Ryerson University

Ryerson Urban Water

Integrated Water Resources Evaluation Tool (IWRET) Workshop

Summary Workshop Report

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INTRODUCTION

Given the challenges of climate variability, pressures of population growth, and unprecedented urban intensification and aging infrastructure, the conventional urban and water infrastructure planning paradigm has become an obstacle in achieving sustainable development for many urban regions around the world. One of the main legacies of this paradigm is that urban regions rely predominantly on centralized water systems that typically consist of separate drinking water, stormwater, and wastewater sub-systems. Typically, these sub-systems are managed independently. However, this practice represents an enormous engineering and social issue as further extension and expansion of existing systems, required to carry additional loads, are not economically or environmentally viable. In view of this, development of water systems that utilize decentralized and distributed sets of solutions is seen as a feasible and more sustainable alternative. Such solutions generally operate alongside and in combination with existing centralized systems and form so-called hybrid water services systems. One of the main benefits of hybrid systems is that they utilize alternative water sources typically seen as a nuisance by conventional approach, such as rainwater, stormwater, greywater, or wastewater. While hybrid water systems offer manifold benefits, they are still characterized by a level of uncertainty when it comes to the performance on the system level.

Researchers at Ryerson Urban Water (RUW) are collaborating with Waterfront Toronto and partners at Toronto Water, the Toronto Region and Conservation Authority (TRCA), the Ministry of Environment and Climate Change (MOECC), and the Water Technology Acceleration Project (Water TAP) (this collective herein referred to as the Project Steering Committee) to develop an Integrated Water Resource Evaluation Tool (IWRET). This decision-making support tool will analyze and compare the sustainability performance of alternative approaches to integrated urban water management planning against a baseline conventional (i.e. centralized) approach on a neighbourhood level. The tool will equip decision-makers, planners, and developers with a tool that facilitates assessment of the benefits and costs of incorporating alternative decentralized (distributed) water servicing solutions in their planning. In order to address the matter of sustainability of urban neighborhoods in a holistic manner, the tool will use a set of criteria based on the urban water metabolism approach that are not typically considered in the decision-making process, such as energy savings, greenhouse gas (GHG) emissions, climate change resiliency, chemical use, and nutrient recovery. The tool itself will be transferable, non-proprietary, and applicable to other neighborhoods, jurisdictions, and municipal settings, serving the objective of market transformation towards higher performing and more sustainable hybrid water servicing solutions.

Complex issues related to water infrastructure planning and management in urban environments typically include a vast number of authorities and organizations that frequently have conflicting responsibilities and interests. Therefore, in the first stage of the project, Ryerson Urban Water (RUW), in collaboration with the Project Steering Committee, held a workshop on March 29, 2017 with engaged stakeholders from governmental institutions, technology developers, providers and distributors, developers and builders, consultants, and non-governmental organizations. The main goal of the workshop was to receive stakeholder feedback to inform the planning and development of the tool. Discussions included current and future approaches to water infrastructure planning, design, and management, as well as policy/institutional/regulatory opportunities, challenges, and constraints. Workshop participants provided expertise and feedback on anticipated technologies to be included in the tool, the selection of quantitative and qualitative sustainability indicators for the evaluation of alternative technologies and hybrid approaches, and opinions on the tool's graphical user interface (GUI). This stakeholder feedback was registered and will inform the development of the tool architecture.

In order to capture the different perspectives and relate them to the appropriate stakeholder group of interest, workshop participants were asked to identify to which stakeholder group they belong. Table 1 shows 10 stakeholder groups and number of participants within each group.

Stakeholder Group	Number of Participants
Lower-tier and Upper-tier Municipality	12
Academic Research	6
Public Administration and Government	6
Consultant	5
Technology Provider or Distributor	3
Non-profit Organizations	3
Provincial Ministry	3
Conservation Authority	3
Developer or Builder	1
Industry Association	1
Total Number of Participants	43

Table 1. Stakeholder groups and number of participants

SESSION 1 | CURRENT PRACTICES AND CHALLENGES IN URBAN WATER INFRASTRUCTURE PLANNING

In the opening Session, the welcome was given by the host Ryerson Urban Water (Angela Murphy and Darko Joksimovic). The present and future challenges were presented by Waterfront Toronto (Aaron Barter and Dave Madeira). One of the main challenges was identified as stormwater management practices along Toronto's waterfront, in particular that existing water infrastructure is undersized for future development. In addition, all future development of the infrastructure in highly dense communities of the Toronto's waterfront is driven by high cost of real estate and flat topography. As example, currently planned stormwater management practices assume conveyance via minor system, where sewer connects to a stormwater management pond that provides quantity and quality controls with wetland features. Since such solutions in given context might not be economically sustainable, the speakers indicated that it would be particularly valuable to assess the alternatives.

Patrick Cheung, Toronto Water, and Tom Kaszas, the Ministry of Environment and Climate Change, addressed the most important issues related to the planning of traditional water systems and obstacles in implementation of new technologies in the context of the City of Toronto and the province of Ontario. They presented perspectives on relevant current and future standards, regulations, codes, and guidelines and how they affect daily work, as well as, the challenges related to incorporating new concepts (e.g. hybrid/decentralized solutions, water reuse, integration with energy systems, etc.) and technologies.

Following the opening session, the workshop participants were given an opportunity to provide feedback and briefly outline any relevant issues not already addressed by the speakers. Table 2 summarizes the responses by the stakeholder group.

Stakeholder group	Relevant issues raised by participants (not addressed already by speakers)
Public Administration and Government	Ensure reliable sources of funding streams
	Technical challenges to development of new approaches
	Long-term availability of performance data
Municipality	Early planning of "at-source" (SWMP*)
	Development of reliable and standardized performance metrics
	Limitations of MOECC approval process
	Management of hydro costs
	Scattered maintenance of responsibilities and distributed ownership of infrastructure
Consultants	Learning curve and required time investment
	Inability to provide assurance of performance to clients
	Lack of straight forward guidelines
	Rigid regulations
	Low cost of water
	Open data for planning purposes
	Absence of an integrated modeling platform
	Regulated monitoring of system performance
	Cost sharing for development and management of distributed water infrastructure
	Lack of incentives for technology developers
Conservation Authorities	Integration as the key factor – collaboration across planning authorities, upper and lower tier municipalities, and jurisdictions that share a common natural boundary
Provincial Ministry	Extension of planning capacities to include distributed technological issues, such as water reuse
	Assessment of environmental risks
	Regulated water reuse plumbing standards
	Improve understanding of the barriers associated with collaboration and innovation
Non-profit Organizations	Procurement process to include scoping of alternatives before the environmental assessment
	Lack of tools for comparison of different options and cost-benefit analysis

Table 2. Current issues in urban water infrastructure planning, design and management
*SWMP: Stormwater management plan.

