication in water bodies given historic depositions of phosphorus in sediments. When on-going phosphorus loads are reduced, the change in chemical equilibrium can trigger the release of stored phosphorus from sediments. The form of phosphorus released from sediments can have high biological availability [2], [3] , delaying recovery from eutrophication even when external loads have been reduced [2]. Two of the important questions facing decision-makers in nutrient-stressed watersheds are: 1) how to identify and implement options to equitably share responsibility for the effects of both current and historic phosphorus loads; and, 2) how to adaptively manage phosphorus reductions as new understanding emerges about the effectiveness and time-scale required for watershed recovery. Lake Erie is a high-profile example of a waterbody that has demonstrated long-term effects of excess phosphorus and the need for adaptive responses as new information emerges[1].

Long-term, chronic effects of urban wastewater and stormwater on receiving water environments are difficult to assess for many reasons, including other concurrent stressors, legacy issues (such as sediment contaminants) and limitations of scientific understanding. More importantly, each waterbody has its own natural geology, soils, groundwater interconnections and water sources, flow rates, land use, resource use and natural resource extraction history, biota and climatic influences. The scale of watershed chosen for analysis, from local stream reach to continental basin, also influences the approach used to assessing urban impacts.

Canadian Water Network (CWN) hosted a workshop in February 2017 to discuss the long-term effects of urban systems on the water environment. Prior to the workshop, CWN commissioned a background paper to provide an initial summary of current scientific knowledge on contaminants and issues that may contribute to, or

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[1] For more information, see for example Heidelberg University's website dedicated to Lake Erie algae at URL: http://lakeeriealgae.com

impact, the long-term, chronic effects of urban wastewater and stormwater on the environment. Five categories were identified:

1. Conventional and legacy pollutants (e.g. phosphorus, metals, pathogens, sediments);
2. Emerging contaminants (such as endocrine disruptors, nanoparticles, micro and fibrous plastics);
3. Physical alterations (i.e. hydrologic and geomorphologic changes, thermal regime changes and anthropogenic responses to erosion and flooding);
4. Global environmental trends (i.e. climate change, biodiversity loss, invasive species and urban population growth)
5. Interactions and local context (e.g. receiving water characteristics, synergistic or antagonistic effects of stressors and management approaches such as total load management).

A list of workshop attendees is provided in Appendix A.

At the workshop, many of the specific challenges were itemized, such as changes to water chemistry, temperature, flow regimes and geomorphology. Some consequences of the effects were also discussed in more detail, including eutrophication, algal blooms and broader ecosystem impacts that reduce biodiversity, change the structure and function of ecosystems, or trigger endocrine disruption in fish. The importance of understanding the context for the impacts was reiterated, including consideration for the variability of solutions to suit specific watershed characteristics and ecological features, as well as the need to garner political support and to obtain necessary budget resources.

The concept of integrated watershed management was generally recognized to be essential to successfully addressing long-term impacts to the water environment. Although there are many challenges, there are also success stories involving municipalities, senior government levels, conservation authorities, academic researchers and/or other collaborators. This document outlines elements of some of the successful approaches used to advance integrated decision-making and highlights select programs and projects as pragmatic examples.

2. Challenges

Urbanization and urban effluents are rarely the only stressor within a watershed. In addition to the challenge of identifying and mitigating long-term effects from urban sources, agricultural, industrial and resource extraction activities can also contribute to watershed-scale effects. Attributing cumulative effects to individual stressors is often difficult. For example, urban watercourses typically exhibit stressed aquatic populations and reduced biodiversity very early in the urbanization process (consistently by the time a watershed is 10% urbanized but as early as 0.5% urbanization [4]–[6]). Scientific investigations into the source of stress have identified potential culprits to be altered water flows, impaired water quality, increased water temperatures, altered aquatic habitat or a combination of some or all of these factors. The term *urban stream syndrome* [7] was coined to refer to the impaired condition of urban watercourses. This term acknowledges the difficulty in identifying a simple causal relationship to explain the globally consistent observations that aquatic biodiversity becomes impaired with urbanization.

Cumulative effects may be initially imperceptible or not observed with standard monitoring programs. Eventually, tipping points can be reached that fundamentally change the ecosystem. For example, the long-term effects of endocrine disrupting substances on aquatic ecosystems are unknown. Exposure of fish species to estrogenic compounds is known to result in altered sexual development, the presence of intersex species, changed mating behavior [8] and an increased proportion of female to male individuals in some species [9]. Thresholds have not been identified in natural systems but scientific experiments indicate concentrations may reach tipping points beyond which biotic communities become severely impaired. In an experiment within Canada's Experimental Lakes Area[2], very low dosages of an endocrine disrupting substance, equivalent to typical concentrations in wastewater effluents, had substantial negative effects on minnow populations within a 2-year period, leading to near extinction of the species from the lake [10]. The minnow population recovered after the dosing was discontinued.

In the natural environment, away from controlled experimental conditions, aquatic ecosystems are highly complex. The interactions of pollutants with aquatic ecosystem structure and function are not well understood, in part because of the potential for synergistic or antagonistic chemical-biotic interactions and in part due to the numerous potential scales upon which changes take place. Ecosystems operate across spatial scales from the molecular and cellular level to the scale of continental water basins. Similarly, time scales range from the immediate to the long-term. For example, depressed levels of dissolved oxygen can quickly cause fish deaths, but eutrophication in lake systems can take years of excess nutrient loading to become evident and may still not be fully expressed in lakes such as Lake Erie, Lake Winnipeg and Lake Simcoe. As either space or time scales increase, new ecological variables and emergent interactions occur [11], [12]. Within this context of complexity, assessing the relative importance of urban stressors to long-term effects within a watershed is difficult [9] especially now that changing climatic conditions are creating additional variation in aquatic system responses to stressors [13]–[15].

The complexity and multiple scales of ecosystem structure and function require long-term perspectives, especially to understand and address chronic stressors. If a tipping point is reached, returning the watershed to its original state can take much more effort than simply removing the stressor, as has been the experience with

[2] The Experimental Lakes Area, in Ontario, is managed by the International Institute for Sustainable Development, see URL: https://www.iisd.org/ela

removing current phosphorus sources to address eutrophication. An adaptive approach that allows decision-makers to incorporate new information, including trends evident from monitoring ecosystem conditions, is necessary.