In Session 2 of the Workshop, Darko Joksimovic and Vladimir Nikolic, Ryerson Urban Water (RUW), provided a theoretical background on essential concepts that form a methodological base for the tool development, such as the concepts of urban metabolism and urban water metabolism. Based on the literature review, urban metabolism has been recognized as a holistic framework that quantifies the overall fluxes of energy, water, materials, nutrients, and wastes that go into and out of cities in search for sustainable solutions. The importance of water-related fluxes in the urban metabolism model is particularly highlighted since the urban water cycle has a rather substantial influence on flows of materials, energy, wastes, and nutrients and thus has important social, economic, and environmental impacts. Growing misbalance between resources that are required for healthy functioning of a city on one side, and significant amounts of waste that is produced on the other, a search for technological solutions that balance the urban metabolic processes is needed. In case of urban water metabolism, technological solutions are offered by the Integrated Urban Water Management (IUWM) paradigm. IUWM encourages development of alternative water systems that utilize decentralized (distributed) sets of solutions that can also minimize the environmental impacts. Such systems use alternative water sources (such as rainwater, stormwater, greywater, or wastewater) and can be implemented at various spatial scales (household, cluster, neighborhood, or city level). They generally operate alongside and in combination with existing centralized systems and form so called hybrid water services systems. From the aspect of urban water metabolism and conventional water systems, hybrid water systems offer engineering options that allow more effective control of inputs, outputs, and storage of energy, materials, and nutrients in urban water metabolism model. All introduced concepts are discussed and presented in greater detail in the background paper (Appendix A).

Following the presentation, workshop participants were presented with a list of the main decentralized urban water management infrastructure options divided and grouped into three flows (water supply, wastewater, and drainage), and their integration through recycling/reuse. This list was compiled based on the literature analysis. In this exercise, the participants were asked to specify the importance of options presented on the scale (1 – not important to 5 – very important) from their own perspective. Moreover, they were asked to add any other decentralized technologies that should be included in the Integrated Water Resources Evaluation Tool (IWRET). The most important technologies, identified based on the input from Workshop participants, will be included in more detail during the tool development.

Figure 1 illustrates the value that participants placed on the identified 'water supply technologies.' For instance, participants considered water saving devices as amongst the most important technologies to be included in IWRET. Following this were smart water meters and integration of smart water and energy metering. On the other side, downspout disconnections and stormwater reuse systems were considered amongst the most important distributed stormwater features that should be included in IWRET (Figure 2). Regarding wastewater distributed systems, packaged wastewater treatment plants and constructed wetlands were valued as the most important technologies (Figure 3). Finally, greywater systems and rainwater harvesting technologies were valued as the most important technologies to be included in IWRET for the recycling/reuse side of the urban water cycle (Figure 4).

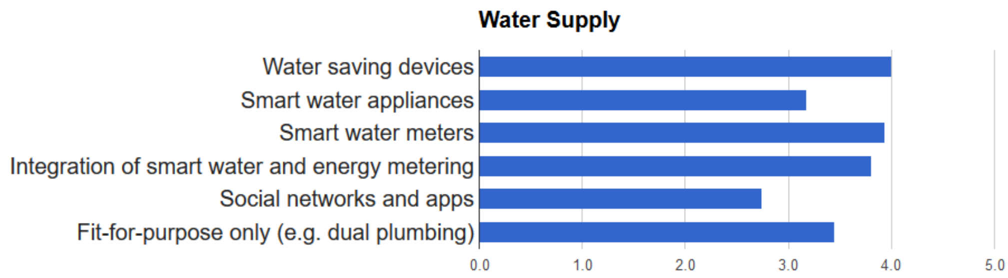

Figure 1. The value that participants placed on distributed water supply technologies (using a scale of 1 (not important) – 5 (very important).

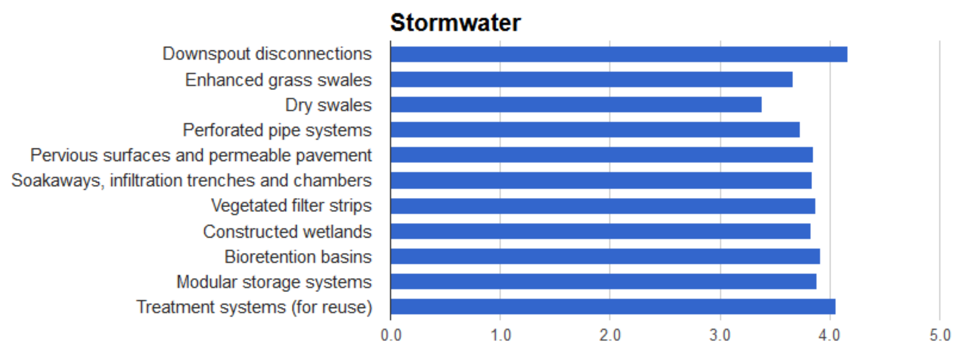

Figure 2. The value that participants placed on distributed stormwater technologies (using a scale of 1 (not important) – 5 (very important).

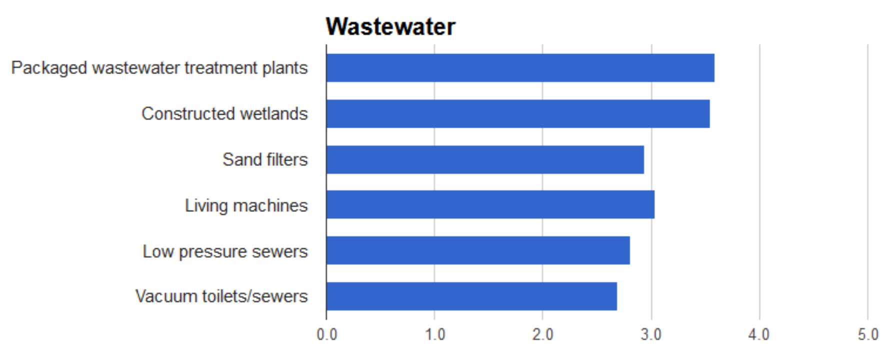

Figure 3 The value that participants placed on distributed wastewater technologies (using a scale of 1 (not important) – 5 (very important).

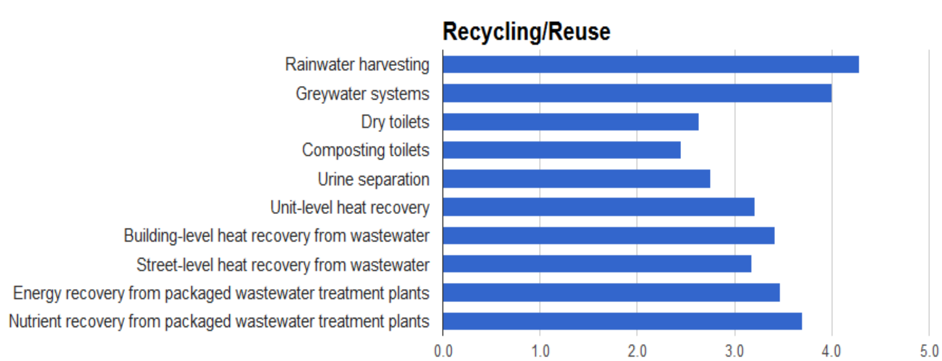

Figure 4. The value that participants placed on distributed recycling/reuse technologies (using a scale of 1 (not important) – 5 (very important).