In addition to scientific challenges, several governance and management issues can also arise. Setting priorities and engaging stakeholders in the development of a common set of goals and priorities takes time and leadership. Various stakeholders can differ in their perceptions of risk, in the desired uses for watershed resources, and in how ecosystem services may be valued. Further, watershed management typically requires collaboration among multiple organizations, which each cover only a portion of natural water systems because they rarely have boundaries that match the geographic drainage boundaries of watersheds.

Within the political realm, challenges arise due to competition for funding priorities. The Canadian infrastructure deficit reflects a need to repair and replace existing infrastructure even before consideration for technological or other upgrades. Municipalities and other governments face pressures to embrace economic development opportunities, even those that are known to stress aquatic environments. For example, land development for housing in previously un-urbanized catchments brings property tax revenues, provides housing for growing populations and satisfies the expectations of land developers who own the land. Municipalities often face pressure to support conventional suburban development patterns that are perceived to be desirable to the home-buying public and with which municipal staff and developers are familiar. Conventional subdivision developments increase the urban extent and perpetuate an urban form that can contribute to long-term impacts, even in subdivisions where developers have adopted low impact development techniques (e.g. due to flow regime changes [5], [7], road salting [16], temperature regime change and loss of riparian cover).

Perhaps one of the most significant challenges to addressing the long-term effects of urban stressors to waterbodies is the need for sustained commitment to monitoring and action over timeframes that well exceed political election cycles of 3 to 5 years. Political support and on-going public support for necessary funding, data collection and management measures requires consistent nurturing and resources. In other words, attention, time and effort are needed to develop and maintain political and public support to sustain data collection programs, to implement operational improvements and to make capital improvements.

These challenges are important but not insurmountable, as discussed further in Section 4, Approaches.

3. Integrated Watershed Management

Integrated watershed management (IWM) – also called integrated water resource management (IWRM) – is an adaptive approach that can include urban and non-urban stressors, as well as multiple stakeholders representing a range of activities and ecosystem needs. Conceptually, this approach is favoured by watershed decision-makers to address long-term chronic impacts because it considers multiple aspects of watershed health, is flexible and can readily incorporate a long-term perspective. However, it is not a consistently defined term and there is no single, accepted definition of IWM. The term may be used interchangeably with integrated water resource management (IWRM) and can mean different things to different audiences. Provided stakeholders agree on the use of the term for their purposes, the flexibility provided through the IWM concept is an advantage because it can enable issues to be dealt with in an equitable manner through consultation with stakeholders with multiple interests and with targeted strategies to improve watershed health.

It is not the purpose of this report to closely define IWM. Instead, it is the conceptual approach of considering multiple aspects of watershed health that is important. At common scales of watershed assessment (for example, the scale of Ontario's Conservation Authority watersheds or the International Joint Commission watersheds), urban areas are only a portion of each watershed's land use. To understand watershed ecosystems, urban stressors cannot be considered in isolation of each other or in isolation from non-urban stressors. For example, both stormwater and wastewater systems alter nutrient loads to waterbodies. Similarly, agricultural sources can contribute significant nutrient loads on a watershed scale. An integrated approach may begin with urban sources of nutrients but with the intention to expand to include all sources, such as nutrient loading from agricultural, industrial or recreational activities. The IWM concept provides the flexibility to incorporate different aspects of watershed health. The scope of issues addressed can be broadened as resources become available, as stakeholders become engaged and as an understanding builds regarding a watershed's health and stressors.

Watersheds are the decision-making unit for IWM approaches to manage surface water. However, alternative units may be used, such as ecozones, when integrated decision-making is based on other features or activities, such as groundwater resources, ecological conditions, natural resource extraction or endangered species. The Polis Project on Ecological Governance describes four underlying concepts for an integrated governance approach to water resource management [17]: precaution in recognition that prevention of harm is better than subsequent compensation or remediation; ecosystem-based management with ecosystem integrity setting the context for management decisions; matching of authority to jurisdiction with "nested" jurisdictional powers; and, adaptive management so that plans and policies are continually modified to respond to ecological, economic and social feedback.

IWM is place-based, taking into consideration a watershed's natural features, human uses, ecosystem needs and other factors, such as legacy contamination. The key feature of IWM is that it takes into consideration multiple factors, conditions and stressors for a waterbody. Using the IWM concept allows decision-makers to form a vision for a watershed that is inclusive of the needs of the ecosystem, while considering human uses of the watershed resources, normally in consultation with stakeholders. The concept has flexibility in terms of how action plans can be built around the vision. It also allows for adaptive management as conditions change, as opportunities arise and as new scientific understanding develops. Action plans can be developed based on institutional responsibilities, priorities, available budgets, opportunities for collaboration, direction provided by leaders or champions, available research and data, etc. For its flexibility and adaptive potential, IWM is an approach that may help resolve the challenges of multiple and long-term, chronic impacts.

4. Approaches

There is no single formula or approach to implement integrated watershed management. Watershed characteristics, stressors, scale, socio-economic context and political leadership all contribute variables that require place-based solutions. We explore four themes that can be incorporated as part of the goal for integrated watershed management. In all cases, monitoring programs can provide vital data needed to better inform decisions. Similarly, collaboration with research agencies can boost resources deployed in understanding long-term impacts of urban infrastructure. The four themes explored are:

1. Holding a long-term vision
2. Using opportunities to take action
3. Using existing science-based protocols and tools
4. Regulatory support for the watershed scale

Theme 1: Holding a long-term vision

A compelling vision for the ecological health of local waterbodies can mobilize political and public support. It can also attract collaborators and leverage the resources of multiple stakeholders. Similarly, a vision for infrastructure renewal, with goals for environmental protection and continuous improvement, can garner needed support for infrastructure investments, operating budgets and, if needed, research to optimize the design and operation of these investments.

Projects of all sizes and durations may be implemented when working towards a long-term vision. From pilot projects or multi-million dollar capital investments, each project and decision can be a stepping stone to achieving the long-term vision, and can provide lessons about long-term impacts and how to best achieve the ecological health of a given waterbody by reducing contaminant releases, restoring natural flow regimes, protecting aquatic habitat, etc.

Achieving a long-term vision requires an adaptive approach, which takes into account the experience of previous projects and informs successive stages of detailed planning using the cumulative results to date. This approach is generally open to considering new opportunities, such as research partnerships and innovative technologies or funding models. It is also open to new scientific understanding developed through monitoring programs. In the case of infrastructure renewals, discussions on the need for both reliable levels of service and for doing things differently can build working relationships across the organization and with partners and stakeholders. Decision-makers, such as political representatives, must have confidence that recommendations for infrastructure renewal are sound.

Identifying benchmarks or metrics to assess progress and to communicate with stakeholders can be an important tool to maintain relationships and to inform next steps. Monitoring is essential but, due to budget limitations and scientific uncertainties, will not answer all data needs. Nevertheless, over time and with an adaptive approach, new information can be incorporated into decisions as it becomes available. Over time, with a long-term vision, organizations can build data sets and further the understanding of relevant science, technologies, costs, benefits, and trade-offs. The Grand River Conservation Authority provides one example of an organization that has built long-term datasets and research collaborations over many years to the benefit of numerous watershed stakeholders (Box 1).

Long-term visions for ecological health or infrastructure renewal require constant communication. For instance, the operational and capital investment needs of aging water infrastructure create an on-going requirement for communication of a long term vision that merits careful nurturing through years of budget deliberations, in addition to public queries about maintenance, construction and operations. There may be challenges when members of the public, the press or council do not understand the big picture and criticize shorter-term actions. The City of Montreal is an example of a municipality working towards a long-term vision for continuous improvement (Box 2).

Box 1: **Decades of Collaboration for the Grand River**

The Grand River Conservation Authority (GRCA) is the oldest water management agency in Canada. Ontario's Conservation Authorities are non-profit organizations, established under the *Conservation Authorities Act* (1946), with a mandate to manage and restore waterbodies and natural habitat, to manage programs to prevent flooding and erosion, and to provide opportunities for the public to access and learn from Ontario's natural environment[3]. The Grand River is a tributary to Lake Erie. The watershed includes 39 municipalities, two First Nations territories and about 1 million residents[4].

The GRCA has long-term monitoring programs for hydrology and water quality. It collaborates and partners with researchers from several universities who benefit from access to GRCA data and, in turn, further scientific understanding of the watershed. Municipal governments, the Ontario Government and the federal government also collect and share data within the watershed. The GRCA maintains water flow gauges, water quality monitoring stations, rain gauges and other weather-related instrumentation. Among other objectives, research undertaken through collaboration aims to improve watershed health and resilience, understand the assimilative capacity of the river and environmental flows, assist in resource planning and increase awareness of natural and human heritage within the watershed.

Challenges to the long-term health of the ecosystem include population growth and associated land use change, point and non-point source pollution, flow alteration and related sediment regime changes, and emerging issues, such as pharmaceutical products in wastewater effluents. Trace pharmaceutical contamination, with the potential for endocrine disruption of fish populations, was documented in the Grand River at least as early as 2005[5]. Concurrently, the increasing importance of tools to evaluate cumulative impacts of multiple stressors was recognized.

No single trend can provide sufficient information for watershed-scale cumulative effects assessment. With a long-term view to understanding ecological and river health, monitoring and projects undertaken by the GRCA and its partners collectively contribute to advances in decision-making and protection - at times in unexpected ways. An investigation into endocrine disruption in fish populations provides one example.

A research consortium[6] working through the Canadian Water Network in collaboration with the GRCA and area municipalities, identified feminization effects on fish populations within the watershed[7]. The study spanned an interval during which technological changes were being made at municipal wastewater facilities to reduce nitrogen (ammonia) releases to the river. The study results indicate the technologies to reduce municipal wastewater ammonia plumes also appear to reduce the impacts of endocrine disrupting contaminants[8]. This finding has potential implications for wastewater management within the Grand River Watershed, as well as elsewhere in Canada and globally. Decades of monitoring initiatives and research collaborations inform decisions to meet goals for ecological health, informing adaptive responses for further research and infrastructure investments.

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[3] Conservation Authorities of Ontario, URL: http://conservationontario.ca/about-us/conservation-authorities
[4] Grand River Conservation Authority, URL: https://www.grandriver.ca/en
[5] Scott and Imhof, 2005, Exceptional Waters Reach: State of the Resource Report, Paris to Brantford, URL: https://www.grandriver.ca/en/our-watershed/resources/Documents/Fishery/Fishery_Exceptional_State.pdf
[6] A CWN research initiative, Development of The Healthy River Ecosystem Assessment System (THREATS) for Assessing and Adaptively Managing the Cumulative Effects of Man-made Developments on Canadian Freshwaters.
[7] See for example Tetreault et al, 2013, Fish community responses to multiple municipal wastewater inputs in a watershed, Integrated environmental assessment and management, 9(3) 456-68
[8] Hicks et al., *Environ. Sci. Technol.*, **2017**, *51* (3), pp 1811–1819, URL: http://pubs.acs.org/doi/abs/10.1021/acs.est.6b05370

Box 2: **Continuous improvement for Montreal's sewage infrastructure**

Montreal is one of Canada's oldest and largest cities. Given its history, over two thirds of the city's sewer system is a combined system, conveying stormwater and sanitary sewage to the Jean-R. Marcotte wastewater treatment plant, an advanced primary treatment facility discharging to the St. Lawrence River. This facility is the largest wastewater plant in North America since it treats sanitary sewage for more than 2 million people and has a significant residual capacity to treat wet weather flows. Many factors pose challenges for managing and upgrading Montreal's wastewater infrastructure, including the age of the infrastructure, the density of the metropolitan area and the cost of upgrades to both linear infrastructure and treatment processes.

Those responsible for Montreal's wastewater management are tackling these challenges on two fronts: the use of real-time control technologies to minimize combined sewer overflows (CSOs) in wet weather conditions; and, ozone treatment at the wastewater plant. These two approaches require long planning horizons for both engineering design and technical developments as well as for budgetary allocations and political support.