While various categories of sustainability criteria have been suggested in the past to evaluate alternative urban water management solutions, literature analysis shows that most fall into the finite number of primary groups including human health, economic, environment, social-cultural, and an assessment of resilience to future challenges. Because they are strongly context driven, the workshop participants were presented with the preliminary list of sustainability indicators for the IWRET tool based on similar tools developed around the world. Participants were encouraged to suggest the most relevant indicators that potentially are important from their stakeholder group perspective. More particularly, the workshop participants were asked to specify the importance of presented sustainability indicators (on the scale 1 - not important to 5 - very important), and add any other indicators missing from the list that they think should be considered in IWRET. Participants were organized into four roundtables to discuss: environmental, economic, social, and technical indicators.

Participants seated at the **economic roundtable** identified life-cycle costs and operational costs as amongst the most important factors to sustainable water infrastructure planning (Figure 5). This result reflects the main motives of discussion around the economic table that stressed that financial aspects of operation maintenance must be carefully considered. When it comes to the analysis of the return of the investment, several factors must be looked at, primarily the payback period instead of the quality of the investment itself. The main recommendation is to have more focus on operational rather than capital cost. Finally, the participants at the table discussing economic indicators recommended that the IWRET tool should be able to optimize for operational expenditure, capital expenditures, and lifecycle costs, and that it should add incentives from the municipality (e.g. capital cost reduction, economic incentives, or quicker approval) if the project is to proceed to more detailed stages of planning and design.

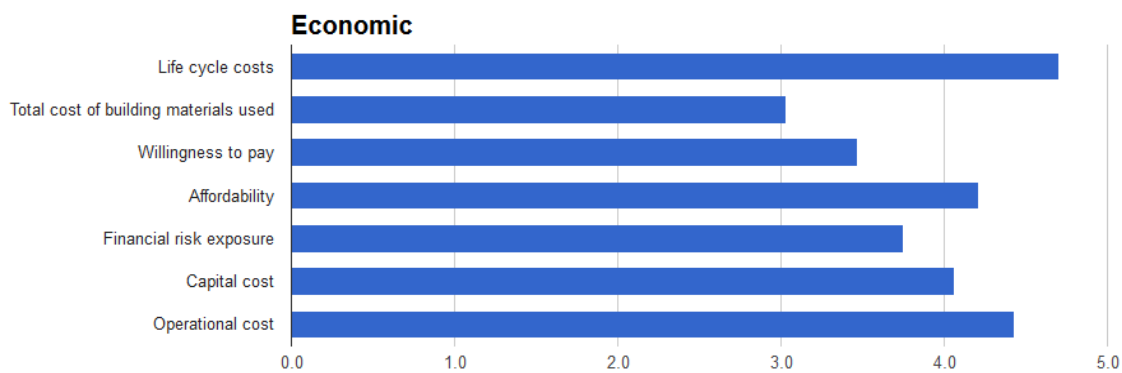

Figure 5. The value that participants placed on the list of economic indicators and their overall importance (using a scale of 1 (not important) – 5 (very important).

Recommendations coming from the **technical roundtable** identified performance and reliability of assets as amongst the most important criteria to integrate into the IWRET. The participants expressed the opinion that the IWRET model should include dynamic analysis of device (e.g. pumps) performances, and also recognize that operational complexity is missing from the list of indicators. Furthermore, the participants suggested that long-term maintenance and security of replacement parts and regulatory approval requirements should be amongst the most important indicators.

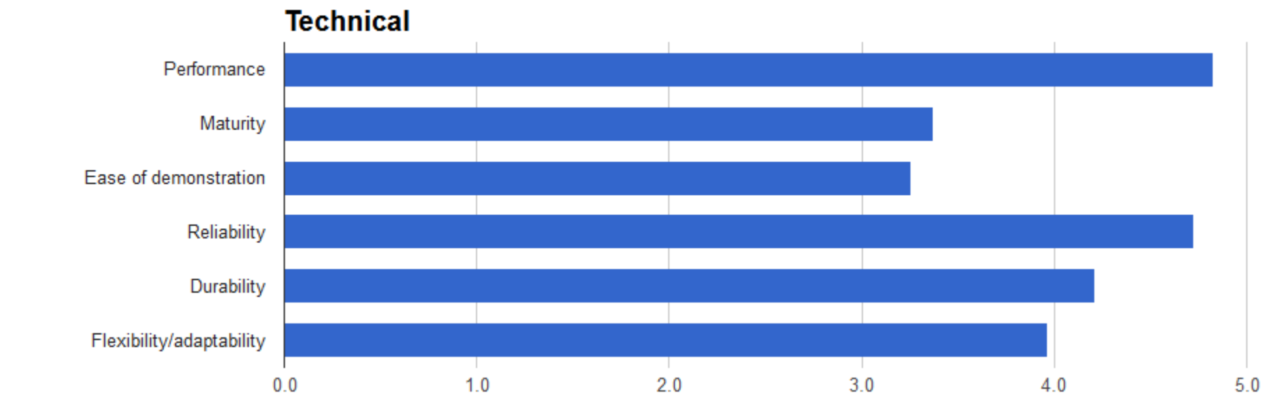

Figure 6. The value that participants placed on the list of technical indicators and their overall importance (using a scale of 1 (not important) – 5 (very important).

Participants seated at the **environmental roundtable** identified many indicators as important to integrate into the IWRET (Figure 7). Amongst the 14 indicators identified, the majority were valued at least 3.5 out of 5. Amongst the most important indicators were rainwater runoff, both quality and quantity, in addition to, savings in wastewater generation and indicators related to energy use and energy reductions.