Montreal's real time combined sewer system is designed and operated to better manage CSOs by maximizing flow and storage capacities. Instead of static weirs that allowed sewage to discharge from locally stressed sewers, automated real time control allows the modulation of gates and pumps to better manage flows in anticipation of forecast rainfall and changes as the rain event takes place. Rain patterns are never the same with high spatial and temporal heterogeneity; rainfall moves across a region, with sporadic pockets of greater intensity than others. The real-time system uses weather forecasts and a network of rain gauges to set and adjust gates and pumps, sending flows to parts of the sewer infrastructure with remaining storage capacity. Also, monitoring and forecasting data are continuously updated allowing the real time control system to adjust itself to the changes and status of the flow conditions during any type of storm events.

Planning and approvals for Montreal's sewage treatment facility upgrade to include ozone treatment are in place and construction is in the works. The project was first announced in 2008 and requires the generation of ozone, a powerful disinfectant, on-site for use by the facility. Ozonation destroys pathogens (bacteria and viruses) but it also appears to reduce the negative impacts of pharmaceuticals, personal care products and other endocrine disrupting substances on aquatic biota. The addition of ozonation to a primary facility will make Montreal's Marcotte plant unique. It will also have the largest ozone unit in the world.

With these improvements in place, Montreal management will continue to monitor performance and make adjustments with the goal of continuous improvement. Holding a long-term vision, staying the course through controversy, building political capital and monitoring to support continuous improvement is taking a system with some of Canada's oldest sewage infrastructure in one of its largest cities into the 21st century.

Theme two: Using opportunities to take action

Opportunities to take action to address issues affecting long-term ecological health come in many forms. Prepared agencies can leverage circumstances to build support for broader objectives, whether it is on the basis of conditions that have persisted for decades or an episodic event that captures public attention. Even the scrutiny garnered from a large public funding request can be used to raise awareness of chronic ecological effects and to gain endorsement for measures to tackle their causes. This section features case studies from two poles of the spectrum in terms of circumstances leading up to program improvements and integrated decision-making.

Hamilton Harbour has a decades-old legacy of contamination that has had the attention of municipal, provincial, federal and international governments since at least the 1980s. The contamination in the harbour was severe enough to garner international attention. Public support for ecological improvements has been maintained through the decades. Monitoring of contamination and aquatic biota has supported adaptive decision-making through the years. Improvements to scientific understanding and better appreciation for the complexities of controlling point and non-point sources of pollution have developed as information improved (Box 3).

On the other hand, an unforeseen flood in Cooksville Creek led to greater political and public awareness and support for urban infrastructure improvements. Although the event was unexpected, the Credit Valley Conservation Authority and area municipalities were aware of the need for an integrated understanding and broader vision for improvements required. They leveraged the flood episode to build an appreciation among politicians and senior decision-makers on the need for comprehensive improvements to infrastructure planning, design and operations (Box 4).

Flooding incidents can be symptomatic of chronic management problems such as under-funding for required infrastructure improvements or inadequate deployment of newer techniques (e.g. low impact development for stormwater). Other incidents or conditions that come to the attention of the public may arise from on-going environmental challenges, such as contaminated sediments that impair fish community health, elevate fish tissue contaminants, or increased erosion due to urbanization. Negative publicity and criticism can be difficult, but it may be possible to seize the opportunity to turn some of the publicity towards the underlying root causes leading to the problem and to communicate a long-term vision for improvements.

Emergency incidents, expensive infrastructure improvements (see Box 2 above) and legacy contamination can all be sources of motivation if the underlying root causes can be identified and explained to engage a broader community of stakeholders. Even though all information may not be available immediately, decisions to take action and monitor outcomes can be made as part of an adaptive approach that makes advances in addressing long-term impacts.

Box 3 **Living with a legacy: Hamilton and a Remedial Action Plan**

Hamilton Harbour is an Areas of Concern (AOC) under the Great Lakes Water Quality Agreement (GLWQA) between Canada and the United States. AOCs require Remedial Action Plans (RAP) to restore the ecological functions and to reduce risk to human health from historic industrial activities and other stressors, including population growth. Work by the federal government, in collaboration with numerous other agencies, to remediate the historic industrial and sewage pollution in the Harbour has been on-going since the 1970s. By the mid-1980s, many point source problems had been reduced but it became clear that additional actions to address non-point and legacy contamination would also be needed.

Fourteen Beneficial Use Impairments (BUIs)[9] are being tracked to assess progress, all of which must be remediated to delist Hamilton Harbour as an AOC. Three of the BUIs are not currently impaired in Hamilton Harbour: *tainting of fish and wildlife flavour*; *restrictions on drinking water consumption*; *added cost to agriculture and industry*. Three BUIs need more study to determine their status: *fish tumours and other deformities*; *bird or animal deformities or reproduction problems*; *degradation of phytoplankton and zooplankton populations*. One of the remaining impairments, *eutrophication or undesirable algae*, is being addressed through significant investments in municipal infrastructure to reduce nutrients released to the Harbour. In addition, the City of Hamilton operates its wastewater infrastructure to exceed minimum effluent quality requirements and is undertaking non-point source reduction initiatives. These improvements will also contribute to other beneficial uses pertaining to benthic invertebrate and fish health.

Actions to reduce City of Hamilton's non-point sources of phosphorus and sediments, including from urban runoff[10], construction and development erosion control[11] and rural watershed runoff, have been identified. Within the urban areas of the Hamilton Harbour watershed, guidance and training to increase the use of low impact development (LID) measures for stormwater management, improve maintenance procedures for stormwater facilities and provide stable and equitable funding for stormwater infrastructure are recommended to reduce urban runoff stressors to the Harbour. Guidance, training, improved application approvals processes and tools for the construction industry to improve construction sediment control performance are recommended. Rural watershed recommendations are expected in spring 2017[12].

The long-term goal for restoration of ecological health of the Hamilton Harbour dates back to the 1960s[13] and has been formalized through successive agreements and action plans. The Cities of Hamilton and Burlington are one level of three levels of government working with Conservation Authorities, industry and academic collaborators as well as non-government organizations and members of the public.

Although the long-term impacts have been severe, a vision for ecological health has inspired public and political support for continuous improvement, monitoring and partnerships for improvements for Hamilton Harbour. At the time the problem was first identified, the complexity of the ecosystem and the role of non-point pollution were not well understood. Work began and,

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[9] See Hamilton Harbour Remedial Action Plan Beneficial Uses 2012 Fact Sheets, at URL: http://hamiltonharbour.ca/resources/documents/2012FactSheet.pdf

[10] See Hamilton Harbour Remedial Action Plan: Urban Runoff Hamilton Report and Recommendations, 2016 at URL: http://hamilton.siretechnologies.com/sirepub/cache/2/tgwqbzcg21a3fa3cd0na4wgu/16754602272017023727251.PDF

[11] See Hamilton Harbour Remedial Action Plan: Erosion and Sediment Control on Active Construction Sites Report and Recommendations, 2016 at URL: https://burlingtonpublishing.escribemeetings.com/filestream.ashx?DocumentId=6588

[12] See City of Hamilton, Watershed Nutrient and Sediment Management Advisory Group website at URL: https://www.hamilton.ca/city-initiatives/our-harbour/watershed-nutrient-sediment-management-advisory-group

[13] See City of Hamilton: Harbour History at URL: https://www.hamilton.ca/city-initiatives/our-harbour/harbour-history

through successive plans and projects, the high profile of the remediation efforts has been maintained. Shorter-term requirements, such as operational infrastructure performance, have dove-tailed with longer-term requirements for changes in land development practices, infrastructure design and capacity development among government agencies, developers, constructors and the general public.

Box 4: **Leveraging the unforeseen: Cooksville Creek**

On July 8, 2013[14], an extreme rainfall event within the Cooksville Creek watershed resulted in extensive flooding of riverbanks and urban catchments in Mississauga, Ontario. This event was the second extreme precipitation event within 5 years (the previous one occurring on August 4, 2009). The flood conditions resulted in power outages, street and railway flooding, extensive property damage and basement sewer backups in over 5,000 properties. Other problems identified within the watershed included water quality degradation, erosion of the channel into underlying bedrock, channelization with loss of meander pattern, and extensive failure of creek banks.

Cooksville Creek is a small tributary confluent with Lake Ontario. It runs about 16 kilometers[15], and has a watershed area just under 34 km^2. It has experienced urban development since the 1940s and is now highly urbanized, with only 6% open space (as of 2012). The majority of land area was developed prior to flood and water quality stormwater controls. The Credit Valley Conservation Authority (CVC), with the City of Mississauga, had identified the need for restoration and retrofit projects in the creek as early as 2006.

The flooding events provided the impetus to build broad-base support for an integrated approach to managing risk within the watershed. Rather than focusing only on the flooding events, the CVC, along with the two tiers of municipal government and emergency response personnel, built capacity and engagement for an integrated approach.

In 2015, a climate change risk assessment within the Cooksville Creek watershed analyzed baseline conditions and projections to 2050 and 2080. The assessment included an integrated estimation of existing and future risks and vulnerabilities regarding stormwater, wastewater, drinking water, and the streams and nearshore of Lake Ontario. The study also examined the interconnections between water infrastructure vulnerability and community social vulnerability. The social aspects required extension of the scope to touch on emergency response services, public health and safety considerations, especially for sensitive populations, and transportation systems. Adaptation measures were identified and a case made for investment in adaptation measures.

One product of the study was a modelling tool to map flood prone areas and their interaction with vulnerable populations and critical infrastructure. Flood prone areas are superimposed with the locations of schools, hospitals, evacuation centers and emergency response service locations as well as areas with concentrations of elderly residents, low income neighbourhoods and basement apartments. The tool can be used to prioritize water management and emergency response during flood events. The tool also can be used to anticipate potential problem areas in advance of extreme events. One finding of the study is that priorities are altered when water infrastructure is considered in an integrated manner with social factors. Investments in adaptation measures need to consider all potential impacts of extreme rainfall and flooding events.

A second product of the study was a better understanding of the potential of extreme precipitation events to transport sediment loads and chlorides via streams to the lake. Further study is underway to assess risks to potable water intakes, recreational activities and other water infrastructure within the nearshore. Real-time monitoring systems are being used to estimate

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[14] Lenarduzzi and Zimmer, n.d., , Linking Climate with Water Infrastructure and Social Vulnerabilities, Credit Valley Conservation Authority, 6 pages

[15] Aquafor Beech Ltd., Cooksville Creek Flood Evaluation Master Plan EA: Final Report, 2012, URL: http://www.mississauga.ca/file/COM/Cooksville_Creek_Flood_Evaluation_Study_Report_Part_1.pdf

water density and movement of nutrient plumes into Lake Ontario under various temperature and weather conditions.

The response to flooding in Cooksville Creek was informed by established monitoring programs already in place. The flood event was leveraged to highlight the need for an integrated watershed approach across regional and local agencies. The resulting collaborations transformed a short-term emergency response into an investment in community resilience. It also brought out community champions who led various aspects of the emergency response, the vulnerability assessment, development of adaptation measures (including water infrastructure, land acquisitions, land use planning) and establishment of instream water quality targets to determine an appropriate level of service for stormwater management.

Theme 3 – Using existing science-based protocols and tools

Many organizations in a range of economic sectors have concerns for aquatic ecosystem health. As a result, a variety of approaches have been developed to assess conditions or to answer specific questions about both potential short-term and long-term impacts. Monitoring needs have also evolved, along with technologies for data collection. Automated technologies can provide capabilities that were not formerly available without considerable human resource commitments. The protocols and tools developed by other sectors to assess aquatic ecosystems can be broadly applicable to watersheds and therefore may be applicable to monitor or investigate urban issues.

Decision-makers looking to start an initiative of any size, from a specific investigation to a long-term monitoring program, can draw on the experience, protocols and tools developed and tested for other applications. A survey of existing practices or tools can provide the basis for adoption or adaptation of methods to suit identified needs. Whether the stressors or long-term ecological impacts have been studied extensively or the situation is just beginning to be assessed, existing tools or protocols may provide useful insights and save development time.