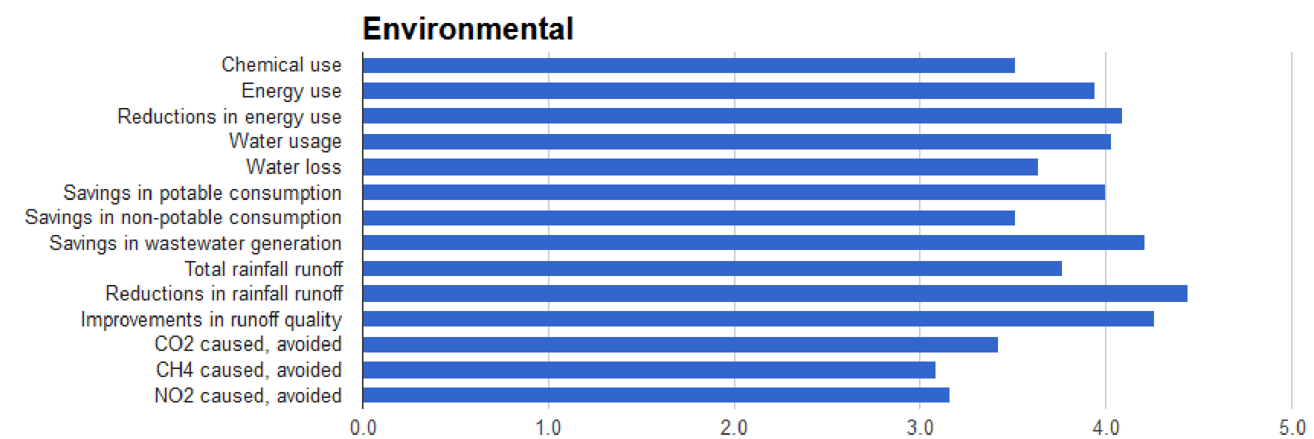

Figure 7. The value that participants placed on the list of environmental indicators and their overall importance (using a scale of 1 (not important) – 5 (very important).

Participants seated at the **social roundtable** identified many indicators as important to include in the IWRET (Figure 8) including " the potential risk to human health" as the indicator of highest importance.

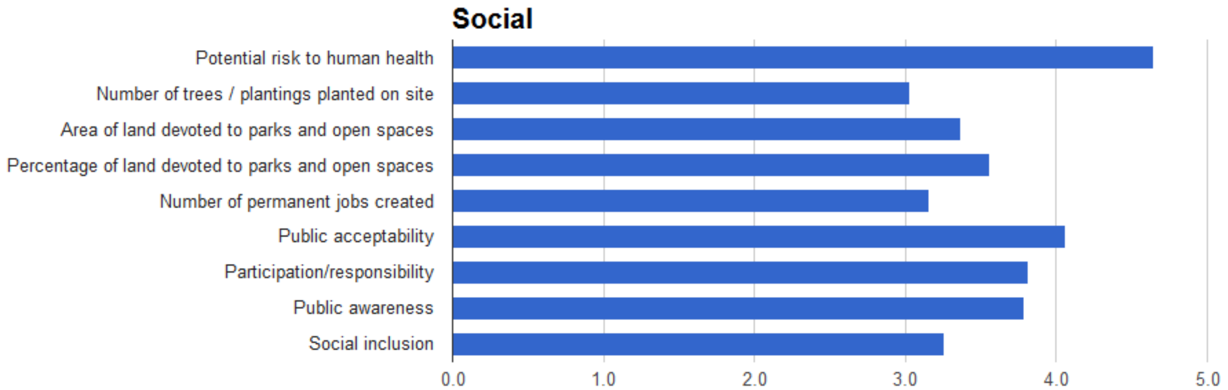

Figure 8. The value that participants placed on the list of social indicators and their overall importance (using a scale of 1 (not important) – 5 (very important).

In addition to the list of provided indicators, workshop participants were given an opportunity to suggest additional indicators not discussed that are important for their stakeholder group. The input received is summarized in Table 2.

Environmental	**Indicator**
Economic	Reserve Demand
Environmental	Infiltration Water Quality
Environmental	Temperature
Environmental	Habitat Diversity
Environmental	Combined Sewer Overflows
Environmental	Risk for non-compliance (resilience of system)
Social	Lifestyle
Social	Aesthetics
Social	Security of Service
Technical	Simple
Technical	Operational Complexity
Technical	Ease of Regulatory Approval
Technical	Measurability (KFLS)

Table 2. List of additional indicators identified by participants as important to their stakeholder group not presented at the workshop.

SESSION 4 | GRAPHICAL USER INTERFACE AND FINAL THOUGHTS

The final objective of the Workshop was to get the feedback from the stakeholder groups to inform the IWRET **graphical user interface** (GUI). The workshop participants were introduced to three different options for graphical user interface, while specific advantages and limitations were detailed for each one of them. Based on a web-based poll taken during the workshop, 55% of participants preferred a user-friendly interface (such as Excel-based) that would incorporate user feedback and rely upon a model with some degree of spatial representation.

The final session also provided an opportunity for **overall feedback** and workshop participants shared several insights that are summarized in Table 3 (below). For instance, participants pointed out that indicators might have correlations and impacts on other indicators, so the tool should have the potential to intelligently take that into consideration. Another issue raised, participants suggested that the tool would be most useful and powerful if IWRET developers focused on the intended user group. For instance, workshop stakeholder groups suggested different technologies, indicators, and interfaces in accordance with the culture, priorities, and language inherent to their stakeholder group. Participants advised that the tool would be less valuable if developers tried to be all things to everyone. It would be most powerful if focused for a particular user group. Additionally, participants advised that this focused stakeholder group should be consulted further during tool development.

Stakeholder group	Final feedback
Consultants	Redundant sustainability indicators should be removed
	Tool should be tailored for the unique requirements of the Greater Toronto Area
	Proper and detailed documentation of all model assumptions
	Tool should be user friendly and easy to use
	Consider development of the tool in a form of web application
Public administration	Tool should be flexible and able to account for social, economic and technical aspects
	Combine multiple sustainability indicators into groups and assign an overall score
Municipalities	Data collection and monitoring before using the tool to more effectively evaluate all changes
	Consider a web-based application with certain GIS features
	Importance of macro impacts more important that individual property impacts
	Minimize the number of criteria and provide detailed description
	Prepare the user manual for the tool
Non-profit organizations	Involve urban planners in the tool development process
Technology Provider or Distributor	Tool should include more specific sustainability indicators
Academic/Research	Costs of distributed solutions might be higher than the costs of currently used technologies
	Allow calculation of external costs for conventional solutions

Table 3. Final feedback provided by participants to guide IWRET development.

Next Steps

The main objective of the Workshop was to consult engaged stakeholders and inform the development of the IWRET, a tool for the evaluation of alternative strategies for integrated urban water management. Following the Workshop, a report was drafted and shared with all workshop participants.

RUW researchers will continue to develop the IWRET and plan to have a draft tool prepared by Fall 2018 to test on Villiers Island as a case study. Pending funding availability, a group of stakeholders may be engaged for a second workshop to further the development of the IWRET. As example, stakeholders may be asked for feedback on the framework IWRET and asked to test it with their own case studies.

Once the IWRET is finalized, it will be placed on a publically available web interface so that Canadian decision makers have freely available access to it.

Integrated Water Resources Evaluation Tool (IWRET) Workshop

Appendix A - Background Paper

Prepared by:
Vladimir Nikolic, Post-doctoral Researcher
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1. Project Motivation and Workshop Objectives

With the challenge of climate variability, pressures of population growth, unprecedented urban intensification, and aging infrastructure, the traditional urban and water infrastructure planning paradigm has become an obstacle to achieving sustainable development for many urban regions around the world. In order to address the challenge, researchers at Ryerson Urban Water are collaborating with Waterfront Toronto and partners at Toronto Water, the Toronto Region and Conservation Authority (TRCA), and the Ministry of Environment and Climate Change (MOECC) to develop an Integrated Water Resource Evaluation Tool (IWRET). This decision-making support tool analyzes and compares the sustainability performance of alternative approaches to integrated urban water management planning against a baseline conventional approach. The motivation is to equip planners and policy makers with a tool that facilitates assessment of the costs and benefits of alternative decentralized (distributed) water servicing solutions. The tool will use a set of criteria based on the urban water metabolism approach that are not typically considered in the decision-making process, such as energy savings, GHG emissions, climate change resiliency, chemical use, and nutrient recovery. The tool will be transferable, non-proprietary and applicable to other neighborhoods and jurisdictions, allowing it to be widely adopted for educational purposes and applied in municipal settings, servicing the objective of market transformation towards high performing and sustainable water servicing solutions.

In the first stage of the project, a workshop is being held with stakeholders (technology developers, providers and distributors, developers and builders, consultants, and non-governmental organizations) to discuss the participants' perspectives on current approaches to water infrastructure planning, design and management, as well as policy/institutional/regulatory opportunities, challenges and constraints. A summary of future trends and innovative concepts in urban water infrastructure planning, such as urban metabolism, urban water metabolism and integrated urban water management will then be presented. Finally, feedback will be sought from the workshop participants that will define the tool architecture and drive development, such as discussion of anticipated technologies to be included in the tool, selection of quantitative and qualitative sustainability indicators for the evaluation of alternative solutions, and opinions on tool's graphical user interface (GUI).

This report is intended to provide a background on essential concepts that form a methodical base for the tool development. In the first section, we outline a number of drivers that call for change in urban water systems planning. This is followed by the introduction of the concepts of urban metabolism, urban water metabolism and Integrated Urban Water Management (IUWM), with special attention given to hybrid urban water systems. The Villiers Island case study, potential sustainability indicators used to assess the system performance and capability of tools to represent different alternatives are discussed in the concluding section.

2. Drivers for Change in Urban Water Systems Planning, Design and Management Paradigm

Over the last several decades, a rapidly growing number of urban centers has become challenged by a diverse set of issues associated with planning and management of municipal water resources and infrastructure. For numerous cities around the world, fresh water of sufficient quantity and quality is rarely readily available from unpolluted sources. Not only do many urban regions experience alarming water shortages, but the increased demand and stringent health regulations also impose unsustainable costs on water treatment and distribution. At the same time, the volume of wastewater discharged to the local water bodies is mounting, with the quality of receiving bodies deteriorating in many cases. The intensified effects of climate variability and the distinctive changes of urban landscape additionally amplify arising challenges. Extreme variations in the hydrologic cycle, in addition to the permanent alterations of the physical conditions, can devastate urban water infrastructure causing severe social, economic and environmental degradation. Additionally, aging and inadequate infrastructure also represents a problem that many cities are currently facing. Cities like London, Paris and New York, as well as many Canadian municipalities, already suffer from the impacts of aging infrastructure. However, one particularly important trend can be detrimental to urban water infrastructure if not addressed timely. It is projected the global population to increase at astounding rates in the following decades, especially in urban centers. Due to the significant growth of population on one side, and a lack of accessible land for future developments on the other, cities like Toronto are increasing the rates of population density in urban cores. According to Toronto's Secondary Master Plan, the pace and magnitude of growth that is occurring city's urban core is already overwhelming the capacity of the system faster than projected, and in some cases placing unanticipated stress on the water system due to the increased height and density of many of the proposed developments. This document confirms that symptoms of this stress have already been felt by local residents that experience water pressure problems. While environmentally justified, intensification efforts raise numerous concerns since the scale of new developments and a range of new social and economic activities within the existing systems of infrastructure challenge their ability to sustain and improve the quality of life of local residents. In Canada, according to the 2016 Infrastructure Report Card, one-third of our municipal infrastructure is in fair, poor or very poor condition, increasing the risk of service disruption. Nearly 35% of assets are in need of attention. Although potable water, wastewater and stormwater infrastructure assets are in a slightly better shape compared with roads and municipal buildings, they are expected to face similar problems in the near future. In addition to all other pressures, the urban intensification has raised a concern whether the current systems of urban infrastructure can sustainably accommodate its continuation. This leaves urban planners battling with important questions regarding planning and managing sustainable communities in new environmental conditions, and more importantly, seeking tools and criteria that should be used to accurately assess the sustainability.

3. Concepts of Urban Metabolism and Urban Water Metabolism

The process of planning, development and retrofitting of urban infrastructure is not only financially intensive, but also demanding in terms of water, energy, materials, or labor requirements. The unpredictable reaction of environment shadows this process as well. In 1965, American scientist and sanitary engineer Abel Wolman envisioned the concept of *urban metabolism* - a holistic sustainability paradigm that takes into account all these aspects simultaneously. This concept quantifies the overall fluxes of energy, water, materials, nutrients and wastes that go into and out of cities in search for sustainable solutions. After years of continuing evolution, Kennedy et al. (2007) have defined the urban metabolism concept as the "sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste". Urban metabolism, therefore, represents a model that facilitates the analysis of the inputs (inflows), outputs (outflows) and storage of resources arising from socio-economic activities in an urban region, and regional and global biogeochemical processes, depicted in Figure 1.

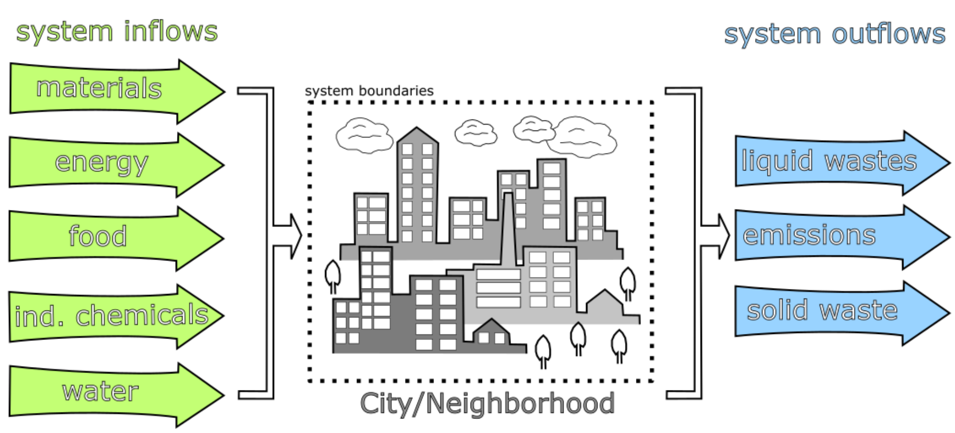

Figure 1. Urban metabolism model

Unlike healthy natural ecosystems, modern cities have metabolism that requires high inputs, consume great through flows, and produce tremendous outputs. With the growing environmental concerns, the search for the more balanced urban metabolism has become a key element in determining levels of sustainability and health in cities around the world.