Information needed for integrated watershed decision-making is varied and often complex. In addition, information needs will likely evolve as action plans are deployed and new understanding emerges, as has been the case for Hamilton Harbour (Box 3). Although each watershed has unique combinations of stressors and ecological conditions, many techniques for data collection are well established and can be applied to meet a variety of needs. An ongoing commitment to monitoring and database development is compatible with holding a long term vision (Theme 1) and using opportunities to take action (Theme 2).

An existing science-based protocol, developed by Environment and Climate Change Canada to assess the environmental effects from certain industrial effluents, was adapted by the City of Ottawa to assess environmental effects of municipal facilities (Box 5). The City already had in place several surface water monitoring programs, including collection of baseline water quality data. However, rather than monitoring individual contaminants, the environmental effects monitoring approach provided a holistic way of identifying and quantifying effects from specific pollution sources. If effects are detected, an investigation can be undertaken into the contaminants or conditions causing the effects. Targeted monitoring for effects at regular intervals over time can help assess the presence of chronic conditions. It can also inform plans to mitigate the impacts and determine whether mitigation measures have been successful. For example, environmental effects monitoring could include regular investigations into endocrine disruption in fish communities to assess trends in this emerging issue.

As an alternative approach to advanced monitoring techniques, monitoring to establish baseline conditions is a place to start to understand trends in essential water column properties, such as dissolved oxygen and temperature (Box 6). Automated equipment has had extensive field deployment over the past decade and there is a wealth of experience among government agencies and the private sector for purchasing, use and maintenance of equipment. Database development and analytical tools can range from spreadsheets to custom script, depending on budget and staff resources available.

There is no need to reinvent the monitoring wheel. Technology to support science-based protocols can be used as part of continuous improvement towards understanding and mitigating long-term effects of urban stressors on ecosystems.

Box 5: **Environmental Effects Monitoring in Ottawa**

The City of Ottawa, population of 960,000, initiated an environmental effects monitoring (EEM) program in 1998. The objective of the program is to assess the effects of municipal facilities on receiving water environments. The protocol for the EEM program was adapted from that used under the federal *Fisheries Act* to assess the effects of pulp and paper mill effluents. It is also used for metal mining effluent assessments and had been refined by the federal government over several pulp mill reporting cycles before the City of Ottawa applied it.

The protocol uses a weight-of-evidence approach to include data from a variety of indicators. The elements of Ottawa's EEM program include water quality data at reference locations and within discharge plumes, benthic invertebrates at reference and discharge locations and fish habitat data. An assessment of the wastewater plant effluent and water purification waste alum waste stream also included whole effluent toxicity testing, plume chemistry assessment and sentinel fish species monitoring within the applicable reaches of the Ottawa River. When it was first initiated, the City of Ottawa developed a training program to develop staff capacity to undertake future EEM studies with reduced reliance on external resources.

To date, the City of Ottawa has applied the EEM protocol to study: waste discharges from water purification plants, which resulted in a change in waste management practices; wastewater treatment plant effluent to assist with pollution prevention planning in accordance with Environment Canada's pollution prevention plan for chlorinated effluents; evaluation of the West Nile Virus Control Program; impacts of discharges from snow disposal facilities on receiving streams; and, impacts of stormwater management facilities (City of Ottawa, 2007). These programs have positioned the City well in terms of responding to more stringent environmental controls and public expectations for aquatic environment protection.

The EEM approach provides an alternative to broad-scale, multiple variable monitoring to assess impacts. It is designed to identify effects that are attributable to an identifiable source of pollutants in a manner that is integrated with the specific environmental conditions. Most urban waterbodies have multiple pollution sources; the weight-of-evidence approach is intended to assess the likelihood that a particular facility or practice is creating an impact. Over time, successive EEM studies can potentially identify negative cumulative effects - or improvements where facilities have been upgraded. Also, elements to assess other effects can be added to the protocol. For instance, feminization of fish downstream of wastewater plant effluents could be a specific aspect of an EEM study. As emerging contaminants and sources are identified, potential chronic and long-term effects can be assessed using the EEM concepts.

Many established scientific methodologies and tools are available for aquatic ecosystem monitoring and assessment; some of these can be tailored to suit budgets and institutional capacity.

Box 6: **Using technology to develop a baseline**

Advances in technologies and ease-of-use for water quality and flow monitoring offer opportunities for automated and continuous data collection that were previously unaffordable due to labour and/or capital costs. Flow monitors, automated water samplers, water quality probes, temperature loggers and meteorological equipment, such as rain gauges, can kick-start data collection or be incorporated as part of a comprehensive long-term monitoring regime.

A handful of water column variables monitored in-stream, such as dissolved oxygen and temperature, can build a picture of trends, including cyclical or seasonal patterns. These data can identify where more in-depth investigation may be warranted or help to allay fears about degradation.

The Credit Valley Conservation Authority's real time monitoring program includes 11 stations, funded by the Region of Peel's Climate Change Program, that collect data on water and air temperatures, dissolved oxygen, turbidity, pH, conductivity and chloride. The system is designed to send notifications if data fall outside expected values, thereby providing a spills detection function. The real time results also provide context for grab sampling, insights to emerging water quality problems and support for numerous other initiatives. One finding from the data has been discovering the extreme peaks in chloride levels during spring snow melt.

The Grand River Conservation Authority (GRCA) also monitors temperature, dissolved oxygen, turbidity, pH and conductivity as well as nitrates. It collaborates with 27 municipalities, Six Nations of the Grand River, two Ontario Ministries, Water Survey of Canada and researchers at the University of Waterloo on a suite of initiatives, including monitoring programs, increasing the capacity to collect relevant data.

Memoranda of understanding can be developed to pool data with other applicable sets collected by agencies such as Environment Canada, the Department of Fisheries and Oceans, provincial ministries, municipalities, conservation authorities and other science-based organizations (e.g. universities). Data can also be provided on-line as a public service and to encourage public interest.

In addition to data collection and associated staff effort to place and check equipment, additional components necessary for a data collection program of any size or complexity include a database to house the information and staff tasked with analyzing and reporting results.