From the perspective of urban water resources and infrastructure, the importance of water-related fluxes in urban metabolism model is particularly highlighted since the urban water cycle has a rather substantial influence on flows of materials, energy, wastes and nutrients and thus has important social, economic, and environmental impacts. In some cases, broad interpretation of urban metabolism considers both the direct and indirect metabolism of resources. In the case of water, this means direct (real) flows of water from surrounding regions ('local metabolism'), but also to indirect (virtual) water embodied in the goods and services produced using water from elsewhere ('global metabolism') (Farooqui et al., 2011). For the sake of this project, we consider a tighter interpretation of urban water metabolism and focus on direct resource exchanges. Therefore, urban water mass balance has been identified as a preferred approach for evaluating local water metabolism because it forces a comprehensive account of all water flows and fluxes. Traditional water metabolism models have largely focused only on centralized potable water and wastewater systems, with the intent of matching supply to demand, as illustrated in Figure 2. These models have become characterized by an increasing disproportion between system inflows and outflows. Typically, they treat wastewater and stormwater as waste products that must be removed from the location as quickly as possible for treatment and disposal.

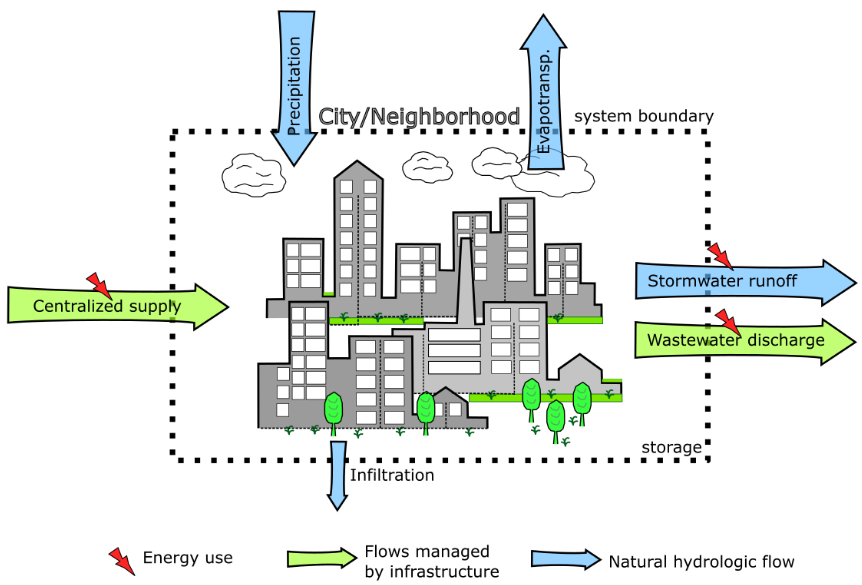

Figure 2. Traditional urban water metabolism model containing centralized water system

In contrast, models that are more recent have introduced the assessment of decentralized (also known as distributed) engineering solutions that allow more effective balancing of inputs, outputs, and storage of energy, materials and nutrients within an urban area. This approach accounts all water flows and fluxes, and treats them as an alternative resource of water and water-related energy.

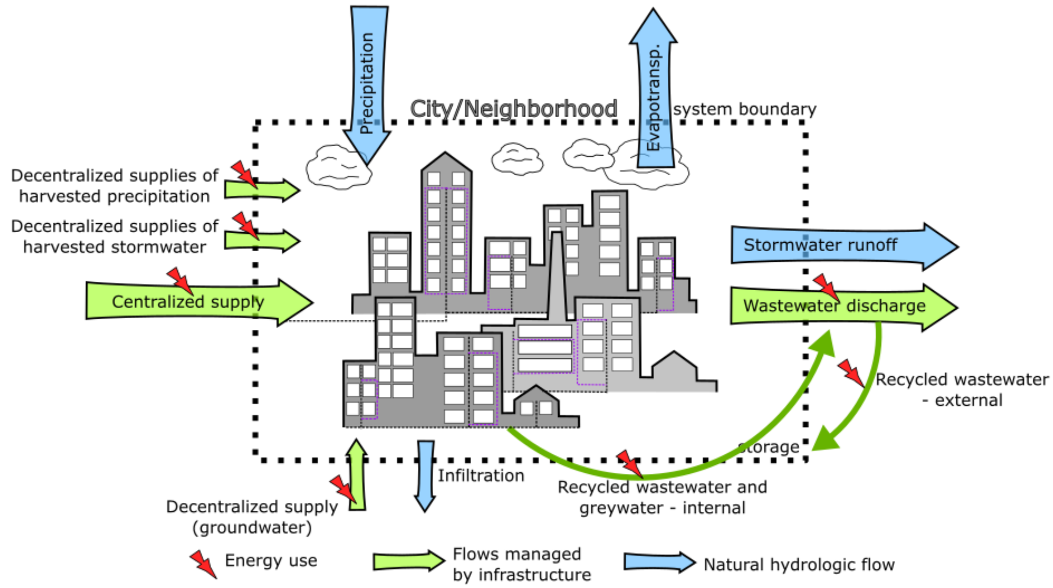

Figure 3. Urban water metabolism model containing decentralized options

4. Concepts of Integrated Urban Water Management (IUWM), decentralized options and hybrid water systems

In order to deal with the mounting pressures over the valuable resource and systems of municipal water infrastructure, the international water community has introduced a holistic approach named Integrated Urban Water Management (IUWM). IUWM process encourages water utilities to plan and manage water supply, wastewater and stormwater systems in a coordinated manner in order to maximize their contribution to economic development, stimulate overall community wellbeing, and minimize their impact on the natural environment. As such, IUWM provides a framework of city's relationship to water resources and infrastructure by:

- encompassing all the water sources in an urban catchment: blue water (surface water, groundwater, transferred water, desalinated water), green water (rainwater), black, brown, yellow and grey water (wastewater), reclaimed water, stormwater, and virtual water;
- matching the quality of different sources (surface water, groundwater, different types of wastewater, reclaimed water, and stormwater) with the quality required for different uses;
- considering water storage, distribution, treatment, recycling, and disposal as a cycle instead of discrete activities, and plans infrastructure accordingly;
- planning for the protection, conservation, and exploitation of water resources at their source;
- recognizing and seeks to align the range of formal (organizations, legislation, and policies) and informal (norms and conventions) institutions that govern water in and for cities; and
- seeking to balance economic efficiency, social equity, and environmental sustainability.

Yet one of the main legacies of the conventional approach is that urban regions since 1800s rely predominantly on centralized water systems that typically consist of separate drinking water, stormwater and wastewater sub-systems in which those systems are managed independently. For many cities, this practice represents an enormous social and engineering issue as further extension and expansion of existing systems, in order to carry additional loads, is not economically or environmentally viable. In view of that, IUWM promotes development of alternative water systems that utilize decentralized (distributed) sets of solutions that can also minimize the environmental impacts. Such systems use alternative water sources (such as rainwater, stormwater, greywater, or wastewater) and can be implemented at various spatial scales (household, cluster, neighborhood or city level). They generally operate alongside and in combination with existing centralized systems and form so called *hybrid* *water services systems*. Within a built environment, there are four groups of decentralized solutions available to water utilities:

- Water-supply and water-demand management;
- Low Impact Development (LID) and Green Infrastructure (GI);
- Green buildings; and,
- Greywater management and onsite reuse technologies.

In increasingly resource restricted environment, application of metabolism concept is a desirable next step in designing sustainable cities because it promotes reinvention of urban morphology and adoption of new technologies. From the perspective of urban water metabolism, all four categories of decentralized solutions can assist lowering required inputs, decreasing production of outputs and growing the storage capacities of urban water systems, Figure 4. Firstly, *supply and demand management* have the main objective to improve the productivity of water use by education for water conservation, rebate programs, or watering restrictions during times of drought. Secondly, *Low Impact Development* (LID) techniques tend to simulate natural systems and thus reduce stormwater runoff volumes and increase infiltration into the ground allowing additional storage. On the other hand, *green infrastructure* has similar effects, but includes only certain LID techniques implemented on different elements of municipal infrastructure, such as rain gardens, permeable pavements, bioretention facilities, and vegetated rooftops. Thirdly, rising environmental pressures have become strong motivation for the development of environmentally friendly buildings, especially ones that more efficiently manage water resources. *Green buildings* use high performing fixtures (such as low flow toilets, building wastewater recycling, wastewater reuse and rainwater harvesting) to reduce the demand and waste production. Finally, current estimates suggest that greywater represents 50% of the total indoor used water and thus represent a potential resource to replace potable *water in a reuse cycle*. Therefore, there is a growing trend constructing building-scale decentralized systems, where the wastewater generated within a residential and commercial building is treated and reused to satisfy the non-potable needs.

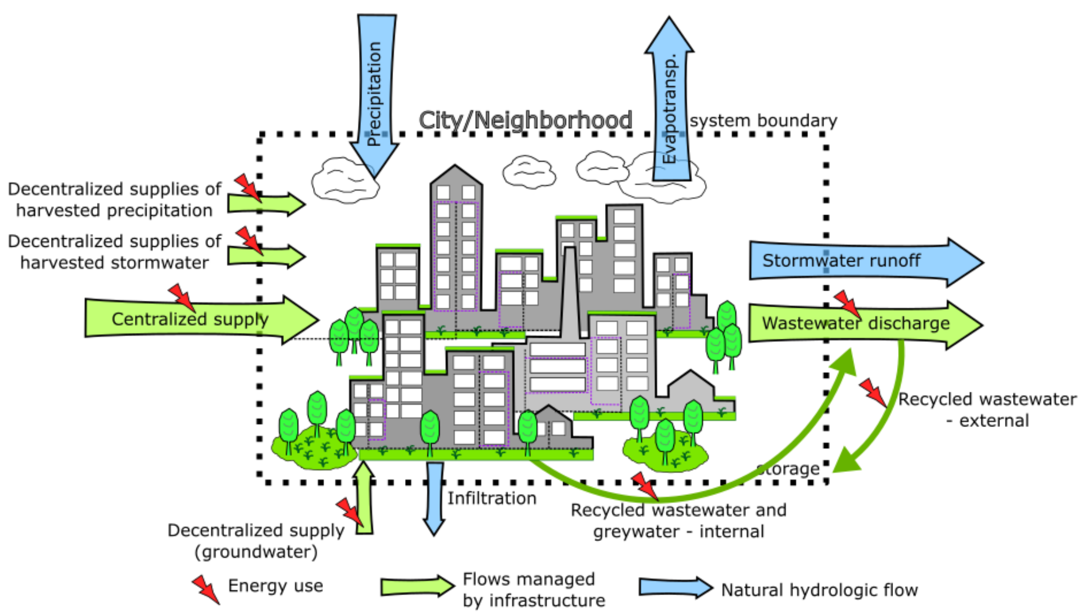

Figure 4. Urban water metabolism model amended with IWRM decentralized solutions

From the aspect of *urban water metabolism* and conventional water systems, *hybrid water systems* offer engineering options that allow more effective control of inputs, outputs, and storage of energy, materials and nutrients in urban water metabolism model. Table 1 shows the main *decentralized urban water management infrastructure options* divided and grouped into three flows (water supply, wastewater and drainage), and their integration through recycling and/reuse. The table also includes hyperlinks that describe each technology in greater detail and also provides indications of potential benefits.

Your opinion (Session 2)

Which urban water management infrastructure options should be supported in IWRET?

5. Indicators for Assessing Sustainability of Hybrid Water, Stormwater and Wastewater Service Systems

All four categories of decentralized solutions have been successfully applied across the world with the objective to regulate water metabolic processes. For instance, the City of Philadelphia manages stormwater runoff with green infrastructure implemented throughout the city, including stormwater planters, rain gardens and green roofs. Through a set of guidelines, the City of Philadelphia focused on eight Land-Based Green programs to promote the green infrastructure development: green streets; green schools; green public facilities; green parking; green parks; green industry, business, commerce and institutions; green alleys, driveways, and walkways; and green homes. Similar examples of can be found in New York (US), Amsterdam (the Netherlands), and Malmo (Sweden). On the other hand, in order to protect against droughts, the City and County of San Francisco apply water conservation strategies and utilize alternative water supplies for non-potable purposes, such as toilet flushing, irrigation, cooling/heating application, process water, dust control and soil compaction, decorative fountains and water features, and washing of clothing. Therefore, the City of San Francisco has issued a set of guidelines that describe types of alternative water sources available and the potential on-site uses for treated water sources. Guidelines also include all steps that are required for constructing an on-site treatment system. Three municipal institutions oversee implementation of such systems. San Francisco Public Utilities Commission (SFPUC) reviews project water budgets, serve as a technical resource, and provides financial incentives for customers who are interested in on-site non-potable water use. San Francisco Department of Building Inspection (SFDBI) oversees design and construction of on-site non-potable systems, issues permits, conducts inspections, and issues final approvals for building occupancy. Finally, San Francisco Department of Public Health (SFDPH) regulates the water quality and monitoring requirements for non-potable systems and issues operating permits and establishes reporting requirements for on-site treatment systems.