Theme 4: Regulatory support for the watershed scale

Watersheds are nested within successively larger drainage areas, up to the continental scale where the mainstem river flows into a marine waterbody. Integrated decision-making needs to consider the larger spatial scales of watersheds as well as both the shorter-term and longer-term implications for changes, such as contaminant releases and changes to flow regimes.

Jurisdictional boundaries rarely align with watershed boundaries, except for those select organizations that have established mandates pertaining to particular watersheds. The organization and policies of government institutions can hinder or facilitate integrated watershed management, depending on the degree to which the spatial scale and nested nature of watersheds is recognized. Even within a single jurisdiction, approvals requirements at a sub-watershed scale can lead to fragmented approaches and provide a disincentive to engage in integrated watershed management. However, regulatory support for more integrated watershed management approaches and the establishment or use of organizations that foster watershed-based decision-making can foster a more integrated approach to water management and provide the basis for managing long term impacts from urban wastewater and stormwater.

The Ontario Ministry of Environment and Climate Change's pilot approach to permitting stormwater approvals in London provides one example of an initiative to provide regulatory support for improved integrated decision-making at the municipal level on a sub-watershed scale (Box 7). Ontario's *Lake Simcoe Protection Act* (LSPA) (2008) is another example of an approach designed to foster integrated decision-making on a watershed basis. Lake Simcoe is a large inland lake that has high phosphorus loadings and chloride levels that threaten the ecological health of the system.[16] Lake Simcoe lies completely within Ontario and the LSPA requires jurisdictions within the Lake's drainage area to collaborate in the development and implementation of a Lake Simcoe Protection Plan.

The International Joint Commission (IJC)[17], Ontario's Conservation Authorities[18], the Mackenzie River Basin Board[19], and Europe's Water Framework Directive[20] are examples of watershed-based decision-making units. These organizations were

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[16] Province of Ontario, URL: https://www.ontario.ca/page/ministers-annual-report-lake-simcoe-2015

[17] A map of IJC watersheds is available on its website, see URL: http://www.ijc.org/en_/Transboundary_Basins

[18] A map of Conservation Authorities in Ontario is available on Conservation Ontario's website, see URL: http://conservationontario.ca/library?view=document&id=302:map-of-conservation-authorities&catid=65:corporate-documents

[19] The Mackenzie River Basin Board mandate and map is available on its website at URL: http://www.mrbb.ca/

[20] The EU Water Framework Directive website provides information on the integrated river basin management for Europe at URL: http://ec.europa.eu/environment/water/water-framework/index_en.html

established specifically to navigate the requirements of multiple jurisdictions to achieve desired watershed outcomes. They have mandates for integrated decision-making while also relying on governments within each respective watershed to take actions consistent with identified watershed objectives. Each of these watershed-based organizations has been able to promote integrated watershed decision-making.

Box 7: **Area-wide Environmental Compliance Approvals in London**

The City of London, in Southwestern Ontario, has a population of just over 383,000 (2016) and is situated within the Thames River watershed. The Thames River is confluent with Lake St. Clair in the Great Lakes Basin. London is a pilot area for an Ontario Ministry of the Environment and Climate Change (MOECC) approach to managing stormwater in a holistic manner.

Design and construction of stormwater infrastructure by the City of London for new subdivisions involves many stakeholders, including developers, city council, the Upper Thames River Conservation Authority and the general public. The MOECC is the approvals authority and establishes operating requirements for stormwater facilities.

The new approach for stormwater management entails area-wide stormwater Environmental Compliance Approvals (ECA). Instead of issuing a series of individual approvals for each sub-division within a sub-watershed, the MOECC is assessing approvals on a sub-watershed scale. The approval establishes performance-based objectives for environmental outcomes using a systems approach and cumulative impact assessment that includes all current and planned land development within the sub-watershed. The stormwater infrastructure includes source controls, conveyance systems and end-of-pipe facilities. The approach also includes requirements for monitoring and reporting to the province on environmental performance in context of the established objectives.

Stormwater works will be constructed over a 20-year period within the Dingman Creek sub-watershed in London. The new approach provides the opportunity for the City to look at longer time scales and to build the basis for assessing achievement of stormwater performance targets through long-term monitoring of tributaries, tracking operations and maintenance activities, annual reporting against targets. It also better enables the City to focus on potential problem areas as needed. One variable the City is particularly interested in assessing over a longer time frame is erosion.

The approach allows the City to undertake analyses on various spatial scales, including local Low Impact Development measure assessments, neighbourhood scale performance and sub-watershed or reach scale assessments. It also streamlines the approvals process by coordinating a class environmental assessment for pre-approval of eligible works.

The area-wide ECA applies to municipally owned stormwater infrastructure. Combined sewage, sanitary and agricultural drainage systems are not included, nor are pollution discharge limits established through the approach.

This holistic and coordinated approach by the MOECC streamlines provincial procedures, establishes environmental performance objectives, enables integrated municipal stormwater infrastructure decision-making and supports adaptive decision-making at the municipal level over a longer time frame.

5. Conclusion

Integrated watershed management is a flexible and evolving approach to understand and mitigate long-term and chronic effects of urban stressors on freshwater systems. One common element of successful IWM is the development and communication of a compelling vision for ecological health, with the engagement of stakeholders of the watershed. With the vision as a first step to make future improvements for long-term ecological health, successful action plans to realize the vision are rooted in present realities and may comprise a series of relatively small steps over many years. A series of small steps, supported by monitoring and adaptive decision-making conditions can lead to important improvements over time.

A long-term vision and action plans for continuous improvement can be leveraged to build political and public support for capital investments, monitoring programs or other resource needs, even under circumstances that are unplanned. Similarly, established science-based protocols and tools can be used to advance or initiate monitoring programs and to investigate long-term effects and the success of mitigation measures. Where possible, decision-makers within watersheds can work with senior government levels to ensure the concept of integrated approaches also apply to required approvals that are compatible with a holistic and long-term watershed management approach.