One the most important lessons learned from such examples is that both decentralized solutions and hybrid systems built in urban settings contain complex interactions that are multidimensional and span over various aspects of water availability, quality, and energy use, as well as environmental, legal, economic, and social sectors. Therefore, decisions to implement hybrid water systems require decision-makers to consider all dimensions conjointly in order to select the optimal combination. One of the major challenges in water systems engineering practice is the development of tools to quantify and enhance urban infrastructure sustainability planning, design and management. The integration of sustainability assessment into decision-making processes is therefore becoming an essential task for water service providers. Typically, quantifying sustainability is a vague process; one that requires considerable attention to respond to the particular characteristics of the problem at hand. However, there are a number of examples around the world that have successfully implemented the matter of sustainability into their decision-making practices.

Your opinion (Session 3)

How would you rank suggested sustainability indicators?

What sustainability indicators would you add to the list?

While various categories of criteria have been suggested to evaluate solutions, most fall into the following primary groups including human health, economic, environment, social-cultural dimensions, and an assessment of resilience to future challenges. Table 2 presents recommended sustainability indicators for the IWRET tool. However, this is not the final list, and the workshop participants will be encouraged to suggest indicators that potentially are important from their own perspective.

6. Problem Statement and Project Objectives

In order to most effectively deliver economical, adaptable, and sustainable water services to highly urbanized and dense communities, water infrastructure systems will increasingly rely on integration of centralized and decentralized approaches. While hybrid systems provide the opportunity for a number of benefits, such as cost reduction, resource efficiency, service security, system failure reduction, local economic strength, community wellbeing, and environmental protection, they typically involve the trade-offs between water use, energy use and land use that must be taken into consideration. Perhaps the biggest challenge facing the implementation of hybrid systems is the lack of empirical information depicting system success and failure. In particular, there are no available studies concerning the implementation of decentralized systems at full system scale. Having that in mind, the key objective of this project is development of a tool that will assist planners, utility managers, engineers, and other decision-makers to determine the optimal trade-offs in order to support sustainability at the community level. IWRET decision support tool will analyze and compare the sustainability performance of alternative approaches to integrated urban water management strategies and technologies against a baseline conventional approach. The model will be based on the concept of urban water metabolism that takes into consideration water, energy and nutrient flows. IWRET focuses on the intermediate level (new development, community or neighborhood) and investigates the impacts of decentralized urban water management technologies on a number of indicators, including water and energy consumption.

IWRET will be applied to a newly created community at Villiers Island as a case study to optimize the utilization of water, energy and nutrients for the proposed development. The model will allow definition of a number of alternative strategies that include decentralized options for water, wastewater, drainage, and recycling. The strategies will vary from the traditionally centralized baseline to fully decentralized systems. *Baseline strategy* assumes application of current practices with centralized water service systems that do not include recycling or reuse. This scenario is driven by currently valid regulations on municipal and provincial level, such as Design Criteria for Sewers and Watermains (2009), Wet Weather Flow Management (2006), and Low Impact Development Stormwater Management Planning and Design Guide (2010). Wastewater system alternative includes the system enlargement and extension of existing systems to convey flow via Carlaw Avenue inter-connecting sewer. Additional operating and capital cost will be given to the Ashbridges Bay Treatment Plant which is in direct proximity and has sufficient treatment capacity. However, currently decentralized treatment for some flows is eliminated since the implementation would require compliance with a complex and undefined regulatory approvals process. On the other hand, current regulations define the stormwater system preferred alternative to consider Low Impact Development (LID) measures. On the other hand*, fully decentralized* strategy incorporates solutions under more significant constraints, including severe limitations in the wastewater system capacity or severe limitations in the water supply system capacity. Baseline strategy is amended by including water efficiency measures in households. A distinction is made between potable/non-potable water. The strategy includes a dual water supply system, with non-potable water sources (local groundwater or rainwater) exploited at community level. There is no change to wastewater management technology. Stormwater improved by more extensive source control measures and/or on-site underground storage. Other LID technologies are used to improve stormwater quality, such as ponds, constructed wetlands or infiltration basins.

Table 1. Decentralized Urban Water Management Infrastructure Options for Implementation in IWRET

Sub-system	Option	Potential Benefits								
		Reduced water demand	Runoff quantity control	Runoff quality control	Erosion	Water balance	Nutrient capture	Nutrient recovery	Reduced energy demand	Energy recovery
Water Supply	Water saving devices	x							x	
	Smart water appliances	x								
	Smart water meters	x								
	Integration of smart water and energy metering	x							x	x
	Social networks and apps	x							x	
	Fit-for-purpose only (e.g. dual plumbing)	x								
Stormwater	Downspout disconnections		x							
	Enhanced grass swales		x	x						
	Dry swales		x	x						
	Perforated pipe systems		x							
	Pervious surfaces and permeable pavement		x							
	Soakaways, infiltration trenches and chambers		x	x						
	Vegetated filter strips		x				x			
	Constructed wetlands		x	x	x	x	x			
	Bioretention basins		x	x						
	Modular storage systems		x			x				
	Treatment systems (for reuse)		x	x			x			
Wastewater	Packaged wastewater treatment plants			x						
	Constructed wetlands		x	x	x	x	x			
	Sand filters		x							
	Living machines		x	x					x	
	Low pressure sewers		x	x					x	
	Vacuum toilets/sewers		x							
Recycling/Reuse	Rainwater harvesting	x	x			x				
	Greywater systems	x				x				
	Dry toilets	x								
	Composting toilets			x				x		
	Urine separation			x				x		
	Unit-level heat recovery									x
	Building-level heat recovery from wastewater									x
	Street-level heat recovery from wastewater									x
	Energy recovery from packaged wastewater treatment plants									x
	Nutrient recovery from packaged wastewater treatment plants							x		

Table 2. Suggested Sustainability indicators for implementing in IWRET

Capital	Indicator	Indicator Unit
Environmental	Chemical use	liters
	Energy use	kWh
	Reductions in energy use	kWh
	Water usage	m^3
	Water loss	m^3
	Savings in potable consumption	m^3
	Savings in non-potable consumption	m^3
	Savings in wastewater generation	m^3
	Total rainfall runoff	m^3
	Reductions in rainfall runoff	m^3
	Improvements in runoff quality	%
	CO_2 caused, avoided	m^3
	CH_4 caused, avoided	m^3
	NO_2 caused, avoided	m^3
Economic	Life cycle costs	$
	Total cost of building materials used	$
	Willingness to pay	1 - 5
	Affordability	1 - 5
	Financial risk exposure	1 - 5
	Capital cost	$
	Operational cost	$
Social	Potential risk to human health	1 - 5
	Number of trees / plantings planted on site	#
	Area of land devoted to parks and open spaces	m^2
	Percentage of land devoted to parks and open spaces	m^2
	Number of permanent jobs created	#
	Public acceptability	1 - 5
	Participation/responsibility	1 - 5
	Public awareness	1 - 5
	Social inclusion	1 - 5
Technical	Performance	1 - 5
	Maturity	1 - 5
	Ease of demonstration	1 - 5
	Reliability	1 - 5
	Durability	1 - 5
	Flexibility/adaptability	1 - 5