Urban wastewater and stormwater systems have long-term cumulative effects on freshwater systems. They are also only part of the overall contribution made by all stakeholders within watersheds to the chronic effects and degradation of freshwater systems. The challenges faced by aquatic ecosystems under conditions of multiple stressors - and a changing climate - require decision-makers to take a long-term and holistic perspective and to promote collaboration among the multitude of watershed stakeholders. Such a perspective is adaptive and integrates information from multiple spatial and temporal scales. It is also implemented with a spirit of humility that recognizes the limitations of scientific knowledge and the vital importance of thriving, healthy aquatic ecosystems.

Appendix A Workshop Attendees

Name	Affiliation
Alain Charron	Ville de Montréal
Ben Longstaff	Lake Simcoe Region Conservation Authority
Bernadette Conant	Canadian Water Network
Christine Zimmer	Credit Valley Conservation Authority
Greg Kuntz	City of Regina
Jacque-Ann Grant	Canadian Water Network
Jiri Marsalek	Environment and Climate Change Canada
Joanne Little	Alberta Environment and Parks
Karen Kidd	University of New Brunswick
Karl Schaefer	Environment and Climate Change Canada
Katrina Hitchman	Canadian Water Network
Khizar Mahmood	City of Calgary
Leland Jackson	University of Calgary
Mark Bainbridge	City of Hamilton
Mark Spanjers	Canadian Water Network
Mary Trudeau	Envirings Inc., CWN Consultant
Patricia Chambers	Environment and Climate Change Canada
Peter Vanrolleghem	Université Laval
Richard Fontaine	Ville de Montréal
Roger Phillips	University of Western Ontario
Sandra Cooke	Grand River Conservation Authority
Sarah Dorner	École Polytechnique de Montréal
Scott Lister	York Region
Scott Mathers	City of London
Simon Courtenay	University of Waterloo
Thom Sloley	Durham Region
Yves Comeau	École Polytechnique de Montréal

References

[1] D. W. Schindler, R. E. Hecky, and G. K. McCullough, "The rapid eutrophication of lake winnipeg: Greening under global change.," *J. Great Lakes Res.*, vol. 38, pp. 6–13, 2012.

[2] G. K. Nürnberg and B. D. LaZerte, "More than 20years of estimated internal phosphorus loading in polymictic, eutrophic Lake Winnipeg, Manitoba.," *J. Great Lakes Res.*, vol. 42, no. 1, pp. 18–27, 2016.

[3] R. Carey and K. Migliaccio, "Contribution of Wastewater Treatment Plant Effluents to Nutrient Dynamics in Aquatic Systems: A Review," *Environ. Manage.*, vol. 44, no. 2, pp. 205–217, 2009.

[4] T. D. Fletcher, H. Andrieu, and P. Hamel, "Understanding, management and modelling of urban hydrology and its consequences for receiving waters: A state of the art," *Adv. Water Resour.*, vol. 51, pp. 261–279, Jan. 2013.

[5] A. Chin, "Urban transformation of river landscapes in a global context," *Geomorphology*, vol. 79, no. 3–4, pp. 460–487, 2006.

[6] C. J. Walsh, A. H. Roy, J. W. Feminella, P. D. Cottingham, P. M. Groffman, and R. P. Morgan II, "The urban stream syndrome: Current knowledge and the search for a cure," *J. North Am. Benthol. Soc.*, vol. 24, no. 3, pp. 706–723, 2005.

[7] C. J. Walsh, A. H. Roy, J. W. Feminella, P. D. Cottingham, P. M. Groffman, and R. P. Morgan, "The urban stream syndrome: current knowledge and the search for a cure," *J. North Am. Benthol. Soc.*, vol. 24, no. 3, p. 706, 2005.

[8] H. Hamid and C. Eskicioglu, "Fate of estrogenic hormones in wastewater and sludge treatment: A review of properties and analytical detection techniques in sludge matrix," *Water Res.*, vol. 46, no. 18, pp. 5813–5833, 2012.

[9] D. J. Marcogliese, C. Blaise, D. Cyr, Y. de Lafontaine, M. Fournier, F. Gagné, C. Gagnon, and C. Hudon, "Effects of a major municipal effluent on the St. Lawrence River: A case study," *Ambio*, vol. 44, no. 4, pp. 257–274, 2015.

[10] K. A. Kidd, P. J. Blanchfield, K. H. Mills, V. P. Palace, R. E. Evans, J. M. Lazorchak, and R. W. Flick, "Collapse of a Fish Population after Exposure to a Synthetic Estrogen," *Proc. Natl. Acad. Sci. U. S. A.*, vol. 104, no. 21, pp. 8897–8901, 2007.

[11] S. A. Levin, "Multiple scales and the maintenance of biodiversity," *Ecosystems*, vol. 3, no. 6, pp. 498–506, 2000.

[12] G. M. Kondolf and K. Podolak, "Space and Time Scales in Human-Landscape Systems," *Environ. Manage.*, vol. 53, no. 1, pp. 76–87, 2014.

[13] M. Floury, C. Delattre, S. J. Ormerod, and Y. Souchon, "Global versus local change effects on a large European river," *Sci. Total Environ.*, vol. 441, pp. 220–229, 2012.

[14] M. Floury, P. Usseglio-Polatera, M. Ferreol, C. Delattre, and Y. Souchon, "Global climate change in large European rivers: Long-term effects on macroinvertebrate communities and potential local confounding factors," *Glob. Chang. Biol.*, vol. 19, no. 4, pp. 1085–1099, 2013.

[15] K. Van Looy, M. Floury, M. Ferréol, M. Prieto-Montes, and Y. Souchon, "Long-term changes in temperate stream invertebrate communities reveal a synchronous trophic amplification at the turn of the millennium," *Sci. Total Environ.*, vol. 565, pp. 481–488, 2016.

[16] A. M. Wallace, M. V Croft-White, and J. Moryk, "Are Toronto's streams sick? A look at the fish and benthic invertebrate communities in the Toronto region in relation to the urban stream syndrome.," *Environ. Monit. Assess.*, vol. 185, no. 9, pp. 7857–75, Sep. 2013.
[17] O. Brandes, K. Ferguson, M. M'Gonigle, and C. Sandborn, "At a Watershed: Ecological Governance and Sustainable Water Management in Canada," 2005.